9th Research in Engineering Education Symposium and 32nd Australasian Association for Engineering Education Conference (REES AAEE 2021)

Engineering Education Research Capability Development

The University of Western Australia
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5 – 8 December 2021

Editors:

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The Research in Engineering Education Network is an international community of scholars interested in conducting high quality work in, and advancing the field of, engineering education research. The Symposium (REES) is an international conference held every two years by the Research in Engineering Education Network.

REES is widely recognised as the top engineering education research conference globally. The Australasian Association for Engineering Education (AAEE) is an important and constant contributor to the advancement of engineering education aligned bodies and societies, providing platforms for collaboration, increasing the visibility of scholarly activities and the ongoing professional development. Its Annual Conference brings together engineering academics, tutors, students, industry and education specialists to share practice and research in engineering education.

REES AAEE 2021 was the first joint REES AAEE Conference. It was be the 32nd Annual AAEE Conference, and the second AAEE Conference in Western Australia.

Papers and workshops were invited on all topics in the field of engineering education, especially those aligned with the theme, 'Engineering Education Research Capability Development'.

The Research in Engineering Education Symposium and Australasian Association for Engineering Education Annual Conference (REES AAEE 2021) was held jointly on 5-8 December 2021:

- face-to-face at The University of Western Australia, Perth, Western Australia
- hybrid during Perth business hours, and
- online outside Perth business hours.

The session chairs are gratefully acknowledged for supporting the blended sessions in Perth and the connected international online sessions. The chairs were critical to the success of the conference. Sessions in Perth were blended. Session chairs from the Research in Engineering Education Network attended sessions during the afternoon in Perth to report on these sessions at the start of the sessions with the same papers in the online sessions during Perth's night. Additional session chairs co-facilitated the online sessions and reported on these online sessions in relevant blended sessions the following morning.

Research papers were accepted for the Research in Engineering Education Symposium – Australasian Association for Engineering Education 2021. Practice papers were presented for the Australasian Association for Engineering Education. This distinction is evident in the conferences identified in the copyright statement in the footnote of each paper.

Committee

Dr Chris McDonald

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Paper and Workshop Sessions

Themed clusters of papers were presented in 90-minute sessions including a 3-minute recording for each paper followed by discussion on all papers in the session, and culminating in an output for other sessions on the theme. Each paper was presented and discussed in a hybrid session and in an online session at a time suitable for participants sleeping during daylight in Perth. Paper sessions on the same theme were connected throughout the conference.

Workshops were 90 minutes. Workshop proposers nominated their preference for their workshop to be facilitated face-to-face in Perth, facilitated in hybrid mode during Perth business hours, or online only out of Perth business hours.

Peer Review

All papers accepted for the Research in Engineering Education Symposium 2021 and/or the Australasian Association for Engineering Education Conference 2021 were double-blind peer reviewed by at least two independent reviewers.

Review Criteria

The review criteria for the two categories of papers are presented in Table 1.

Table 1. Paper Review Criteria

Criterion	For Review of Research Papers	For Review of Practice Papers
1. Focus of the Paper	The paper clearly describes the research question OR hypothesis and explains the implications of the project to research and/or practice.	The paper focuses on an aspect of academic practice, including the goals or intended outcomes, and explains the implications of this work (e.g. consideration of whether the findings could be applied elsewhere, or how the work reflects on existing literature in the field).
2. Relevance	The paper clearly relates the work undertaken to relevant discussions in the literature and other disciplinary literature as required; and describes its contribution to these discussions.	The paper relates the work done to existing relevant published literature and establishes the significance of the academic practice to engineering education.
3. Approach	The paper clearly describes and justifies the appropriateness of the overall approach, which could include designs, methods, theories and analytic processes; and discusses the limitations of the study.	The paper describes and justifies the appropriateness of the overall approach, which could include designs, methods, conceptual frameworks and analytical processes that have guided the design, implementation and evaluation of the work undertaken.
4. Argument	The paper clearly presents novel ideas or results of significance to others that are supported by convincing evidence, and clearly reasoned, illustrating the connection between claims and evidence.	The paper reflects on the strengths and limitations of the work done, based on the initial goals and evidence from the evaluation process, and provides recommendations for academic practice.
5. Writing Quality	The paper is written in appropriate English language of a sufficient standard to enable the reader to make sense of it.	The paper is written in appropriate English language of a sufficient standard to enable the reader to make sense of it.

Conference Theme: Engineering Education Research Capability Development

The conference theme was *Engineering Education Research Capability Development*. Authors were invited to nominate one of four sub-themes in their submissions. The sub-themes were related, and Theme 4 is open to all topics on engineering education. The themes were:

1. OUTCOMES of engineering education research
2. WHO does engineering education
3. HOW engineering education research is undertaken
4. Engineering education STUDIES

Sample topics for each theme include and are not limited to the following.

1. OUTCOMES: Why engineering education research is needed; what engineering education research is needed; for whom is engineering education research; impact of engineering education research
    - Problems that engineering education researchers should address
    - Funding
    - Impact
    - Publication
    - Dissemination
    - Reviewing
    - Engaging teachers in engineering education research

2. WHO: Who does engineering education research? With whom? When? Where?
    a. Diversity and inclusion in engineering education research practice
    b. Engineering education research capability development in regions
    c. Engineering education research capability development in institutions
    d. Supporting student researchers
    e. Removing institutional barriers
    f. Recognition
    g. Transitioning from engineering to engineering education research
    h. Diversity in engineering education research development
    i. Mentoring
    j. Sponsorship
3. HOW: How engineering education research is undertaken
    k. Methodologies
    l. Theoretical and methodological development
    m. Quality

4. STUDIES: Engineering education research on any topic outside those above

Special Issue of *Australasian Journal of Engineering Education*

Aligned with REES AAEE 2021, papers were invited for a special issue of the *Australasian Journal of Engineering Education* on the theme 'Engineering Education Research Capability Development'. Full papers for the journal special issue to be received by 31 July 2022 for consideration for review. Participants in the REES AAEE 2021 themed interactive paper sessions were invited to develop papers through collaboration during and following the paper sessions. Additionally, papers may have been expanded from a research paper presented at REES AAEE 2021, or they may have been be original papers on the theme.

Keynote Speakers

REES AAEE 2021

Dr. Cecilia Chan

President of The Asian Society for Engineering Education (AsiaSEE).

Head of Professional Development/Associate Professor, The University of Hong Kong

Assessment Literacy in Holistic Competency

Many universities around the world have acknowledged the importance of holistic competency (HC) for student development and have integrated HC into their educational missions (Male, Bush & Chapman, 2011). However, many such competencies remain loosely embedded in their curricula without being explicitly documented or assessed as expected course learning outcomes (Badcock, Pattison, & Harris, 2010; Luk & Chan, 2020). HC assessment is a longstanding challenge in higher education (Gibb, 2014; Chan et al., 2017).

Many studies (Hughes & Barrie, 2010; Hooker & Whistance, 2016; Nghia, 2018) argue that the lack of a formal framework for HC assessment has discouraged teachers and students alike from taking HC development seriously. High-level assessment literacy should unquestionably be a common expectation of university academics (Campbell, Murphy, & Holt, 2002). However, according to many programme evaluations, assessment illiteracy is resulting in inaccurate assessments of students (HKUSLEQ, 2017, n.p.). Furthermore, a plethora of inconsistent and varied assessment approaches are used in different universities and countries, with the inventories used by different universities often containing different items. With little understanding of students' and teachers' HC assessment literacy (Chan & Luo, 2020; Chan & Luk, 2021), and no evidence-based framework or guidelines for assessment design, universities lack convincing data to introduce policies to tackle the issue of assessment in HC development.

Do students want to be assessed for HC development?

Do employers want to see graduates' HC development?

Do universities have a systematic plan for HC certification?

To implement such a plan, we must first have an understanding of teacher and student HC assessment literacy.

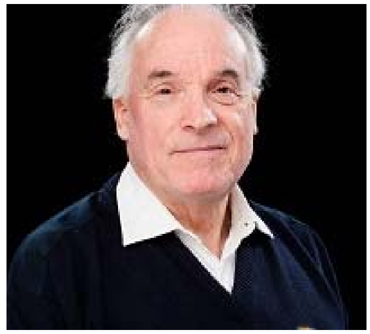
In this talk, we will address the questions above from an evidence-based approach and provide a plan in progress for HC certification.

Dr. Cecilia Chan's Biography

Dr. Cecilia Chan is the Head of Professional Development in the Centre of the Enhancement of Teaching and Learning and an Associate Professor in the Faculty of Education at The University of Hong Kong (HKU). Cecilia has a dual cultural background; she was born in Hong Kong but grew up in Ireland. In addition to her dual cultural background, she also has a dual discipline expertise in engineering and education; she has been playing a key role in enhancing engineering, and science education as well as teaching and learning in higher education. Her combined expertise in these fields and multi-cultural experience enabled her to lead and conduct research on topics such as assessment and feedback, experiential learning, technology enhanced learning and the development and assessment of 21st century skills spanning in education from east to west.

Dr. Chan also has substantial experience in holistic competency development and assessment in higher education and has been researching in this area for over ten years. She has developed a framework to assist teachers to integrate competency into the university curriculum and is also researching in approaches to assess these competencies. Her work is employed in many parts of the world. She has been invited as keynote speaker and panel speaker to many international educational conferences in Korea, Singapore, United States, Estonia, United Kingdom, Macau, Thailand, Malaysia and Switzerland on teaching, learning and the assessment of generic competency including the Harvard Graduate School of Education. Cecilia holds a PhD in Engineering from Trinity College, a postgraduate diploma and a MA in Higher Education. She also held a Fellowship from King's College London. Dr. Chan is involved in over 40 research/projects worldwide and was awarded the University of Hong Kong's Young Outstanding Researcher Award and Knowledge Exchange award. She is the Chair for the Engineering Education Community in Hong Kong and the President for the Asian Society for Engineering Education (AsiaSEE) - https://www.asiasee.org/.

More information can be found on the Teaching and Learning Enhancement and Research Group (TLERG) website: http://tlerg.cetl.hku.hk/



Emeritus Professor James Trevelyan

School of Engineering, The University of Western Australia

What We Know and Mostly Don't Know About Engineering Practices

Many papers at engineering education conferences directly or indirectly reference curriculum reforms, often justified in terms such as "meeting industry needs" or "improving graduate employability".

However, higher education reforms over the last two decades have generated little change in employers' perceptions of graduate capabilities. Further, career outcomes do not correlate well with performance in higher education assessments.

Engineering practice research since the 1990s has contributed a considerable body of knowledge demonstrating how social interactions are inextricably intertwined with technical capabilities in engineering workplaces. Responding to this, many educators have argued for much more emphasis on social skill development to balance the current overwhelming focus on technical capabilities. However, the evidence that education changes lead to measurable performance improvements in engineering workplaces is missing.

I shall explain why new research directions in engineering practice and engineering education might address this critical weakness in education reform arguments. Recent research has exposed deeply embedded education and workplace practices that attenuate the influence of education reforms on the performances early-career engineers. Engineering workplace practices rely on intrinsically oral, *interdependent* social cultures embedded in and shaped by the cultures of the host societies. These cultures overwhelmingly shape engineering performances, along with workplace infrastructures. Formal education, in contrast, privileges *independent* thinking and actions, and also privileges writing over oral interactions.

It will take time to accumulate sufficient research on these issues to support curriculum changes with empirical evidence. In the meantime, there are simple education improvements that might 'move the dial' on workplace performances. I shall explain some in the talk.

Emeritus Professor James Trevelyan's Biography

Emeritus Professor James Trevelyan is an engineer, educator, researcher and recently a start-up entrepreneur.

CEO of Close Comfort, he is introducing new energy saving, low emissions air conditioning technology for a global market.

His research on engineering practice helped define the Engineers Australia professional competencies for chartered engineers. His books "The Making of an Expert Engineer" and "Learning Engineering Practice" are influencing the future of engineering education in universities and workplaces.

He is best known internationally for pioneering research on sheep shearing robots from 1975 till 1993 and for the first industrial robot that could be remotely operated via the internet in 1994.

Web pages:

https://www.closecomfort.com/

https://JamesPTrevelyan.com/

https://research-repository.uwa.edu.au/en/persons/james-trevelyan

https://www.linkedin.com/in/jtrevelyan/

Best Papers

REES – AAEE 21 Best Paper

was awarded to

Mackenzie B. Sharbine, James L. Huff,

Nicola W. Sochacka, and

Joachim Walther

for the paper titled

'Professional Shame as a Socio-Psychological Mechanism for Marginalization in Engineering Education'

AAEE Best Paper

in the Practice category

was awarded to

Glenn J. Bradford, Paul N. Beuchat, and Gavin Buskes

for the paper titled

'Evaluating Outcomes in Two Engineering 'Clinic' Subjects'

Duncan Fraser Award for Best Student Paper at REES – AAEE 2021

- Sponsored by Engineering Institute of Technology -

was awarded to

Hellen Agumba and Zach Simpson

for the paper titled

'Rural knowledge practices and engineering study: a case study from South Africa'

Commendation

was awarded to

Bryce Neuman and Jonathon Truslove

for the paper titled

'Volunteer Professionals in an Undergraduate Design Challenge: Contributing to and Practicing Globally Responsible Engineering'

Commendation

awarded to

Dhinesh Radhakrishnan, Jennifer DeBoer,

and Nrupaja Bhide

for the paper titled

'Recentering local knowledge and developing collaborative relationships: Reflections on the design of a localized engineering program for former "street youth" in western Kenya using an asset-based framework'

Program Notes

Notes

1. **All paper sessions involved 5-minute recorded paper presentations followed by facilitated discussion including questions to the authors and discussion on what the papers say about where we need to take the field next based on the papers in the session.**
2. **For every paper, at least one author attended at least one of the sessions in which their paper was presented in order to answer questions.**
3. **The papers in hybrid Session 4 were presented again in online Session 6. The discussion in Session 6 built on the discussion in Session 4 and was reported in hybrid Session 7.**
4. **The papers in hybrid Session 11 were presented again in online Session 13. The discussion in Session 13 built on the discussion in Session 11 and was reported in hybrid Session 14.**
5. **Keynote presentations were presented live, in hybrid Session 10 and online in Session 12.**
6. **Papers were available to read before the conference. Delegates were strongly encouraged to do so.**

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Papers

Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

Creating community and engagement in large cohort online STEM courses effectively

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ABSTRACT

CONTEXT

Nothing has changed the delivery of education as fast as the impact of COVID-19. Online learning is the 'new normal' with many STEM (Science, Technology, Engineering and Mathematics) courses having to rapidly make this transition from traditional on-campus teaching. The literature shows that rich environments of formal face to face lectures and verbally engaging workshops provide a sense of community, social contracts and development of collegiate relationships between students. It is essential that education providers continue to offer opportunities for students to experience this element of higher education, rather than overlook this component of learning, as it can easily be lost in computer screen to computer screen engagement.

PURPOSE OR GOAL

This paper described how the literature surrounding online engagement was applied to enhance student engagement in a large cohort undergraduate course. In particular the transition from face to face to online and mixed modalities was investigated. Key engagement metrics as outlined in the literature and student survey results were utilised to gauge student satisfaction when development of a social environment is taken into consideration during course development.

APPROACH OR METHODOLOGY/METHODS

This work examines a transitioned large cohort course to quantify the effects of creating online community that replicates much of the face-to-face environment. It uses teaching survey instruments to identify pre and post intervention effectiveness from past cohorts and those exposed to the intervention. Semi structured surveys in the form of open questions were used to elicit free form responses and word frequency analysis is used to measure engagement.

ACTUAL OR ANTICIPATED OUTCOMES

In content heavy subjects such as STEM disciplines, the development of the online environment and teacher presence as well as social presence in subject delivery has a demonstratable effect on student engagement as measured by student satisfaction and learning outcomes.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Key elements in the learning environment were found to have contributed substantially to the outcomes. These include supporting students in time management, supporting developing brains in undergraduate cohorts, peer interaction and developing online community. Although there was concern that the inclusion of online activities and games would be perceived as additional work, these contributed to enhanced student engagement in the online space.

KEYWORDS

https://doi.org/10.52202/066488-0001

Engagement, online learning, Student satisfaction

Introduction

2020 will not be forgotten by university academics around the world for some time to come. While Australia wasn't the first country in line to experience the disruption of COVID-19, it was significantly impacted in the first teaching period of the academic year. Universities offering traditional on-campus courses pivoted quickly to the online space, and students were generally understanding and forgiving of the disruption while academics managed the transition (Aguilera-Hermida, 2020). With the onset of the next teaching term, it became apparent that while learning was still occurring, the students were not experiencing a cohesive feeling of being in a cohort. They hadn't had the opportunity to get to know other students in their courses, leaving many feeling isolated from peers, peer advice and study groups.

Many felt lost in the online environment, not knowing where or how to find access to academics or peers. There was a common misconception that, as this generation of students had grown up with computers and smart phones, they were tech savvy and unlikely to struggle with the transition. However, students were quick to point out that the various online platforms utilised by the University were as new to them as they were to the academics.

Online teaching is not a new concept across higher education and has long been a topic of discussion in literature. As early as 2000, Garrison, Anderson, and Archer proposed a conceptual framework to better the higher educational experience as the use of computer mediated communication was becoming prominent. Their framework revolved around three essential elements, cognitive presence, teaching presence and social presence. Initially, research was directed towards establishing and maintaining student socialisation in what was prominently a written chat-based world which lacked visual and social cues. Interestingly, social presence was originally coined in 1976 by Short, Williams and Christie, however current articles are still defining the concept (Kreijns, Xu and Weidlich, 2021). Irwin and Berge (2006) suggested that socialisation is the ability of people to establish connections. With the ubiquitous use of platforms utilising digital cameras and microphones, one might think that online socialisation would now be largely irrelevant, yet the problem of feeling isolation in present times continues.

It has been suggested that if students are to engage in their learning, first academics need to adopt engagement practices (Pittaway and Moss, 2014). This aligns with the notion of teaching presence which Garrison, Anderson, and Archer (2000) defined as the structures and processes used within the course, but also implies that students need to be able to connect with the teaching staff. This presence must be intentionally built into the course when delivered predominately via online technologies. The Gilly 5 stage model (Salmon, 2013) suggests that students should be guided through five structured developmental processes which develop expertise in learning online.

STEM disciplines have their own unique challenges in the online space. STEM courses are often content heavy and have emphasis on practical, hands-on activities as well as the development of critical thinking skills. Learning STEM is usually learning about 'things' for example, maths equations; the courses are not usually people centric (Su and Rounds, 2015) - the human component comes through working on activities together which is absent in a didactic online mode (Henriksen, Creely & Henderson, 2020). Ensuring that online delivery of STEM courses is student centric rather than product (STEM) focused requires deliberate inclusion in online course design.

The Gilly Salmon model (Salmon, 2013) outlines a framework for students to successfully learn in online environments. The model steps back from the knowledge push approach to examine the preconditions which facilitate learning. It serves as a useful framework to examine the transition to online learning encompassing many of the aspects associated with facilitating the learning process. These include accessibility through technology and

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technological literacy, motivational factors, the development of an equivalent social structure to that of an in-person environment and information exchange. Social development is a by-product in face-to-face environments; however care must be taken to construct its equivalent in the online environment. While STEM disciplines transitioning to online have focused on content (knowledge) delivery, significant peer based and two-way information exchange with the knowledge provider need to be teased out and developed to ensure an efficacious online replication of the in person environment. This paper uses a reflective case study approach to determine the success of strategies aimed at increasing the sentiment of an online community and social presence, implemented in a previously face-to-face undergraduate course.

Methodology

Using Garrison, Anderson, and Archer's (2000) framework and specifically focusing on developing teaching and social presence in the online space utilising the first three stages of Gilly's five stage model; a first year, first trimester large cohort course within the Sciences Group at Griffith University was redeveloped in 2021 to align with pedagogical good practice for online delivery. This course is core to multiple degree programs within the Sciences had been traditionally taught face-to-face prior to pivoting to online delivery.

Enrolment in the 2021 offering of the course was high with 645 students, 79% of these students were commencing study for the first time and approximately 45% of the cohort were first in family. Due to travel restrictions, only 2% of students were identified as international, however almost a quarter of the cohort did not speak English at home. These factors suggested that overly complicated or multiple online platforms would be a hinderance to learning. There was a need to provide a comprehensive learning experience that engaged students without increasing their workload with superfluous activity.

Data Collection

Success in creating community and engagement was evaluated in this cohort using student satisfaction data. Students' experience of the course was measured initially with a survey called Taking Care of the Student Experience (TCoSE) which was issued by the University and conducted during week 5. Students provided anonymous short answer responses to four open ended questions:

1. What is going well and should be continued?
2. What is not working and should be stopped or changed?
3. What is missing and should be started?
4. Have you experienced or anticipate barriers or hurdles to successful completion due to recent lockdown restrictions? (Queensland had a short snap lockdown early in the trimester).

Just over 10% of the enrolled students responded to this survey. Student Experience of the Course (SEC) (https://www.griffith.edu.au/surveys/student-surveys/experience-at-griffith) measured student experience between weeks 10 and 12, closing just prior to Examinations. This survey had quantitative and open-ended questions requiring short answer responses. The response rate for the SEC survey was 18.6%. To measure success of the redevelopment, the course characteristics were analysed in a reflective capacity using thematic analysis of keyword frequency in free text responses (Guest, MacQueen & Namey, 2012) in the surveys to measure the successfulness in engaging online learners. Ethical clearance to use the survey data was obtained from the Griffith University Human Research Ethics Committee (Ethics number 2021/581).

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Course Redevelopment

In 2020, the same course began as face-to-face and pivoted as a result of COVID-19 to online in week 4. During the first three weeks students had been able to visualise and engage with the teaching team and had begun to build rapport, especially as small group workshops had already been conducted. The University followed the State Based Health directive that no course with over 100 enrolments could have face to face lectures which continued into 2021. There were also looming threats of further lockdowns should community transmission of SARS-CoV-2 continue to occur. Therefore, the course needed to undergo significant re-design in 2021 to ensure that the incoming cohort would thrive in the University environment. It was especially important to take into consideration that the majority of the course cohort had a disruptive senior year at high school in 2020. The redevelopment of the course to the online space was scaffolded against the first three of Gilly Salmon's Five stage model as outlined below. This scaffolded progression through the course provided necessary supports to establish student confidence to take control of their own learning.

Stage 1. Access and Motivation

The initial change implemented stemmed from the decision to limit the digital platforms used to deliver the course content. This decision arose because the majority of students were commencing university and thus had limited experience in tertiary study, as well as in the use of a Virtual Learning Environment. Once a student accessed the course site in the Learning Management System (LMS), all content was available without having to navigate to another digital platform.

Online learning can be delivered in two ways: synchronously such as when students all join an online meeting at a scheduled time, or asynchronously when students access prepared content at different times. Due to uncertainty around employment since the start of COVID-19, students expressed their need to work when able. With such high numbers of students enrolled, it appeared prudent to allow the students to access course content asynchronously by using pre-recorded mini-lectures in a flipped classroom, enabling flexibility in time management of studies. The course consisted of modules broken into 3-4 topics. Each topic consisted of a short overview video along with content mini-lectures, reading, practice problems to complete prior to workshops and a games-based online activity. All modules followed the same configuration so that students knew what to expect as they progressed through the course. The topics facilitated concentrated bursts of learning with focused content and enabled students to identify gaps in knowledge and understanding. Of note, the accepted view is that online videos should not be longer than six minutes (Guo, Kim & Rubin, 2014). Within STEM disciplines that are content heavy, this would lead to multiple videos and cohesion would be lost, therefore it was decided that video length would be based on the content covered and usually ranged in length from 11 minutes up to 30 minutes.

Stage 2. Online Socialisation

Prior to the commencement of the course, the course convenor sent out a welcome video to the students which explained the purpose of the course, the layout of the course site in the LMS and allowed the students to 'meet' the convenor. The majority of correspondence from academics to students occurred through the announcement page of the LMS and concurrent emails. Information given to students outlined suggested best approaches to learning and the length of time required to spend on tasks. Students were reminded of topics to be completed in the week and assessment items due. Parker and Herrington's (2015) research suggests that development of community in online learning requires establishment of a positive learning environment by: building rapport (using inclusive communication and being approachable); engendering a sense of belonging (encouraging participation and recognising learning progress); and monitoring performance, providing feedback and setting clear goals. To encourage the development of community, announcements were presented with inclusive language portraying the learning process as a shared endeavour for the whole cohort, for example, students were addressed as 'Team' to build online community. During the trimester, students were also on occasion reminded of the range of student support available to them within the University.

The weekly videos, at least initially, heavily featured the teaching academic, creating a strong visible teacher presence for the cohort. As the mini-lectures were replacing face to face lectures, they provided students with an opportunity to connect with the convenor presenting each weekly overview in a casual and friendly manner. Of note, not all videos used in the course were new recordings, in later modules, edited lecture capture was used with an additional overview of the topic recording which featured the academic. Videos were available with transcripts and closed captions assisting both students with accessibility requirements as well as those with English as their second language. This also provided a base for note taking and written clarification of scientific terms that students may not have been familiar with.

Peer to peer interaction is also an important part of online socialisation. This aspect was challenging due to the large numbers of students enrolled, making it difficult to have all cameras and microphones enabled, students utilised the chat function extensively during the synchronous online sessions and often answered other student's questions. Anonymous polls using multiple choice questions within Collaborate Ultra were utilised to include students who did not wish to participate in the chat. To meet the student cohort needs for peer to peer interaction, on campus workshops designed as virtual escape rooms were utilised. Activities in the escape rooms were structured so that students were required to work together. Each student had the opportunity to attend a total of four workshops during the Trimester. Results from the on-campus activities are outside the scope of this paper.

Stage 3. Information Exchange

Online weekly Collaborate Ultra sessions facilitated information exchange by presenting students with the opportunity to nominate the topics to be reviewed. This student centric approach encouraged students to self-assess their learning and identify gaps in knowledge and understanding. Open discussion increased social presence among students and feedback from peers.

In addition, each topic included an online game to be completed independently. This acted as a self-assessment tool for students to gauge their knowledge, which was more interactive and dynamic than additional quizzes or worksheets. Games were utilised that were simple and easily accessible, and platforms were re-used in order to provide familiarity with these activities. Some activities included timers and scores so students could play and repeat games to master content knowledge.

Stage 4. Knowledge construction and Stage 5. Development

These aspects of the five-step model concern the learner starting to take control of their own learning and then integrating knowledge. The outcomes of these steps can be measured using assessment; however, this is outside the scope of this reflective case study.

Results

Stage 1 Access and motivation.

In response to the TCoSE survey (Table 1) 78% of students thought the mini-lectures were an important aspect of the course that should be continued. Students mentioned that they liked the flexibility of having the recordings available to watch at a time that suited them. Although the mini-lectures were longer in length than generally recommended, no students commented that they were too long. There were seven comments in response to Question 3 regarding the need for face-to-face lectures which was low (11%) in comparison to the overwhelming support for the mini-lectures. 41% of the respondents found the course layout,

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including navigation and content display, to be working well. A representative statement of this was “This course has been really well-structured, especially for first-years like me who are new to the L@G [LMS] site. All our modules, videos and topics are so organised on where to go and what to do in the course site”. In response to Question 4 above, students felt that due to the organisation of the course content, even though they experienced a lockdown, their learning experience wasn’t particularly affected, with one student writing “this was the only course that I wasn’t stressed about because of the COVID lockdown”. Students indicated their appreciation at the amount of thought and time that had gone into the organisation of the course.

These responses were mirrored in the end of trimester SEC survey (Table 2) with the question “This course was well-organised” receiving a mean of 4.5 (out of 5), well above the comparative mean of 4.1 for similar sized first year courses. The question regarding the course structure also received a mean score of 4.5. In this survey, 33% of students spoke favourably of the mini-lectures with only 3% of respondents thinking that fewer, longer length videos would have been better, and 4% stating the course would have been better with face-to-face lectures.

Table 1. Thematic analysis of keyword frequency in free text responses to the TCoSE survey.

TCoSE survey: 63 Respondents							
Working		Not working		Missing		Barriers due to COVID-19	
Videos	49	Synchronous session needs to be longer	2	Practice quizzes	2	Motivation	5
Activities	19	Content should be bundled based on weeks, not topics	1	Answers to Cloze sheets	2	Lack of face-to-face	6
Content Display/ LMS Navigation	26	Too content heavy	1	In person lectures	10	No barriers in this course	29
On campus Workshops using virtual escape rooms	26	Content is available at start of week, should be earlier	2	More workshops throughout trimester	4		
Synchronous online revision session	18	Having the workshops in person	1	More online activities	5		
Cloze (summary) sheets	12			In person laboratories	2		
Mastering A&P	10						
PASS	12						
Marked Reviewed button	8						

Stage 2 Online Socialisation.

Students resonated strongly with the provision of a welcome video. They bonded to the course prior to starting and were surprised that all courses didn’t have one (personal communications). Having the lecturer feature prominently in the mini-lectures for the first part of the course made the students feel connected, with one student commenting directly to one of the authors (Willis) ‘It’s strange this is the first time we’ve met but I’ve watched the mini-lectures, so I feel like I already know you’. Students also appreciated the email communications with representative comments such as “helped in organising my week” and “Charlene is extremely approachable”.

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Stage 3 Information Exchange.

Of the respondents to the TCoSE survey (Table 1), 30% mentioned the benefit of having the online activities and games within the course helping in both content knowledge and being fun. There were multiple comments requesting an increase in the number of online activities. Students (29%) also noted the benefit of attending the synchronous online class that occurred every Friday. They liked that they could nominate the topic for revision. Comments showed that having a commitment to turn up to a class on Friday motivated them to stay on top of the self-paced learning. However, motivation and mental health was an issue for the cohort as mentioned by multiple students in response to Question 4 above. In the end of trimester SEC survey (Table 2), the question "This course engaged me in learning" received a mean score of 4.1, well above the mean comparison score of 3.8 or similar sized first year courses. The overall satisfaction rating for the course was 4.3 (with a mean comparison of 3.9 for similar sized first year courses).

Table 2. Thematic analysis of keyword frequency in free text responses to the SEC survey.

SEC survey: 103 Respondents			
Done well: 80 Responses		Could be improved: 75 Responses	
Videos	26	Course is content heavy	12
Activities	13	The layout of the course	1
Content Display/ LMS Navigation	17	Needs face to face lectures	3
On campus Workshops (using virtual escape rooms)	25	Needs more workshops throughout trimester	10
Synchronous online revision session	8	Long lectures instead of short videos	2
Cloze (summary) sheets	4	Release content earlier than start of week	2
Mastering A&P	4	Need more online activities	2
PASS	3		
Marked Reviewed button	2		

Of note, assessment tasks were changed for the course in 2021, student grades cannot be compared across cohorts which is why student grades are omitted from the analysis of the success of the course redevelopment.

Discussion

The value of the traditional lecture has been under discussion for a number of years, especially in the divisive age of Lecture Capture. Although new pedagogy such as active and student centric learning has kept the relevance of the traditional lecture alive (Cananagh, 2011), there is no mistaking the lack of student attendance especially when many students have multiple commitments for their time including work and family. It was surprising when students didn't immediately respond positively to online learning when it was thrust upon universities in 2020 which traditionally taught face-to-face. In this author's experience at the time of the pivot, less students attended online classes than had previously been present on campus.

With the State Based Health directive in 2021 stating that courses with more than 100 student enrolments could not hold lectures on campus, it was decided that this large cohort, first trimester core course should be redeveloped to foster student engagement and satisfaction in the online space.

The first consideration was the design of the course in the LMS. Due to the majority of students enrolled in the course being unfamiliar with university and online studies, the decision to limit the number of platforms the students needed to access was successful with students finding the course easy to navigate. The next consideration was the flexibility of synchronous versus asynchronous online lectures and how this might impact student's time

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management. A recent systematic review concluded that the use of asynchronous multimedia usually improves student learning outcomes (Noetel, Grifith, Delaney *et al.*, 2021). The mini-lectures were a success, and although students were given the opportunity to switch to synchronous online lectures at the end of week two, >95% of participating students voted to continue having the course content delivered via the mini-lectures. Student approval was also voiced in both the TCoSE and SEC surveys conducted during the teaching period. Student preference for asynchronous mini-lectures due to the inherent flexibility was also reported in a recent study based in China (Ramo, Lin, Hald & Huang-Saad, 2021). There is some discussion around the presence of academics in pre-recorded videos as some students find it distracting, however the general consensus is that including the academic visually within pre-recorded material makes it more engaging (Kurzweil, Marcellas, Henry & Meyer, 2020). Student comments in the current study indicated that the strong lecturer presence in the videos was appreciated as it made them feel that the lecturer was approachable and provided connection with the course. The mini-lectures were longer in length than the commonly accepted view but this did not appear to be detrimental to the student experience and is perhaps explained by the large amount of content that needed to be covered in the course. Benefits of the mini-lectures included that they divided the content up into manageable sections and that they could stop and start the videos to enhance comprehension.

The 2021 cohort had higher than usual numbers of students who commenced University directly from high school. This age group biologically has more difficulty with time management and extrinsic motivation because the prefrontal cortex of the brain has yet to fully mature (Choudhury, Charman & Blakemore, 2008). Although there was concerted effort both within the course structure and the weekly announcements to ensure student were aware of tasks that needed to be done in specific weeks, there were student comments that suggested that a small number of students did lose motivation and fall behind during the trimester.

Overall student satisfaction with the online version of the course was very high, as shown by SEC quantitative data, suggesting that the changes to the course had a positive impact on the engagement of students in the online space. These results demonstrate that students that might have expectations of face-to-face learning due to historical experiences, can be successful and satisfy learners in the online environment when the course is structured around their requirements.

Recommendations

The take home messages are:

- Students require a strong teacher presence in the online space, at least initially, to foster a sense of belonging.
- Students value the asynchronous approached as learning can be undertaken when convenient, however this approach requires heavy support from the academic. Throughout the course LMS site were lists of things to do, timetables of assessment and at least weekly emails, yet still some students fell behind and lost motivation.
- To foster engagement, some synchronous learning where two-way interactions can occur is beneficial. Students can identify as partners in these sessions and determine the direction of their learning.
- Online activities such as gamification hugely enhance the student experience and are a sought after component of online study.

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Practical problem-based learning during and 'post' COVID; a case study of ENGG1500

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ABSTRACT

CONTEXT

This paper is concerned with the delivery of a large scale, highly practical, design-and-build engineering course through the transition to online learning during 2020 and blended learning in 2021. While the nature of face-to-face project-based learning can be very engaging, delivery faced enormous challenges with lockdowns and online requirements during 2020. The unprecedented nature of this situation, and compressed timeframes in which to adapt provided an opportunity to try a range of novel delivery methods. Some of these methods created for 'emergency teaching' can provide value even as the situation returns to normal – while we believe others should be noted as lessons learnt.

PURPOSE OR GOAL

In this paper, we analyse the efficacy of strategies used in transferring a large project-based course to an online environment in the short timeframe dictated by COVID19. We aim to:

• Determine, where possible, the key parameters that dictated success/failure in this case.

• Discuss application of these learnings to a second, semi-online delivery and evaluate their effectiveness for the future.

We are particularly interested in; informal platforms for content delivery (Discord and YouTube livestreams), involving students in course design delivery and assessment, and facilitating design and build by students in an online environment.

APPROACH OR METHODOLOGY/METHODS

This is a case study of the Course ENGG1500 running over 2020 and 2021 as compared to pre COVID offerings. The Student Feedback on Courses is the main source of both qualitative and quantitative data. Interviews with teaching staff on their experience have also been used to best capture the relevant data. The course ran several parallel discipline specific projects – each with different levels of difficulty and utilising a range of strategies.

ACTUAL OR ANTICIPATED OUTCOMES

Creating less formal engagement platforms for students has been widely successful. Discord was shown to be a superior platform over Blackboard Collaborate and YouTube over Zoom. Students and staff were found to remain highly engaged and supportive when brought into the change process and this involvement of students is believed to be a major success factor.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

While the workload was significantly higher than in face-to-face environment, practical, design and build, project-based learning can be successfully conducted in an online environment. However, consideration must be given to the varying levels of student success.

KEYWORDS

Online project-based learning. Blended mode. YouTube. Discord.

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Introduction

Project based learning / lab based (PBL) or experiential learning are common teaching techniques which are often employed to bring greater interaction and engagement with students and course content. This corresponds to more face time for students but can result in high resource consumption, both in terms of capital or consumable equipment for students to construct projects or complete labs, and in terms of staff time as the highly engaged nature of the course with increased face time requires more supervision.

The University of Somewhere, presents a course to all first-year engineering and surveying students (~650 students) ENGG1500, which serves as a means of introducing students to their engineering degree and the skills they will need. The course utilises a semester long, open scope "design and build" project to scaffold the student journey. Through completion of this project students are required to not just create a practical solution to the project but also engage in non-technical skills such as communication, teamwork and project management.

The course design, structure and learning outcomes are described in detail (Cuskelly & McBride, 2017), but the pertinent details are as follows:

- Lecture content focused on generic skills such as engineering problem solving and communication skills delivered to all students en masse.
- Semester-long discipline specific projects to apply and contextualise the content and skills required. 10 different projects ran in 2020, and 2021.
- All projects are open ended without a prescribed solution. Solutions are evaluated on criteria such as technical validity, robustness of design, cost to performance ratio, safety considerations, social and environmental factors, product market fit, ethical considerations.
- All projects require a functional device by test day (in the last week of semester) and it is this testable solution that gives the projects much of their success. Projects are phrased to the students though as an industry body (client) is expanding into a new market and wants to determine which solution they should invest in.
- Assessments via reports, marked peer review, project testing and reflection are all centred on the project.

In semester 1 of 2020, COVID-19 began to impact the course heavily in week 4 of our 12-week teaching semester. On Wednesday of week 4 a decision was made to go online (before online teaching was mandated at our university). By Monday of week 5 in 2020, ENGG1500 was entirely online – the rapid and novel nature of the change meant the transition and delivery was a learning experience.

It was seen as critical to the course to maintain as much of its flipped classroom, practical construction, and teamwork fundamentals as possible, despite the complexities of the online delivery, and lack of established platforms and methodologies.

In 2021 the course was delivered in mixed mode with lectures online and tutorials (workshops) face-to-face. Some changes from the 2020 interventions were maintained in the new blended style.

In this paper, we discuss our experience adapting this large, PBL course to online delivery, the changes kept for 2021, and the success or failure of the strategies implemented. This work is presented as a practice paper detailing the process and unexpected outcomes, along with permanent modifications made to the delivery of this course. Obviously our adaptation was rapid and not pre-meditated. An extensive literature was not conducted, discussions from Assistant Deans Teaching and Learning and direct consultation with course coordinators of similar courses revealed no strong evidence of a clear best practice, given the unprecedented nature of the situation. Similar courses moved to theoretical projects with more traditional delivery, others cancelled entire courses. We limit our discussion to the

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standard Course Experience Survey results and opinions of teaching staff. Our findings presented here are intended to be informative, not prescriptive.

Major 2020 Changes

Our goal was to maintain the spirit of the course as much as possible given the circumstances. This required facilitating the project-driven team design-and-build experience despite social distancing/lockdown requirements and online delivery of the course content and workshop sessions.

Class Delivery Platforms

Uncertainty (both at the time and ongoing) around the ability of university-supported platforms (Zoom, Blackboard Collaborate) to service the ~650 student cohort in a period of drastically increased usage, led to the investigation of alternative platforms that are less commonly used for teaching but well-known to cope with these loads. These platforms were primarily utilised to deliver scheduled classes.

Lectures on YouTube

The conventional, 2-hour face-to-face weekly lectures were replaced by a combination of pre-recorded lecture videos and live-streamed Q&A sessions, both delivered via the YouTube platform. Lecture videos were recorded with a picture-in-picture webcam view of the presenter over Powerpoint slides. These pre-recorded videos were heavily timestamped (an inbuilt YouTube function) for ease of navigation and revision. Videos were uploaded over the weekend several days before the timetabled lecture session each week.

These videos were supplemented by a YouTube live-stream in the scheduled lecture timeslot. The livestream objective was not to deliver new content but to discuss content with students. While some revision or follow-up content was usually presented in the first half-hour, the majority of time was dedicated to Q&A and discussion. Students interacted through the inbuilt YouTube live-chat which was also displayed onstream for convenience. These sessions were deliberately kept informal, and topics related or unrelated to course content were discussed. Obvious preference was given to course content but many students found value in discussion topics such as; active research at the university, industrial experience, program plans and course/degree structure, job opportunities, start-up companies. Totally disparate conversation around strategies for maintaining mental health in lockdown, pets and video games was facilitated because it encouraged extended engagement.

These live sessions were additional and supplementary to the original scheduled classes and students were told they were optional. Average attendance for these classes was approximately 1/3 of the course with more watching the recorded sessions after the fact. This was in stark contrast to previous years, where face-to-face ‘help’ Q&A sessions run to fulfill a similar purpose, had very poor attendance.

In 2021 lectures were still unable to be presented face-to-face, and it is foreseeable this will continue once class delivery returns to (the new) ‘normal’ post pandemic. YouTube has been maintained as the platform through 2021 following a similar structure as 2020 and was again well viewed / attended.

Workshops on Discord

A more extensive study into the evolution and use of Discord as a teaching tool is covered in (Reilly, et al., 2021). The key points related to this work are summarised here.

Workshops in this course pre-COVID19 varied in both style and content including presentations of discipline-specific lectorial content, individual analytical calculations, teamwork activities, and team based practical design and construction. In all workshops, the first 1-2 weeks of the course are driven by the workshop leader, but this is quickly merged with student driven activities and the second half of the course entails 100% student driven

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teamwork on the project. Despite the challenges associated with COVID19 restrictions, we wished to facilitate this collaborative, student driven learning experience while also allowing mass communication of information.

Any mechanism/platform for our workshops needed to ensure students could maintain the sense of community and belonging, and engagement with the course and their peers that the physical workshop environment provides. It was also important that our multidisciplinary teaching staff had the ability to easily monitor and float between several teams, classes, workshops, and projects.

The Discord platform was used for 8 of 10 projects, with the other 2 using Zoom. Discord is a voice/text communication service best known for video-game chat. It allows for a setup of servers, categories, and voice / text channels. Users are given roles which were linked to permissions to control which categories and channels they can see and contribute to.

For example, a server can be set up for a course, a category can be set up for a tutorial, and channels set up to replace ‘breakout’ rooms. Additionally, team channels can then be set up, allowing students to have a private place to work either during or outside of their tutorial. Staff can be given permission to a larger subset of these channels related to their own classes projects and administrative duties as required.

These channels are perpetual – they are set up once at the beginning and remain through the entire course with students having access 24/7. While students were expected to attend during their scheduled class time, they were also able to work effectively as a team outside of scheduled class time. This proved enormously beneficial for students to undertake teamwork, communicate effectively, and build a sense of community – students would log into Discord to socialise as well as work. At any given time during the week, hundreds of students were logged into Discord, regardless of if they had classes that day or not.

This consequently changed the communication dynamic. While information was posted on the official Blackboard site and sent via email, it was replicated on Discord, and this is where most students engaged. Discord quickly became the main:

- source of information delivery (in combination with YouTube lectures and livestreams),
- way for students to get help both inside and outside of class,
- communication method with course coordinator,
- and community for students to engage with peers for both on and off topic discussion.

As a result:

- email traffic was almost entirely replaced with Discord messages,
- meeting requests replaced with Discord calls,
- course wide announcements consumed via Discord,
- workshop classes conducted as Discord sessions,
- and lectures reached through Discord links.

The centralisation of these activities proved enormously beneficial from an administrative perspective for both students and teaching staff.

The communication aspect of Discord proved useful enough to transcend the fact that it was originally selected as a platform to deliver online workshops and a Discord server was adopted in 2021 despite having face-to-face classes.

Despite the additional benefits it provided, Discord was most importantly used as a way of teaching with a flipped classroom online. From a teaching point of view, the ease at which workshop leaders could ‘float’ between team channels with a single button press, and students could ask for help was critical. The feel of teams working independently within a class, and a tutor walking around and helping out as required, was able to be maintained in

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Discord. Additionally, the ability to effectively communicate with students in the course, a specific project, in a specific group, or at a personal individual level is helped.

From an administrative perspective, Discord allows the use of open software ‘bots’ running scripts to be mounted onto a server. There are many prewritten bots that exist to serve many functions and custom bots can be readily created in Python. Bots were used to automatically sort students into projects, workshops and teams, and manage their permissions. This along with all channels being perpetual, drastically reduced the administrative load in running these classes.

Projects

Project and testing scope

All project descriptions in the course are opened ended to facilitate diversity of thought and design, however the resources available are deliberately limited (budget, restricted use of tools), and project testing conditions are traditionally rigorously specified (wind tunnel testing at 10 m/s, volume constraint of 500 ×50×500 mm) to ensure fairness and a consistent baseline measure of success.

In response to lockdown/social distancing restrictions many students were impaired in their ability to physically construct their solutions and almost all were prevented from testing their solution as prescribed.

A policy of “design what you want, build what you can” emerged. All teams were expected to do the conceptual design, then could either proceed with construction or ‘detailed design’ as resources and conditions allowed. Students were encouraged to validate their design decisions as much as possible throughout the process by small scale prototype testing, simulation or experimentation. Normally this design validation serves as a steppingstone before project testing however for many students it was the only available testing system. It was important that the courses learning goals focused on giving students an experience that would enhance their ability to be successful in the future – not necessarily to achieve the original tasks.

In many projects, determining a way to demonstrate the effectiveness of the design – or often to simply demonstrate they had the underlying skills required – was incorporated as an aspect of the project. Teams that were largely unaffected by University closures could construct their own testing facilities similar to that which would have been used at the university. Others created scaled down or modified versions to fit the resources they had access to. Often students deliberately designed tests to demonstrate the aspects of their design they wanted to draw attention to. In many ways these student-developed tests became better for highlighting the novel and beneficial aspects of specific designs than the one-size-fits all standardised testing that had been attempted in the past.

Allowing students to lead the development of their own testing procedure (in combination with tutor advice) is believed to have been a major contributor to the success of the course. Students did not feel as disadvantaged due to lack of resources and felt empowered to demonstrate what they had achieved. It was also noted that students seemed to form a better understanding of the problem scoping process in this environment. As a result, detailed marking rubrics were removed for almost all projects in 2021 and student teams required to nominate aspects of how they wanted their projects tested and assessed (within reason).

This process was overall effective. The flexibility in what was considered a successful project outcome allowed students to engage in the course as best they could given their circumstances. It helped combat students feeling disadvantaged based on the circumstances outside of their control.

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Assessment

The majority of assessments in the course are various forms of reporting based on the project and these remained largely unchanged despite the changes to the course structure. The primary change was to the 30% 'project testing' assessment. Acceptable project deliverables were expanded to include the option of a 'Design Report', a document that would allow a hypothetical team of 4 first year engineers to successfully construct a working solution if not affected by COVID19.

This report could be combined with prototypes and/or a full-scale build. Students were given the option of completing any combination of the Design Report and Project Testing with the ultimate goal of convincing their client of their solution. This allowed students to focus entirely on the design report, the project testing, or any combination to succeed depending on their abilities/resources.

General findings

Project independence

Due to the nature of the course with many different projects with different constraints running simultaneously, a large amount of freedom has always been given to projects, tutors and even individual teams to determine how they meet the learning goals. This flexibility was increased with the changing circumstances. While an online-only mode was enforced, individual projects were given a large amount of autonomy to interpret, influence or outright overrule certain course wide requirements or recommendations to better suit their own constraints (with approval).

This was realised in a number of ways. For example, software students were producing an app which could be tested remotely, thus all software teams were required to complete the project with no substantive change to the test day procedure. In contrast, civil students could only complete full scale project testing if they could first establish safe and reliable testing conditions of a 200 kg suspended load, and as such only a handful of teams conducted full scale testing with most opting for simulations and design reports with minimal testing.

Flexibility was also given to teaching staff to nominate in the platform they used to run workshops (Zoom or Discord) and how they engaged with it. While this made overall course management harder, the limited timeframes available meant training all staff to use novel teaching platforms was not always viable. Letting teaching staff use a platform they were already familiar with meant staff members felt more comfortable and confident in their own teaching, which was seen as an overall positive. Given adequate preparation however moving all staff onto Discord would be ideal. A clear divide emerged with younger staff adopting the Discord platform successfully and senior staff using the more traditional Zoom platform.

Student engagement in transition

A deliberate effort was made to 'lean into the disruption'. At no stage were students shielded from the complexities of the situation or from the decision-making process – instead they were integrated as much as possible. This resulted in a general understanding of the process, a constructive student body and strong engagement.

Students were consulted on how to solve the problems related to online delivery to ensure solutions would be suitable to them. Constant student input was sought before decisions were made as well as constant feedback on decisions made. Students often proved very knowledgeable in the 'best practice' for how to operate online platforms and provided useful feedback. Far more importantly this created a sense of staff and students working collaboratively to solve a problem creating 'buy in' from the students.

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Once ‘buy in’ was established students became highly engaged with a clear desire to see the online delivery of the course be successful. Students were helpful to other students even if it provided no benefit to themselves. One highlight was that some students voluntarily and independently purchased Discord ‘server boosts’ to show their support for the course. Discord is a free service but a paid ‘server boost’ allows for novelties such as more emojis and personal customisation, as well as increasing quality of video and audio streams.

We believe that having learning objectives centred around professionalism and industry practice was very important to the success of this course. Teamwork, online delivery, change of scope, and disruption were taught and viewed as a **feature** of the course, as they are now a feature of modern engineering.

Interestingly, anecdotal evidence suggests that projects with more tightly structured weekly milestones and constraints realised lower diversity in solutions, required more attention and maintenance, and had lower student satisfaction.

Overall having students involved in the decision-making process made for a more engaged and helpful student body with better course outcomes.

Staffing

The success of the rapid migration to online delivery is also largely attributed to the agile nature of our teaching staff. ENGG1500 employs predominantly senior undergraduate or early postgraduate students for much of its development, delivery and management.

In general, these ‘student teachers’ adapted to the changing situation far more rapidly and competently than seasoned academics. Our student teachers largely drove the migration to new platforms, reworked the projects for online delivery, and established the engaging culture of the course.

We suspect that their ability to empathise with the current student body, their generally superior knowledge of student culture and communication methods, and lack of indoctrination into established methods are factors in their success.

Untraditional Platforms made for effective workspaces

Concerns were initially raised around perception, teaching efficacy and professionalism of both YouTube and Discord. These were quickly tempered by both the superior functionality that these platforms provided, and positive student experience.

Both YouTube and Discord proved more than capable of handling the high student 650+ load and performed more reliably than officially supported platforms. No dropouts or down time were experienced, latency issues were substantially reduced, and the barrier to entry of platforms is noticeably lower than more traditional systems.

Both the YouTube videos and Discord invite were made entirely public to reduce complexity in accessing content. This was mainly due to the extremely rapid nature of the transition required mid semester to novel teaching platforms. This created the opportunity for bad actors to become involved in the community and could have led to an unprofessional environment. However, this was not observed at any stage. In fact, the exact opposite was seen. A level of professionalism higher than what is seen in face-to-face classrooms was generally demonstrated by students across the board. Only a handful of comments ever required moderation and no students ever needed to be reported for unprofessional behaviour. Both YouTube and Discord provide excellent moderator functions were users can be given permission to moderate other users in various ways to ensure content stays within community guidelines.

Some channels were deliberate created in Discord to allow for more social off topic conversations which allowed the ‘on topic’ channels to be kept free of distractions. This allowed the platforms to provide both a social community and a professional teaching environment.

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The leakage of Intellectual property has been raised as a concern on these platforms. Fair use policy on YouTube clearly outlines what can and cannot be delivered and the rules for education are generally easy to comply with if presenting ones on content. However, content built heavily on previously published work needs to be thoroughly investigated before being placed onto these platforms.

In some cases a barrier to entry for staff may exist in adopting these platforms. Not all staff have experience with this style of platform and some retraining on both technical aspects and teaching approach was required. Younger staff however adopted these systems without the need for substantial training. The only concern that emerged with younger staff was that because they engaged with these platforms in their spare time they would often end up doing more work than they were paid for. While most enjoyed their jobs and happily helped students outside of paid hours (stating they did it because it was fun), ensuring staff are adequately rewarded for their hard work is important.

Student workload

A distinct increase in workload was seen for most students after moving to online delivery. Many students adapted well and while online delivery of PBL courses is clearly possible, it is remarkably challenging both on staff and students.

Despite numerous strategies and continuous monitoring, support and intervention by teaching staff, a subset of students struggled with the course delivery and the workload within many teams was asymmetric. This caused frustration for some students and teams either because they were falling behind or their team members were. Interestingly many acknowledged this uneven distribution but accepted it without complaint given the circumstances.

Changes retained/made for 2021

2021 saw the return of face-to-face workshops and tutorials, while lectures remained online. Some of the modifications to the course that were born out of necessity were maintained, while other aspects improved for the new offering:

- Discord was maintained as an extremely effective communication platform.
  - Team channels allowed students to work collaboratively outside of their regularly scheduled workshop to great success.
  - Additional automation of some aspects of the administration greatly reduced the overall workload of the course.
  - Heavy use of Course_Q&A, Assignment_help, and project specific channels greatly reduced workloads and improved student experience with timely feedback and community peer to peer support.
  - When local flooding caused campus closures face-to-face classes were moved onto online Discord classes within hours and ran successfully.
- Lectures were kept on YouTube to strong student satisfaction.
  - The video quality was improved moving from picture in picture lectures to green screen slides with a centralised presenter, specifically created for online lectures. This significantly increased views and engagement.
- Weekly YouTube livestreams were maintained and continued to reach a large number of students.
- Project scopes were expanded and marking rubrics removed. Students were encouraged to contribute to the way they were marked.
  - A higher diversity of solutions was seen and a better understanding of the projects was developed by students when less structure was given on project marks.

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Course evaluation survey results

Due to the unexpected nature of the transition to online an ethics approved target study could not be performed and so quantitative analysis is difficult. It is acknowledged that much of what has been reported has been formulated on the personal experience of teaching staff and informal feedback from students. The experiences reported should be viewed as informative not prescriptive.

In an effort to attribute some metrics to the success of the strategies presented analysis of the Universities official Course Evaluation Survey (CES) was performed.

Comparing the main metric of student satisfaction the overall course went from 4.10 in 2019 to 4.16 in 2021. While this change is likely within the measurement error it is believed significant that an entirely practical course was capable of rapidly transitioning to online and not suffer a loss of student satisfaction.

In 2021 the course achieved a satisfaction score of 4.51 – the highest since its conception in 2017. This is largely believed to be due to the improved communication via Discord and YouTube livestreams and greater independence in projects.

A simple thematic analysis of the 2020 qualitative comments (part of the CES) revealed a 100% positive response to the use of Discord. A 100% positive response to the use of YouTube and an overall 83% positive response to the way this course was taught online. Comments for the 2021 offering are not yet available at time of writing. It should be noted that as the questions in the CES did not target the online platforms deliberately this analysis should only be considered indicative.

Conclusions

Large scale problem-based learning can be delivered online in an emergency teaching situation. Success was largely due to the use of novel platforms such as Discord to maintain student driven engagement in flipped classrooms. An effective teaching culture was created by engaging with students in less formal online platforms and this was received with almost unanimous positivity by the student body. Giving both teaching staff and more importantly students, autonomy to control their own learning, ways of meeting course outcomes, and the culture of the online platforms all proved highly beneficial.

Learnings from an online delivery have be used to enhance the quality of a PBL course when returning to face-to-face delivery.

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To what extent are active learning strategies in lab-based engineering units implementable in online delivery?

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ABSTRACT

CONTEXT

The mode of class delivery in a university has a huge impact on how an educator delivers the class, and how students learn in the class. On-campus delivery supported by educational technologies has greatly helped academics to introduce active learning strategies to allow students to construct their knowledge using the campus infrastructure, with their peers and from their lecturers. With the change of scenario in 2020 due to the pandemic, everything else exists for a student except the on-campus facility! Will this unavailability of campus access affect the implementation of active learning strategies in lab-based engineering units delivered online?

PURPOSE OR GOAL

Strategies of the 'Focus Education Agenda' at Monash University are focused on integrating rich experiences for students "using the best in educational technologies and spaces", through flexible and innovative teaching and learning. The promotion of academics to prioritize actions in the agenda puts forth a systematic challenge to the improvement of all aspects of curriculum delivery in an engineering unit supported by educational design processes. Due to the pandemic, the learning activities in the educational design were customized to support online delivery. This paper raises questions with suggestions to re-think the learning outcomes and active learning strategies for lab-based engineering units to be achievable online.

APPROACH OR METHODOLOGY/METHODS

This paper describes the educational design process of a lab-based engineering unit and discusses the differences of what might have been achieved by students at different levels and domains of Bloom's taxonomy by implementing the learning activities in virtual space as opposed to physical space. Active learning approaches and strategies are incorporated in the educational design process in which all students in the class are encouraged to actively engage in the learning process.

OUTCOMES

While it is possible to implement some activities online (off-campus) without any changes on the educational design that are intended for physical classroom delivery, others needed adjustment to virtual learning space. This paper explains the virtual implementation of learning activities and assessments, and the lessons learnt through the implementation.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

While a campus infrastructure cannot be established online, learning activities meant for physical classrooms and engineering labs can be improvised to meet unit learning outcomes, industrial skill demands, and learner expectations. This paper provides recommendations for educational design approaches for the online delivery of lab-based engineering units.

KEYWORDS

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Educational design, Learning design, Lab-based engineering units.

Background

What is Educational Designing?

Educational design is a term used to cover both curriculum design and learning design processes. Where curriculum design is concerned mostly with the big picture of organizing the curriculum (instructional blocks) within a unit, learning design usually refers to the design of smaller bites of learning (Mackh, 2018). Usually, educational designing starts by developing specific learning objectives and intended outcomes for each topic/week which fit within the 'big-picture' unit learning outcomes. It also involves planning and preparing learning resources, interactions, activities, and assessments to meet the needs of the learners and the curriculum. As a process, educational designing provides specialized support services to affect a smooth transition to new educational approaches, technologies, and use of learning spaces. The process considers activities that reflect good educative practice, enhances student learning experiences, and informs the expert's preparation for class leadership and feedback (Mackh, 2018). This paper describes the educational design process of a lab-based engineering unit, 'ECE4809 Solid state Lighting', offered to final year engineering students at Monash university, Malaysia campus.

ECE4809 - Solid State Lighting

The unit introduces you to the new age of illumination using light-emitting diodes (LED) and their role in disruptive technologies such as human-centric lighting (HCL), horticultural lighting and visible light communications (VLC) alongside providing energy-efficient lighting.

Topics include the basics of light, colour and human vision, radiometric and photometric descriptions of light, light quality measures, the characteristics of light-emitting diodes (LED), flicker, lifetime and reliability, LED drivers and the effects of light in the built environment in applications such as human wellbeing, plant growth and communication. Laboratories cover radiometric and photometric characterisation of light using a spectrophotometer, the use of standard illuminants, working with colour spaces, performing lumen and light spectrum measurements using an integrating sphere and the implementation of IoT-based smart lighting control. (Handbook, 2021).

The learning outcomes of the twelve-week of study are to:

LO1 - Apply appropriate theories to effectively design solid-state lighting or SSL systems, including the visual and non-visual effects, colour spaces, quality metrics, efficiency, LED characteristics and other aspects such as LED drivers, spectral sensors, smart lighting control and visible light communications of Li-Fi.
LO2 - Assess the energy consumption of traditional versus SSL-based lighting approaches.
LO3 - Design and implement a system to solve a given complex engineering problem in the field of Intelligent lighting control using the knowledge of SSL.
LO4 - Conduct experiments to investigate various relationships in photometry, radiometry, colour quality, the energy consumption of light sources and the implementation of IoT-based lighting control.
LO5 - Assess critically the research literature in the field of solid-state lighting to evaluate recent findings and directions in SSL technology.

Educational Design of ECE4809

To develop students' expertise in navigating professions of the future, 'Focus Education Agenda' at Monash University prioritizes integrating rich experiences for all students through flexible and innovative teaching and learning (Focus Education Agenda, 2021). The promotion of academics to prioritize actions in the agenda puts forth a continuous and systematic

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challenge to the improvement of all aspects of curriculum delivery, leading to the unit coordinator teaching ECE4809 at the Monash University Malaysia, enhancing the unit supported by educational design processes.

The educational design process of ECE4809 starts with the unit coordinator identifying the reasons why the unit needs enhancement by conducting a survey with the industry stakeholders. There are seven industry assortments identified when analyzing the professional demands of solid-state lighting industry: 1) Color Science 2) Energy consumption 3) Light, Buildings and Architecture 4) Software in the light industry 5) Smart intelligent lighting 6) IoT-based lighting 7) Evolving Business Models for Lighting. The SSL industrial needs led to an educational design approach that promotes technological innovation, student-centered active learning pedagogy, use of learning environments and authentic projects.

In the next stage, the educational design process proceeded to the unit's curriculum alignment-involving organization of curriculum in a coherent structure with learning outcomes, content, teaching strategies, learning activities and assessments all aligning to improve both the coherence of curriculum and student learning. Further, in the development stage, the process made use of the data collected, and used that information to create learning activities and assessments that will relay what needs to be taught to the students to address SSL industry demands. New activities are built on previous activities to prevent them from being repetitive, and the rubrics attached to them articulates the expectations by listing criteria, and for each criterion, describing levels of quality. The following paragraphs show descriptions of different types of learning activities and assessments that are designed for ECE4809.

Student to Content Interaction

For the entire semester period, there are 17 pre-class / post-class activities designed based on student to content interaction. The activities are particularly relevant for supporting student progress towards learning outcomes with declarative knowledge (LO1, LO2, LO6), and industrial demands -understanding of typical solid-state technologies and understanding of current and emerging environmental sustainability priorities for smart lighting. The 17 activities fall under one of the following categories: listening to and/or watching a live or recorded talk; reading accompanied with several questions which would help guide students' focus as they engage with the text, and they will be addressed further in a subsequent synchronous session (online or on-campus); questions presented in the form of an online quiz (weighted or unweighted). These activities are more than just reading a book or watching a video, but explicitly requiring students to reflect on the reading and providing directed prompts for that reflection to improve the interaction.

Problem Based Learning

For week 1, an in-class activity which involves students creating mind maps is designed. Students are presented with a problem about lighting quality, which they are then asked to brainstorm by developing a mind-map of the various aspects of lighting quality aimed to arrive at the technical knowledge to tackle the issues. To solve the problem and create a mind map, they are required to have knowledge, understanding, and skills, that they are not taught-they are likely to be motivated to learn them. This activity particularly encourages students on "how to think" rather than "what to think", and achieve creative and factual knowledge (LO1, LO5). The industrial demands addressed by this activity are: Lighting quality and challenges with SSL designs for various building types.

Student to Student Interaction

For the first half of the semester, 3 activities are designed that will support the 'social presence' of a student in ECE4809: 1) 'Name Tags'- the purpose of the exercise is to get students to know more about each other as members of a group 2) '6 Thinking Hats'- the outcome of the activity is to come up with a consensus on whether it would be beneficial to retrofit all traditional

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lamps at Monash University Malaysia with LED lights (LO4, LO6). 3) ‘Fish-bowl’- force students to listen actively to the perspectives of a specific student group about ‘LEDifying’ and allows the unit coordinator to hear the experiences and ideas (LO4, LO6). These activities direct the students to apply or use the set of related knowledge, skills and abilities required to transforming the lighting industry by replacing conventional lighting with Light Emitting Diode (LED) technologies. The activities were completed in smaller groups that help to emphasize individual accountability, positive interdependence, and positive interaction. This active learning strategy leads to grading on a mini project emphasizing the aspects of group work such as collaboration, consensus, and learning.

Reflective Exercise

This exercise is a Classroom Assessment Technique (CAT). In week 3, students are given a post-card to download from the LMS for an activity called, ‘Muddiest Point’. The students are required to write about the clearest and muddiest (easiest and most difficult) points from weekly lectures / tutorials/ reading and other activities for week 1 & 2. After they write their responses on the post card, they must upload the post card into the LMS. This activity is to find out what they find unclear. They must reflect on what they do and do not understand. There will be a follow-up discussion session on the postcard submissions. This technique includes opportunities for students to think and reflect on what they are learning, how they are learning, and the significance of what they are learning.

Gamified Learning

For week 6, a quiz named, ‘Play and Answer’ is designed as a randomized board game (digital) to provide students with opportunities to think about economic and environmental impacts of lighting and use knowledge and information in new and different ways that support their development of critical thinking skills (LO2, LO6). The motivational psychology involved in 'Play and Answer' allows students to engage with educational materials in a playful and dynamic way.

Lab-based Activities

Lab activities are supposed to be delivered at the ‘Intelligent Lighting Lab (ILL)’ at the Monash Malaysia campus, which has facilities for photometric characterization of luminaires, spectral measurement of illumination, a light profiling system, a closed-loop controller for lights with wireless control, Spectral Imaging, and a VLC test bench and many more. The ILL is equipped with the state-of-the-art equipment such as spectrophotometers, integrating spheres, light booths, tunable light sources, and wirelessly controlled lighting systems.

However, the semester workload that involves 1 hour of practical and 2 hours of laboratory per week were affected due to the unavailability of physical labs with the online unit delivery. This resulted in alternate lab-based learning activities and assessments (lab-reports and mini-projects). The 4 lab reports (weighted) are designed either using a downloadable software, ‘Color calculator’, or using lab-manuals and a video-briefing of an experiment. Students must write each report to describe and analyze a lighting experiment that explores an SSL technology (LO4, LO5, LO6).

Mini project 1 requires students to implement an online calculator to determine the economic and environmental impact of ‘LEDification’ of a premise. The mini project 2 is on the implementation of an IOT controlled lighting system that can respond accurately to a control algorithm. These projects are aimed to evaluate the implementation of a Project Based Learning (PBL) incorporating the development of students’ soft skills as well as technical or professional competencies (LO4, LO5, LO6)

The goals of lab-based activities and mini projects in ECE4809 include enhancing mastery of subject matter, promote students’ ability - identify questions and concepts that guide scientific understanding of SSL, understand the inherent complexity and ambiguity of lighting

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phenomena, understanding measurement error, learning to use the tools and conventions of SSL technologies, collaborating effectively with others in carrying out complex tasks and interpret scientific data.

Implementation & Lessons Learnt

While it is possible to implement some activities online (off-campus) without any changes on the design that are intended for physical classroom delivery, others need adjustment to virtual learning space. The lab-based activities require a complete design change in terms of implementation space, learning environment, and the use of technology tools due to the lack of physical lab accessibility. The following paragraphs explain the implementation of the activities described in the previous section, and the lessons learnt through the implementation.

Activities that are implemented without any design changes

The use of Learning Management System (LMS) is helpful in implementing student to content-based interaction activities (lecture slides, video lectures embedded with interactive elements, pre-class quizzes, post-class quizzes, and readings accompanied with questions). They are implemented in the same way as they might have been implemented while the students attend classes on-campus. Their usability is made compulsory and tracked through the 'completion progress' plugin in the LMS. Even though additional research is needed to determine the full relationship between learner-content interaction and course success, previous studies suggest that learners who interact with the content more frequently achieve higher success in online courses, and spent less time to complete quizzes (Zimmerman, 2012), which could be tracked through the activity completion plugins.

The 'Play and Answer' activity is developed as a gamified quiz using SCORM development software, Articulate Studio. It is uploaded to the LMS as one of the weekly activities. It was intended to play in the physical classroom using the students' personal computing devices, however, there is no difference observed in the implementation while the students play the gamified quiz online in one of the synchronous online sessions. The randomness of the quiz questions employed by the dice-interaction led to identification of knowledge-gaps that resulted in students' curious conversations and discussions (Zoom chat) in the same way that would happen in the physical classroom.

Similarly, the mind-map activity about lighting quality made use of an online platform, 'Lucid Chart' implemented during one of the synchronous online sessions. Students were divided into groups to develop the mind-map using zoom breakout rooms. The implementation is observed in the same way as it would happen in a physical classroom where student groups would be sitting at different tables. The student groups presented their mind-maps using Padlet (a collaborative online environment) at the end of the session as they would do in a physical classroom. The collaboration among group members were observed in the online learning space as well.

Students' experience of using LMS and other learning technologies made it possible to implement the student-content interaction activities online. Online implementation of these activities made no difference to support student development of a range of learning outcomes (LO1, LO2 LO6), inclusive of declarative and functioning knowledge of ECE4809 and the industry needs.

Activities that are re-designed for online delivery mode

Certain activities that would foster open communication and group cohesion as well as providing opportunities for active learning in the physical classroom have customized to fit implementation through online collaborative spaces. They are:

1. Name Tags: In a physical classroom setting, the activity requires a white board, in which each student will stick a paper with information (Name & Prior understanding about ECE4809).

In the online learning space, a shared Google sheet is used to collect the information. Irrespective of the learning environment (physical or online) in use, students get to know about each other that helped them form groups for other activities in the unit.

2. Muddiest point: In the physical classroom setting, the activity is planned to be a structured in-class discussion, in which students will reflect on their learning so far. For the online space, the activity required one more step for initiating the discussion, so a creative post-card was made available through LMS to get students' reflection for discussion during the synchronous online session. This prior step helped initiating the focus of discussion and gave time for the students to express the clearest and muddiest points in their learning path (week 1&2 contents). This activity worked well online due to the post-card design compared to the earlier version of discussion in the physical classroom, but the success is not due to the online space but the idea of having a post-card, which might have worked in the physical setting as well. Anyhow, the activity provided the lecturer useful information about students' conceptual understanding in a short time compared to traditional assessment tools.

3. Fishbowl: To run the activity in the physical classroom setting, the class is divided into small groups and a discussion about 'LEDification' is initiated. Their chairs are then moved into 2 circles: one circle is a large "fish-bowl" along the periphery of the room and the other small circle is the "fish" in the middle of the room. The fish tells everyone in the room about what was discussed in their group, while the students in the bowl listen to them and check the accuracy of the views put forward. Any listener who disagrees with what is being said by the "spokes-fish", or wish to add anything, can go up and tap them gently on the shoulder. This means that they will swap places. This exercise would have been a good listening activity in the real class-room class setting to gather experiences and perspectives of a specific group.

For the online delivery, to give the students a similar experience, Padlet is used as an online discussion space, in which a background image with instructions were made available to the students to replicate the physical classroom Fishbowl. The activity worked in the same manner as expected except them being excited, pushing, motivating others when they see their peer eye-to-eye in front of them in physical classroom, which is what we call the 'campus-experience'. With that experience lacked in the virtual space, where student sit alone at their own desk would be detrimental to student development and interpersonal self-esteem (Hasan & Bao, 2020).

4. 6 Thinking Hats: For the physical classroom setting, the activity would have been conducted with different colored hats worn by students in each group, with each member thinks about 'retrofit traditional lamps' at Monash Malaysia campus, using the criteria given appropriate to the colored hats they would wear. The activity is expected to promote parallel thinking- a tool that facilitates creativity and collaboration.

For the online delivery, Padlet is used with a background template that replicates 6 thinking hats. The activity was implemented in the same way as in the physical classroom that promotes collaboration and engagement. However, it is uncertain whether students would achieve the skills required for the SSL industry in terms of procedural knowledge. This is because, the students have neither worked on the hands-on labs (Monash campus) or had a visual tour to collect real data to formulate their thoughts. Also, no real consequences for mistakes may result in students under performing and not being fully engaged in the learning (Metcalfe, 2017). Furthermore, when the students join workforce, they would lack in confidence in what they do that do not leverage their skills (Larsen et al., 2018).

An activity that couldn't be implemented due to online delivery mode

A mini-project is designed as a group activity for on-campus delivery using the Intelligent Light Lab facilities at Monash Malaysia. The project is mapped to learning outcomes that cover intelligently controlled LED light system, and lighting systems for specific needs (LO3, LO5), however they are not implementable due to challenges of providing laboratory equipment in online unit delivery. The mini project is a LED fashion show event to showcase line of clothing or accessories with LEDs and power source embroidered right on to the fabric. Student must include special features to the clothing such as lighting mode, additional effects, and controls. The lights can twinkle, display sequential patterns, change intensity of the light shining etc., Modes and effects can be controlled by a handy switch or remote control, if needed. Alternatively, the mini projects are implemented using remote access to lighting controls at a mock living room situated in the Intelligent Lighting Laboratory.

Lab-based activities

The implementation of lab-based activities is restricted to video illustrations and sample data to work-out problems. For these activities, learners engaged by using the data or illustrations to find out experimental outcomes that yield authentic results. Based on the results, they can deduce a learning outcome. However, research studies show that illustrations, sample data or lab simulations are not a replacement for hands-on experience with real-life devices and tools, to achieve industry required competencies that might be achieved through learning by doing (Taher & Khan, 2015). Furthermore, implementation of a campus-based LED fashion show might have brought a valuable active learning experience for the students like taking a roller coaster ride. For instance, before taking a roller coaster ride, people pay attention to the rules like, "hang on to the handles," "slide only feet first," "stay seated," "don't rock the seat," "get rid of gum before you ride" or "no flipping", which illustrates a real-life phenomenon they would experience that would require a precaution. These rules would be remembered, understood, and applied when people take a ride. During the ride, people enjoy roller coasters due to the combination of speed, conquering fear and the positive effects associated with a massive rise in physiological arousal. Research sets out the intriguing possibility that the enjoyment of intense physical experience may reflect individual differences in brain chemistry (Bransford, 2000).

Similarly, before students attend a campus-based engineering lab activity, they are informed about lab procedures, experiment steps and safety standards. They will comply with them and follow the guidelines and steps when experimenting at the labs. Taher & Khan (2015) believe that by involving students in a learning by doing activity, their ability to think critically is significantly enhanced. It teaches them to rely more on evidence (observed data), encourages them to think independently, and reduces their dependence on authority. That would also help students to identify the potential gaps between theory and practice and lead them to achieve Bloom’s Higher Order Thinking Skills (Mackh, 2018). Also, it is common knowledge that experiences are strongly remembered and reflected on when experienced first-hand, rather than hearing the details of the experience from another person, like the roller coaster ride shows the rider the good, bad and the awareness of huge highs, deep lows, but in the end, they will always be relieved that they did it because the ride gave them the knowledge, experience, and a rounded outlook of the ride. They can imagine the experience vividly enough to apply it anywhere.

Feedback and reflections

In the Student Evaluation of Teaching and Units (SETU) survey, many students have positively commented about the incorporation of active learning techniques in the unit. 81% of the students reported that they can engage in the unit to the best of their abilities, and they mentioned that the learning activities helped them to achieve the learning outcomes for the unit. However, though the implementation of online lab-based activities mapped to the learning outcomes, LO3, LO4 and LO5, the competencies required for the lighting industry such as ability to create lighting for a physical atmosphere, acting decisively, and solving equipment related problems cannot be met by the implementation of online-based lab activities, just like a roller coaster experience cannot be simulated. This is evident from the lack of physical artifacts that could be generated by students through projects in the unit.

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Recommendations & Conclusion

While a campus lab infrastructure cannot be established online, and when video demonstrations, sample data and virtual and simulated labs do not have the capability to enhance engineering students' practical skills or industry required competencies and application abilities, the following are some of the educational design recommendations based on proven studies to support students' learning of lab-based engineering units when delivered online:

1. For online delivery, lab-based activities can be designed by combining multiple pedagogies so that student can take what they have learnt from engaging with the activity and use it in another context, or for another purpose. For example, each lesson in Discovery Education's 'Mystery Science' curriculum contains a central mystery, discussion questions, supplemental reading, and a hands-on-activity. In attempting to stimulate such a move to different pedagogic approaches, academics themselves will be subjected to significant learning both in a move to different pedagogic approaches as well as needing to become expert users in the technologies employed. Familiarizing themselves with the pedagogic theory of online learning is the first step; such a transfer needs to be followed by utilizing best practice such as the five-stage model (Salmon et al., 2010).

2. Mativo et al (2017) found that development, implementation, and evaluation of a set of ill-structured, industry-inspired problems developed in partnership with an industry representative supported student learning in an undergraduate engineering dynamics course. As students move through the process of problem-solving, they take ownership of their learning and build self-confidence. This in-depth guided learning opportunity provides benefits beyond the university labs and transfers directly into the real world. Students internalize problem-solving methods and are prepared to apply this knowledge not only in their course of study, but in their personal lives as well.

3. Truong, Stein, and Nguyen (2021) proposed activities based on a self-contained project kit platform referred to as, "Project in a Box" or PiB kits for remote workshops, to teach a variety of electrical engineering topics, including, basic control theory, robotics, circuits, electronics, and programming. The PiB kits are proposed to provide a way to learn complex electrical engineering concepts in a fun and engaging way through approachable hands-on projects and easy to read documentation. Their future work includes expanding the kits to include more advanced concepts in electrical engineering such as machine learning and wireless communication.

4. Popularity of Arduino has grown in the last years, mainly as part of the Internet of Things (IoT), which is producing a relevant impact in several economic sectors (industry, transportations, energy, agriculture, home automation, etc.). Arduino Engineering Kits are inexpensive but challenge engineering students and help them develop engineering skills (Talley, 2012). The kits are practical, hands-on tool that demonstrates key engineering concepts, core aspects of mechatronics, and MATLAB and Simulink programming, and includes projects to learn the basics of modeling, controls, image processing, robotics, signal processing, and more. Several studies have proved that learning activities designed using Arduino Engineering Kits have been useful to engineering education.

5. Designing lab-based activities using remote instrumentation provides students online access to scientific equipment for manipulation, data collection, and analysis (Crippen et al., 2012). This provides students with concrete and authentic lab experiences complete with the possibility of error and potential for generating unanticipated results. One drawback to this approach is that it can be costly to maintain instrumentation, facilities, and remote access (Crippen et al., 2012). In addition, students' experiences with handling equipment and materials using remote instruments will vary from those attained through on-campus experiences.

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6. Engaging students in field-based experiments provide students with real-world opportunities to collect and analyze data from their locations. For example, citizen science projects such as Cornell University's Lab of Ornithology unites scientists, conservationists, engineers, educators, and students as they engage in scientific discovery and collect data on wildlife in their local communities (birds.cornell.edu). A disadvantage to field-based experimentation is that opportunities may be limited in some locations and may be dependent on particular climates or seasons. In addition, topics can be discipline specific and may not be an option for many courses.

7. There are work in progress activities that use lab kits, in combination with household items, provide the means to conduct experiments at home on a smaller scale and without the need for expensive equipment (Smyser, 2021). This engages online students in authentic, hands-on experiences that promote technical skills development and conceptual understanding, with the small quantities being used reducing hazards and risks. However, kit-based investigations can be limited in scope because of the cost and availability of specialized equipment and materials; the inability to repeat experiments because of limited substances, which requires greater skill when conducting experiments that can be done only once; and there are concerns related to material disposal and lab safety (Crippen & Kern, 2012).

8. The learning objectives of lab-based engineering units, which has the potential to produce physical artifacts with varying student capacities should be re-thought because students might satisfy a unit completion in a measurable way in an online learning space, but they should also have applied skills exhibited during their study to successfully perform in industrial, and other life contexts.

Several studies have explored ways that engineering can be taught online, with a specific focus on the laboratories. This paper provides information based on lessons learnt through educational designing of an engineering unit to show what is possible and not possible. The above recommendations can provide some insights to help online engineering educators to select best practices for course design and instruction for lab-based engineering units.

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Enhancing maths teaching resources: Topic videos and tutorial streaming development

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ABSTRACT

CONTEXT

Engineering maths courses can be challenging for first- and second-year undergraduate engineering students. This situation is especially aggravated when those courses are delivered simultaneously to students representing different degrees, such as Science, Engineering, Information Technology, and Education. In addition, traditional didactic methods, such as lecturer-led teaching, fail to enthuse and inspire students, leading to their disengagement from the course, high failure rate, and eventually lack of student retention.

PURPOSE OR GOAL

This study aims to better relate mathematics courses with engineering applications by encouraging active-learning participation from students. The objective is to develop a set of teaching resources for each of the teaching modules within the course. These resources include topic videos and streamed tutorials, which supplement what is currently offered. This strategy develops extra resources to engage and support students without necessarily changing how the courses are taught.

APPROACH OR METHODOLOGY/METHODS

The Engineering curriculum for the Bachelor of Engineering (Honours) at Griffith University comprises three Mathematics courses. The second-year course, Calculus II, was used as a case study for this pilot project. Topic videos (video bites; 10 to 20 minutes duration) were developed to assist students in developing their understanding of the content and articulate the learning outcomes of each module and their applicability to different engineering contexts. In addition, sets of tutorial problems that target different levels of maths knowledge (starting, intermediate, challenging) were developed to better engage students at different skill levels. These streamed tutorial sets address the varied mathematical ability within the cohort, better supporting both underperforming and advanced students who want to be challenged. The teaching resources were implemented in the teaching period March to June 2021; their effectiveness was measured through surveys and individual/group interviews. Failure rates and grade distributions were assessed by comparison with data obtained from previous cohorts.

ACTUAL OR ANTICIPATED OUTCOMES

The proposed online resources supplemented the current teaching material to better enhance the learning experience of all students, with an emphasis on the Engineering cohort. Outcomes included increased student engagement and reduced failure rates, as the targeted resources better supported students with different maths abilities.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The teaching resources developed in this pilot project may be implemented in all course delivery modes, including online and blended alternatives, making it an attractive additional online resource that can easily be implemented in current pandemic times. The success of the pilot project provides indications of benefits for other schools and programs to apply a similar approach in their maths or other multidisciplinary courses.

KEYWORDS

Mathematics, active learning, educational videos, tutorials, flipped-classroom, teaching resources.

Introduction

Mathematics plays a crucial role in engineering education. Mathematical concepts are indispensable as they describe, analyse, and make sense of the world around us. They allow us to solve problems that arise in all engineering fields (Neale, 2020).

Sound knowledge of mathematics and practical skills to solve maths problems are essential in engineering practice; therefore, students are expected to demonstrate them in maths-related courses/units, especially in their first year of university studies. However, literature and practice show that traditional didactic methods fail to enthuse, inspire, or educate students and may lead to a negative attitude towards the subject and increased cynicism toward its applicability in real life (Wilkins and Ma, 2003). It also has an adverse effect on student outcomes: for example, first-year maths engineering courses at Griffith University have shown failure rates of approximately 34% and 36% in 2017 and 2018, respectively, with a cohort size greater than 140 students. The structure of these courses focuses on fundamental concepts at the expense of discipline-specific content due to the cohort's wide range of needs, which includes Science, Engineering, Information Technology, Computer Science, and Education students.

Adding to this issue, completing prerequisite subjects/courses is no longer a requirement for entering engineering degrees; instead, degree admission criteria typically list 'assumed knowledge' recommended for commencing students. For instance, in Australia, Mathematical Methods is a subject available to Year 11 and 12 students interested in pathways such as engineering (Evans et al., 2019). The subject is not a tertiary-level entry requirement; it is currently listed under the admission criteria as 'assumed knowledge', which indicates the minimum level of knowledge required to undertake an engineering program. Although universities offer a range of bridging opportunities for those students who have not completed the subject or lack the formal qualifications, assumed knowledge is not assessable, which means that any student can apply and enter an engineering program without such knowledge. This potentially poses a risk that students without the necessary assumed knowledge may have difficulty completing first-year engineering maths courses, leading to disengagement, failure, or withdrawal.

It is, therefore, crucial to develop and implement resources that aim to better enhance the learning experience of all students, increase student skills and engagement, enhance student learning outcomes, improve knowledge retention, and reduce failure rates. A meta-analysis of 225 cases demonstrated a 6% increase in grades and a 33% reduction in student failure when active learning is introduced (Freeman et al., 2014). Vos and de Graaff et al. (2004) showed that an active learning approach increases student performance in science, engineering, and mathematics.

Bhagat et al. (2016) suggested that current technologies, including online quizzes and videos, can benefit students, especially low achievers. These resources enable students to learn at their own pace, access online videos before each class, and then use the class time to participate in the learning activities, such as problem-solving and discussion.

Other resources to enhance mathematics courses that have proved effective include the use of computer algebra software (CAS) (Ooi, 2007); step-by-step problem-solving through worked example videos (WEVs) (Kay and Kletskin, 2012, Dart et al., 2020), and problem-based learning approaches (Masitoh and Fitriyani, 2018). Several studies have shown that educational videos are effective educational tools that enhance learning (Rackaway, 2012).

This paper presents a series of learning and teaching resources intended to supplement existing teaching activities in engineering mathematics courses. These additional resources aim to better engage and support students in their learning process without fundamentally changing how the courses are being taught. These resources include (1) topic videos to enhance the student understanding of the course content and (2) streamed tutorials to suit different math knowledge levels, providing students with a personalised or adaptive approach. Both resources, particularly (2), can easily be adopted in online or blended delivery modes. This is particularly important in current times, where face-to-face teaching has been disrupted due to COVID-19, and educators have been forced to move learning activities to online delivery (Espinosa et al., 2021).

Methods

The Engineering curriculum for the Bachelor of Engineering (Honours) at Griffith University comprises three Mathematics courses: Engineering Mathematics 1 (1010ENG) and Engineering Mathematics 2 (1020ENG) in the first year, and Calculus II (2205NSC) in the second year. Similar to other Engineering programs in Australia, the content covered in the three courses include linear algebra, complex numbers, functions, integration, differentiation, vector calculus, and differential equations.

The second-year undergraduate course, Calculus II (2205NSC), was used as a case study for this pilot project. The course was offered in a flipped-classroom delivery mode in the first teaching period (Trimester 1), March to June 2021. Topic videos (video bites; 10 to 20 minutes duration) were developed to assist students in developing their understanding of the course content and articulate the learning outcomes of each module and their applicability to different engineering contexts. In addition, sets of tutorial problems that target different levels of maths knowledge (starting, intermediate, challenging) were developed to better engage students at different skill levels. These streamed tutorial sets address the varied mathematical ability within the cohort, better supporting both underperforming and advanced students who want to be challenged.

Calculus II is divided into four modules, and it covers aspects of vector calculus in 2D/3D, ordinary differential equations, partial differential equations, and Fourier analysis. These topics serve as a base for further courses in the engineering degree, such as electromagnetic fields, fluid mechanics, structural analysis, and signal processing.

The course is offered once per year over a 12-week period. It consists of 24 hrs of 'lectorials' (1 × 2 hrs/week for 12 weeks) and 22 hrs of tutorial sessions (1 × 2 hrs/week for 11 weeks). Both the lectorials and tutorials can be delivered online or face-to-face. The lectorials are sessions dedicated to Q&A from the video bites and numerical problem-solving practice. The course assessment is composed of an online diagnostic quiz conducted at the beginning of the teaching period (2%), three quizzes (30%), three online practice assessments in preparation for the quizzes (8%), ten tutorial mini-quizzes (10%), and a final exam (50%).

Video bites

Video bites consisted of a series of around 5 or 6 topic videos per week, each approximately 15 mins long. One of the well-known problems with using educational videos is that context can be lost if the material is too brief or presented without context. On the other hand, extended videos result in student disengagement. Fifteen-minute videos provided a good compromise, as they allowed to cover the topic in detail and solve some numerical problems.

According to Brame (2016), to maximise the benefit from educational videos, it is important to consider the following recommendations: (1) *keep the videos brief and targeted on learning goals*, (2) *use audio and visual elements*, (3) *use signalling to highlight important concepts*, (4) *use an enthusiastic delivery style to enhance engagement*, and (5) *embed the videos in a context of active learning*. This can be done, for example, by using interactive elements and guiding questions.

Each video bite began by linking previous bites and establishing the significance and context for the current bite. New learning was then presented, followed by an example with a focus on methodology and decision-making. Students were encouraged to pause the video and attempt a given problem to help reinforce learning. Lecture slides, with space for students to add their notes, were provided to complement the videos, assist meaningful note-taking, and encourage students to work through problems with the presenter.

The video bites were developed with the free and open-source cross-platform OBS Studio (obsproject.com), using a Wacom One Creative Pen Display tablet (Wacom.com). The videos were edited with the software Camtasia (techsmith.com). The video editor allows the videos to be incrementally improved over the years, keeping them up to date in terms of video quality and content.

Before recording each video, a script was developed to reduce recording time and minimise cut sequences. The videos were uploaded to the university's learning management system Blackboard (blackboard.com). In the future, it is intended to upload the videos to an online video sharing platform (i.e., YouTube) so they can be available to the broader education community.

The videos were supported by a 'lectorial' each week. These lectorial sessions allowed students to ask questions about the content and allowed them to discuss applications, giving value to what was learnt. Several examples would also be worked through, focusing on each of the main skills developed that week. Questions considered included discipline-based applications, providing relevance to learning.

Gratchev and Jeng (2018) suggested that students appreciate the course content better if they see how it can be applied to real-life applications. As an example, one problem considered a differential equation that modelled the behaviour of an industrial robot arm used to move salt pellets, determined the type of natural response we could expect, and discussed why that is important for this application. Another example considered solving a differential equation to find the voltage across a capacitor in a resistor-inductor-capacitor (RLC) circuit.

Tutorial streaming

One set of tutorial problems was developed for each of the tutorial sessions, and each tutorial set was divided into three different levels of difficulty: starting, intermediate, and challenging. The tutorial set was made available to the students one week before the tutorial session. Students were encouraged to attempt the problems from all skill levels before attending their session.

In the teaching period of 2021, tutorial sessions were delivered face-to-face. During the two-hour session, students were divided into groups of five and asked to continue working on the problems in a discussion group. The tutor would then walk around the groups and offer personalised assistance; if common questions or struggles arose, the tutor would then solve specific problems step-by-step in front of the class. Once all tutorial problems were discussed and solutions verified, the tutor conducted a mini quiz for about 10 minutes (generally at the end of the session). The mini quiz consisted of three numerical problems with difficulty sitting between 'starting' and 'intermediate' levels.

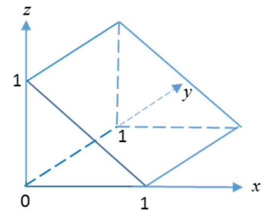
Each tutorial set consisted of approximately 12 problems (four for each skill level). All questions, primarily designed in an abstract form, provided a progressive understanding of each topic delivered in the video bites. As an example of the skill level structure, after the 10-minute video bite on 'Gauss's Theorem' and the corresponding lectorial session, which was mainly dedicated to Q&A, students would then attempt the following problems before their tutorial session:

- *Example of a 'Starting level' question*

A 3D vector field given by $\underline{\mathbf{V}} = 3x^2\underline{\mathbf{i}} + 2y^2y + y\,z\mathbf{k}$, represents the flow of water in a system. Use Gauss's theorem to find the overall flow of water out of a box with $0 \le x \le 1$, $0 \le y \le 1$, and $0 \le z \le 2$. According to whether your answer was positive, negative, or zero, provide an interpretation of the result.

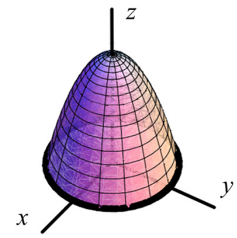
- *Example of an 'Intermediate level' question*

The following figure shows a wedge-shaped closed surface, defined by $x + z = 1$ and the planes $x = 0$, $y = 0$, $y = 1$, and $z = 0$. For the vector field $\underline{\mathbf{V}} = xz\underline{\mathbf{i}} + yz\underline{\mathbf{j}} + z\underline{\mathbf{k}}$, find the overall flux out of the wedge's surface using Gauss's theorem. According to whether your answer was positive, negative, or zero, provide an interpretation of the result.



- *Example of a 'Challenging level' question*

Let V be the solid bounded by the x-y plane ($z = 0$) and the paraboloid $z = 4 - x^2 - y^2$. Let S be the boundary of V (the paraboloid and a disk with radius 2 in the x-y plane), oriented with the outward-pointing normal. Find the overall flux out of the paraboloid and disk using Gauss's theorem where the vector field $\underline{\mathbf{V}}$ is given by $\underline{\mathbf{V}} = (xz\sin(yz) + x^3)\underline{\mathbf{i}} + (\cos(yz))\underline{\mathbf{j}} + (3zy^2 - e^{x^2+y^2})\underline{\mathbf{k}}$ and $0 \leq \theta \leq 2\pi$ in cylindrical coordinates.



As mentioned previously, tutorial problems were primarily designed in an abstract form due to students from different cohorts (i.e., education, science, and engineering) being enrolled in the course. It is, however, in the project plans to expand the tutorial list to include more discipline-specific problems with varying levels of difficulty. This would be particularly suitable for implementation in courses with little desire or ability to adjust the current delivery.

The tutorial sets allowed the teaching team to ascertain individual and overall student performance. If most students struggled with problems at a particular skill level, more emphasis was then added to those problems; otherwise, the tutor would move faster to the following skill level. From the students' perspective, the different levels of difficulty allowed them to determine their understanding of the course content and encourage them to seek immediate help if they were struggling with the 'starting level'. This was important because both quizzes and the final exam were designed based on the 'intermediate level' of difficulty. On the other hand, if students could reach the challenging problems with no difficulty, it would allow them to move confidently to further topics.

Results

To assess the effectiveness of the teaching resources, assessment results for 2021 were compared to results from the preceding six years. Both resources were fully implemented for the first half of the course, so the first assessment item (quiz 1) was used for the analysis. Figure 1a shows the pass/failure rates from 2015 to 2021. As it can be seen, from 2015 to 2019, the failure rate was ≥ 30%; this decreased to 24% in 2020 and 16% in 2021. It is important to note that since 2020, COVID-19 has had a noticeable impact on the overall student outcomes. Although randomised questions and randomised variables were used in the assessments, there was no formal invigilation.

In 2020, additional tutorial questions were partially introduced. In 2021, streamed tutorials + lecture video bites were introduced through the first half of the course, and video bites in the second half (no streamed tutorials).

Figure 1b shows the student outcomes for one of the assessments (quiz 1 – marked out of 10), for the total number of students (110) enrolled in 2021. As can be seen, more than 35% of the students received a high distinction (≥ 8.5/10). This percentage is greater than previous years where it was approximately 20%-25%.

In addition, student feedback in 2021 was collected through a general qualitative and quantitative survey containing the following questions:

Q1. This course was well-organised.

Q2. The assessment was clear and fair.

Q3. I received helpful feedback on my assessment work.

Q4. The course engaged me in learning.

Q5. The teaching team was effective in helping me to learn.

Q6. Overall I am satisfied with the quality of this course.

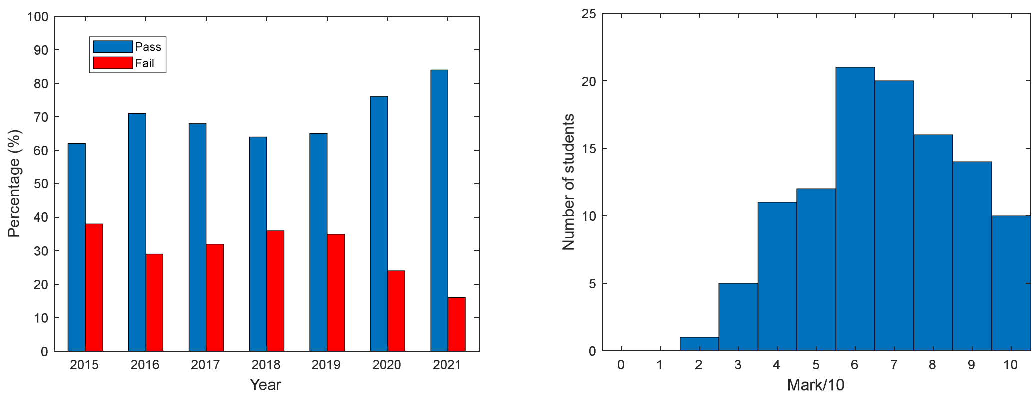


Figure 1: (a) Pass and failure rates from 2015 to 2021 of one of the assessment items, (b) student outcomes for one of the assessment items (marked out of 10) in 2021.

The questions were scored using a 5-point Likert-type response scale, from 1 (strongly disagree) to 5 (strongly agree). The response rate was 30%. Figure 2 summarizes their responses. The 5-point scale was converted to a total score out of 100.

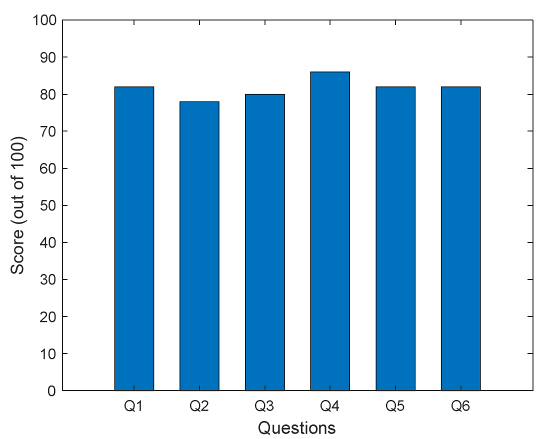


Figure 2: Anonymous survey response from undergraduate students in Calculus II, 2021. Questions 1 to 5 scored out of 100.

According to the feedback, students found the course engaging (average score 86/100) and well organised (average score 83/100), highlighting the importance of the video bites, as they found them valuable and easy to follow. They stated that the videos enhanced their understanding of the course content and their learning in general.

Students found the lectorials helpful, as they helped them connect the conceptual theory with practical engineering applications. In addition, they found the streamed tutorials very well designed, structured, and implemented, as they tested their capabilities through the different levels of difficulty. This allowed better engagement by high performing students, as well as

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those that were struggling. Their ability to work at their own pace was recognised as an essential factor for their learning.

The following excerpts from student feedback provide some insight into their learning experiences:

"Excellent structure and clarity to lecture bites which made learning and understanding the content significantly easier."

"Video bites were very clear, easy to understand and overall, extremely helpful."

"I personally loved the way the streamed tutorial problems were designed, as they allowed me to work and understand the basics (with simple problems) then work my way through and move on to moderate and more challenging problems."

Concluding remarks

As a result of using video bites and streamed tutorials, the maths course targeted by this pilot project was able to better cater to the individual learning styles of its diverse student cohort. The approach used allows either full flipped-class implementation or as supporting resources for a more traditional style. In the flipped-class approach, the lectorials allowed clarification of concepts where students were unclear, and the ability to discuss applications and interpretation of answers, thereby providing a link between the math and the real-world to which it is being applied. By incorporating questions of different competency levels in the streamed tutorials, students of all competencies can participate and achieve some success and be motivated to work their way through to the higher levels of difficulty. Results and feedback showed that students not only enjoyed the course design and resources but improved their learning as well. These results indicate benefits for other universities and programs to apply a similar approach in their maths or other multidisciplinary courses.

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An active laboratory learning experience for chemical engineering students facilitated by hypothesis testing

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ABSTRACT

CONTEXT

The ability to think critically and to be self-directed learners are recognised as pivotal to university graduates in the evolving context of the engineering profession. Lab practices are important learning experiences in undergraduate engineering programs and are generally viewed as main occasions to develop such skills. The use of enquiry-based learning approaches in lab practices supports the development of the graduate attributes of critical thinking and independent learning.

PURPOSE

A traditional approach in engineering educational laboratories is expecting students to achieve pre-determined results by following instructions given, for example, in a laboratory manual. It is recognised that such approach is ineffective in engaging learners in critical thinking or in making design decisions, for example when dealing with multiple objectives and constraints. Holistic approaches emphasizing the use of hypothesis forming and evaluation and design of experiment (DOE) in laboratory practicals are perceived to be conducive to improved learning outcomes. An "open-ended" learning activity has been designed and implemented to foster student's engagement and deep learning. The activity includes an assessment scheme that allows an evaluation of the transformative effect on student learning approach, specifically engagement in critical thinking, and an observation of the metacognitive awareness in the learning process. The laboratory practice covers separation unit operations that are ubiquitous in several industries, nominally continuous distillation.

APPROACH

The approach adopted is rooted in inquiry-based pedagogy. Students are given the task of optimising the operation of a distillation column. Responding to the proposed problem, requires students to model the distillation system, determine optimal operating conditions by simulation, identify the most influential process variables, and design an experimental plan to validate modelling and simulation work. The use of a critical approach is encouraged by the assessment design associated to the laboratory project: students individually submit their hypothesis about the expected outcomes of the experimental practice and a reflection on it considering the results subsequently obtained. Overall, the learning activity proposed is structured to encourage learners to engage critically and, to a certain extent, independently. The use of hypothesis testing, reflections, conceptual questions in assessment, and surveys allows the collection of learning analytics suitable to evaluate learning approaches.

ANTICIPATED OUTCOMES

The proposed activity engages students in a six-steps learning process: modelling of a separation process, hypothesis forming and prediction, process optimization through simulation, design of experiment, results evaluation, and reflection on the original hypothesis. The need to verbalize predictions is expected to improve engagement in the task. It is expected that the sequence of activities encourages students to derive logical conclusions from multiple inputs, question their findings and justify their conclusions. The assessment design allows a longitudinal evaluation of critical thinking and of metacognitive awareness. The combination of students' reflections, summative assessment results (laboratory reports, mid-session exam),

and observations from the teaching team allow for evaluation of dept of learning and skills development.

SUMMARY

An enquiry-based approach has been implemented in a 2nd year chemical engineering laboratory. Such open-ended approach is a closer representation of real-world engineering work that often lack pre-determined solutions. The activity is designed to boost students' engagement with the practical activity and support critical thinking and deep learning. The assessment scheme is an integral part of the learning activity and allows for the observation of students' learning approaches over the duration of the activity and of the knowledge and skills developed.

KEYWORDS

Hypothesis forming, design of experiment, active learning, critical thinking, Chemical Engineering education.

Introduction

Enquiry-based learning and hands-on experimentation provide students with an opportunity to actively construct, process, and communicate their own understanding leading to effective conveyance of concepts (Huet, 2018). Meyers et al. (2009) suggested five principles for effective curriculum design to ensure the attainment of learning outcomes, one of which is to employ authentic, relevant, and real-world teaching and learning resources. It is postulated that students engage more with course content when they feel it is relevant to current real-world practice and necessary to improve their employability. This is particularly true when it comes to engineering students with pragmatic attitude towards knowledge. As such, incorporating unit operations laboratory in chemical engineering curriculum is perceived to be an effective way in exposing students to the real-world application of the theoretical concepts.

Traditional approach in unit operations laboratories is to direct students to carefully follow a laboratory manual to obtain pre-determined and "desired" results (Chandra, 1991; Young et al., 2006). Such an approach fails to inspire students to develop and demonstrate critical thinking, and to make design decisions when dealing with multiple objectives and constraints, the latter being a required graduate attribute by accreditation bodies such as The Institution of Chemical Engineers. Holistic approaches emphasizing the use of design of experiment (DOE) technique and statistical tools in laboratory practicals have been identified as conducive to improved learning outcomes (Doskocil, 2003; Jimenez et al., 2002; Narang et al., 2012; Young et al., 2006). Design of experiment is widely-used in industry to minimise the cost related to experimentation necessary to reach a conclusion while generating results with appropriate levels of accuracy (Doskocil, 2003). Concomitantly, computer simulation and process modelling are being increasingly viewed as safe and cost-effective alternatives to pilot-scale experimentation in chemical industries (Williams et al., 2003). Several educational institutions have applied advancements of information technology to develop virtual laboratories to partially or completely replace bench-scale or pilot-scale unit operations practicals (Brault et al., 2007; Rafael et al., 2007; White et al., 1999; Williams et al., 2003),however, the findings of White and Bodner (1999) suggest that practical laboratory experience is integral to chemical engineering education.

There have been numerous studies suggesting the contribution of hypothesis testing and predictions to active learning and enhancing the students' learning experience (Bertram, 2002; Codella, 2002; Dantas et al., 2008; Modell et al., 2004; Rivers, 2002; Yoder et al., 2005). In a study by Modell et al. (2004) on the effectiveness of hypothesis forming in a physiology laboratory, it was found that students performed better when asked to verbalize their prediction of the outcomes prior to attending the laboratory. This was partly attributed to the fact that students were more likely to engage with the learning task when they had committed to a prediction. However, the literature is limited on the evaluation of the effectiveness of integrated

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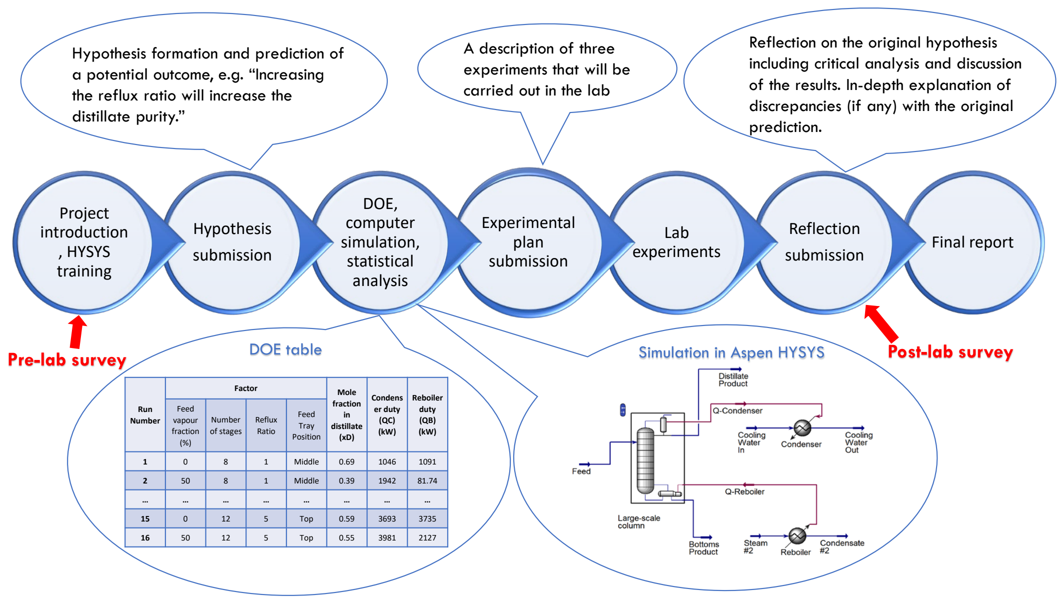
active learning practical labs in promoting critical thinking and independent learning. The latter will be investigated focussing on evidence of metacognition in students' output.

Context of study

The learning and teaching activities included in this study have been designed as part of the educational offer of the Separation Processes courses at School of Chemical and Biomolecular Engineering, University of Sydney. The courses cover the design of separation unit operations commonly used in chemical industries including distillation columns and are offered to second year undergraduate students and to Master of Professional Engineering students. An inquiry-based pedagogy has been adopted articulated in the following main steps: modelling of a separation process, hypothesis forming and prediction, process optimization through simulation, design of experiment (DOE), results evaluation, and reflection on the original hypothesis. Figure 1 presents an overview of the activities.



Run Number	Factor				Mole fraction in distillate (xD)	Condenser duty (QC) (kW)	Reboiler duty (QB) (kW)
	Feed vapour fraction (%)	Number of stages	Reflux Ratio	Feed Tray Position			
1	0	8	1	Middle	0.69	1046	1091
2	50	8	1	Middle	0.39	1942	81.74
...	...	...	...	...	...	...	...
15	0	12	5	Top	0.59	3693	3735
16	50	12	5	Top	0.55	3981	2127

Figure 1. Overview of the teaching and learning activities associated to the distillation laboratory practical.

The hypothesis and reflection submissions are individual tasks and allow for the qualitative longitudinal observation of the students' approach to learning and metacognitive awareness. The assessment scheme of the courses comprises a mid-session individual test that includes conceptual questions. Responses to individual tasks allow an evaluation of student approach with particular attention to evidence of critical thinking and, potentially, to the transformative impact of the intervention.

Students work at the other tasks of the activity in groups of 3 to 4. The activity sets a realistic work scenario in which students are asked to work as chemical engineers in a consulting firm. An ideal client tasks the consulting form to optimise the operation of an industrial-scale distillation column with a specified diameter for the continuous separation of ethanol-water mixtures. The design objective set by the client is to maximise the purity of the distillate with the minimum operating costs: the cost of steam and cooling water consumption in the reboiler and condenser, respectively. The client specifies the pressure at which steam is available. Additional design constrains are that a water-cooled total condenser is used in this column with the cooling water entering the condenser at 30°C and returning to the cooling tower strictly below 40°C. The bottoms from this column are used elsewhere as "process water" and thus cannot contain more than 2 (mole) % ethanol. The client requires the estimation of the total

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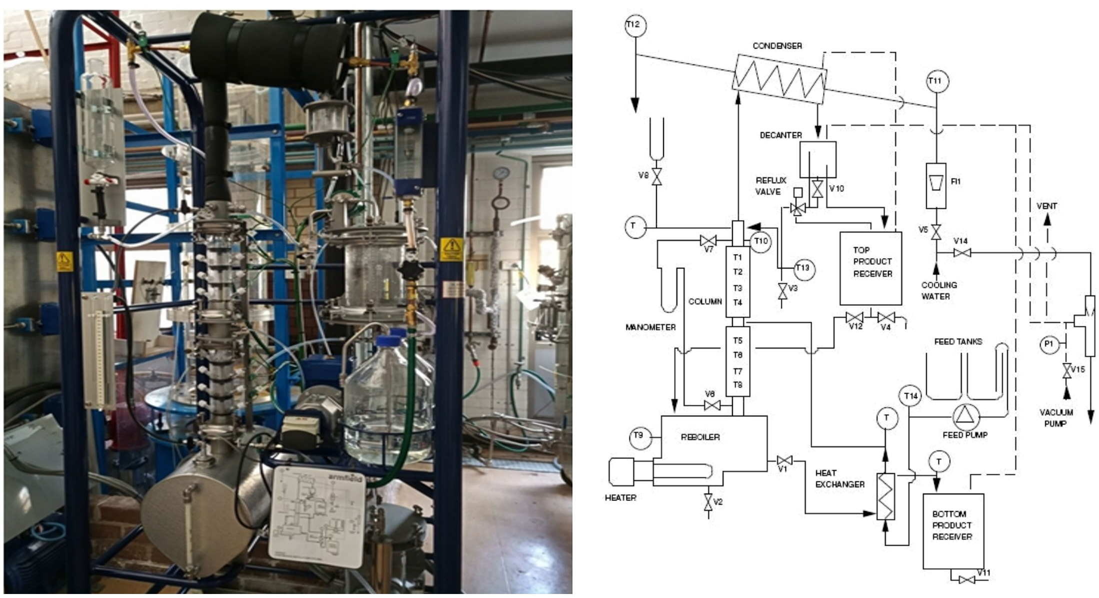
number of sieve trays before proceeding with the procurement and installation of the column internals.

Students carry out a comprehensive experimental study to find optimum operating conditions such as feed temperature, feed tray position, number of theoretical plates, reflux ratio, and reboiler duty using HYSYS. Design of experiment is required to find the minimum number of experiments that maximise the number of variables that could be investigated. Students notice that even after a well-planned DOE, it is unpractical to conduct the experimental study on the industrial-scale column. Hence, the concepts of pilot-scale experimentation and scale-up to large-scale plants is presented, introducing students to a common practice in chemical industries. The distillation equipment available for the practical is a 50 mm diameter sieve plate glass distillation column (UOP3CC, Armfield Limited) containing eight sieve plates. A photograph and a schematic diagram of the equipment are presented in Figure 2. Students are presented with the additional constraint that the session time in the laboratory is sufficient to carry out only three experiments. This leads to the use of simulations to execute the experimental design and investigate the effect of different process variables. The simulation is conducted using Aspen HYSYS simulation software. Subsequently, students perform a statistical analysis of the results and determine the variables that have the most significant impacts on the process. The results inform the selection of the operating variables to be investigated in the practical session when students use the lab-scale experiments to selectively validate the computer simulation data. Students need to estimate the efficiency of the industrial-scale sieve trays to be able to calculate the actual number of sieve trays. This is done by evaluating the tray efficiency in lab-scale column and scaling up the results for large-scale column.



A **B**

Figure 2. A: photograph of experimental rig. B: Schematic diagram of experimental rig

Research Methodology

Enquiry-based pedagogy has been adopted to engage students with the learning process as active learners. Contrary to traditional laboratory approaches that encourage passive learning through prescribing laboratory procedures, the proposed approach provides students with the autonomy to design their own experiments and be actively involved in the learning process. “Autonomy” defined as the willingness to spend time and energy to study is one of the three

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psychological needs contributing to students' intrinsic motivation towards learning according to Self Determination Theory (SDT) (Niemiec et al., 2009; Trenshaw et al., 2016). Autonomy-supportive teaching practice provides students with the voice and choice in the learning activities thereby increasing their interest in self-learning (Niemiec & Ryan, 2009). The activities start by introducing the project scopes and overview of the tasks. A training session on Aspen HYSYS will be given to prepare students for the process simulation activity. Students are then asked to form a hypothesis and make a prediction of the potential outcome of the optimisation task. For example, they may hypothesis that "increasing the reflux ratio will increase the distillate purity". This gives students the chance to develop an understanding of the theory before entering the laboratory and hence have a better appreciation of the distillation theory in practice. Committing to a prediction, students are more likely to be actively engaged with the activity as suggested by Modell et al. (2004). Students will complete the pre-lab survey (Figure 3) and answer few questions about their attitude to self-directed learning and ability to think critically.

Pre-lab survey

Q1. If you were stranded in a canyon, what would your first move be?

Free text response

Q2. Consider the following skill list.

T - Team work

C - Critical thinking

S - Sourcing information

D - Data analysis

P - Data presentation

Which of these skills are your strong points?

Rank these (TCSDP) from 1 (strongest) to 5 (less strong). You should not have two skills ranked in the same way.

Q3. Experiments should be designed by (please tick the option/s you agree with)

The teaching team

The students

Other (please specify)

Figure 3. Pre-lab survey questions to evaluate students' perceptions of their critical thinking skill and self-directed learning.

To evaluate the validity of their hypothesis, students undertake an experimental campaign including DOE, HYSYS simulation, and statistical analysis of the simulation results to find the most significant factors and their optimum values. Lab-scale experimentation is used to validate the simulation data and estimate the real tray efficiency for scale up purposes. Students commit to three distillation experiments of their choice as part of their experimental plan to be carried out on the lab-scale distillation column. Students individually articulate their predictions of the laboratory and reflect on the assumptions they made considering the experimental results of the lab practicals. Finally, each team submits a laboratory report including recommendations for the ideal client. Students will be asked to answer the post-lab survey questions shown in Figure 4.

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Post-test (available any time from the laboratory sessions to the end of the semester)

Please rank the following from 1 (Strongly disagree) to 4 (Strongly agree) or Not Applicable

1. My team decided the scope of the lab practical on our own
2. My team worked out the interpretation of the practical outcomes independently
3. I thought carefully about my predictions
4. I looked at relevant information to interpret the results
5. I thought about what assumptions I made during the project
6. The simulation work and the lab practical together supported my learning
7. I found the project interesting

Each question will also have a free form entry box with the guidance “Please explain your response”.

Figure 4. Post-lab survey questions

The overall experience is designed to support student learning and to provide the opportunity to evaluate student approach to learning at the start of the activity by examining responses to the survey, the hypothesis submission, and the DOE proposed. The first two items are individual and offer the opportunity to evaluate the effectiveness of the experience to shift students learning behaviour toward a more critical approach as opposed to focussing on searching for pre-existing solution algorithms or a memorisation-based approach. This can be achieved by analysing and comparing students’ outputs in the early stages of the experience (pre-lab survey, hypothesis submission, DOE) to outputs generated in later stages of the experience (post-lab survey, reflection, response to conceptual questions in mid-session test). Such evaluation of the effectiveness of active learning in chemical engineering labs is novel and the results are likely to be transferable to other contexts in engineering education applying a similar design. The effectiveness of the intervention on the performance of the general cohort will be evaluated based on the examination of the laboratory reports and of the observations of the teaching team that will be collected by semi-structured interviews.

In general, critical thinking is revealed by indicators, for example:

1- Evidence of evaluation
2- Draw of logical conclusions considering all available data
3- Presentation of arguments
4- Practice of critical reflection
5- Evidence of data analysis
6- Suggestion of alternatives
7- Question credibility and accuracy of information and supporting evidence
8- Justification of procedures/recommendations
9- Accurate self-evaluations

Following are some examples of observations from students’ outputs indicating a critical approach to the specific activities proposed here.

- Use the temperature profile from the HYSYS model and lab-scale column to estimate the composition of ethanol in the top and bottom products using the theoretical T-xy diagram. Compare differences between the temperature profiles. Discuss possible reasons behind the discrepancies (if any).
- Test the accuracy of the thermodynamic property package used in the HYSYS model by comparing the produced phase equilibria data (T-xy diagram) with literature data.
- Scale up from lab-scale to large-scale column and present conclusion on the real number of plates taking into consideration the column efficiency calculated in lab experiments.

Examples of metacognition can emerge from students’ submissions as indications that students identify their abilities in relation to the requirements of the activity and use strategies

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in response to it. For instance, upon recognising that they cannot explain the results of the experiment, student identifies that linking theory to experimental outcomes is their limiting step and seeks help to improve this skill.

The sample evaluations presented in this work, show that the activities are collectively suitable to highlight the aspects of student learning targeted by this educational intervention. The next iteration will include a larger number of participants and will introduce semi-structured interviews. Both aspects will arguably allow for a more systematic evaluation of the intended outcomes.

Conclusions

To support student learning and experience, enquiry-based pedagogy has been applied in the design of the learning and teaching activities in a chemical engineering laboratory. In particular, the approach aims to support critical thinking and independent learning. Both abilities are recognised as pivotal for university graduates to succeed in the evolving context of the engineering profession. The approach is articulated in multiple steps: design of experiments, computer simulation, hypothesis forming and prediction, results evaluation, and reflection. The study investigates the effectiveness of the approach through analysis of student outputs at different stages of the experience integrated with pre-lab and post lab student surveys and interviews of the teaching team. Results from the work are likely to be transferable to other teaching laboratories in engineering as the approach proposed in generalizable. Moreover, the work contributes a readily applicable framework within engineering practical labs to evaluate critical thinking and the effectiveness of interventions directed to support such skills.

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Improving Learning Experience by Embedded Project-based Learning and Mixed-mode assessment in Computational Statics and Dynamics Course

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ABSTRACT

CONTEXT

6522ENG Computational Statics and Dynamics is a third-year course in the Bachelor of Engineering (Honours) program and a core course for the Master of Professional Engineering program in the School of Engineering and Built Environment, Griffith University. There are approximately 60 students enrolled annually. 6522ENG is 12-week, 10 credit-point course that corresponds to one-quarter of the typical full-time load for the trimester. This course presents continuum mechanical basics and computational algorithms to analyse engineering components and structures under arbitrary loading conditions. The course is organised by project-based learning approach (PBL). Students also gain skills in using a finite element analysis package and further deepen their knowledge via two group-projects and two individual exams.

PURPOSE

The purpose of implementing PBL in 6522ENG at Griffith is to enhance the students' learning experience. The motivation for implementing PBL and two individual exams is to introduce concepts early in a course, tie concepts together while monitoring the students' learning process. It encourages students with an active learning experience that aims to simulate a "real-world" engineering experience.

METHODOLOGY

We constructively align the course with Griffith Graduate Attribute and Engineering Australia Stage 1 Competencies via a weekly 2-hour lecture, a 1-hour tutorial and a 2-hour scheduled laboratory time for project work. The assessment plan is designed as a mixed mode with four steps. Group work is project-based learning, known as a pedagogy approach for engineering education (Helle et al., 2006). The large project is divided into two phases, assessed at the fourth and eleventh weeks. Tests are individual work introduced before the first project assessment and after the second project assessment. These tests aim to monitor and promote student engagement. This mixed-mode assessment has been proven efficient in engineering education, and project-based learning has been demonstrated as a key component of engineering programs (Mills and Treagust, 2003).

We use four indicators to evaluate the effectiveness of this approach: feedback from students via student surveys, grade distributions, responses on the test, and the practical success of the proposed project. The survey results were the general university' student experience of courses' that students voluntarily complete. The survey consists of two open-ended questions and six statements ('questions') that quantify students' respond. The survey also includes the students' feedback on online experience during the pandemic Covid-19.

RESULT

Overall, we were able to describe a successful implementation of a project-based learning component in an undergraduate course on computational statics and dynamics. The main merit of the embedded project was in providing hands-on experience of finite element method in design a real engineering structure. This served as scaffolding for introduction of new

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concepts within the course material. The extensometers, designed by students' project, were well-covered by design, analysis, simulation, and validation steps. Students demonstrated geometry optimisation utilising finite element method by both commercial software and hand-calculation, validated result with analytical solution. Students were able to discuss calibration protocol and the selection of electronics components necessary in real engineering design. Furthermore, students enjoyed the course, engaged well with the project and performed well on all assessment items and exam questions connected to the project's themes.

KEYWORDS

Project-based Learning, Computational Statics and Dynamics, Finite Element Method,

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Introduction

Griffith University has emphasised its vision to enhance student learning outcomes, engagement and improve retention by implementing a student-focused learning approach. At Griffith University, Mechanical Engineering discipline has been implementing a range of project-based learning (PBL) initiatives to wholly continuous assessment courses with a strong PBL focus (Palmer and Hall 2011; Hall et al. 2012). This paper presents a third-year mechanical engineering computational statics and dynamics course which was developed using a design-and-build project as the central theme and integrating individual assessment as monitoring tools since 2020.

The PBL approach itself has received much interest, particularly for engineering education (Frank et al. 2003; Helfenbein et al. 2012; Krishnan & Nalim 2009; Lima et al. 2007, Mills & Treagust 2003) since it can shift the learning process closer to a 'real-world' engineering experience and improve connections to the desired graduate attributes. Students do their own learning and the lecturer takes on coaching or supporting role to teach students' how to learn' rather than being a 'provider of facts' to passive listeners (Frank et al. 2003). Helle et al. (2006) suggests three different purposes for implementing PBL, including the promotion of "concrete and holistic experience regarding a certain process", "integration of subject material", and "self-regulated deep-level learning". These promotions are the motivation for implementing PBL in 6522ENG Computational Statics and Dynamics at Griffith University. The implementation will reduce 'chalk and talk' pedagogy and was motivated by a desire to enhance further the learning experience rather than completely replace the existing pedagogy. The purpose of implementing PBL in 6522ENG at Griffith is to enhance the students' learning experience. The motivation for implementing PBL and two individual exams is to introduce concepts early in a course, tie concepts together while monitoring the students' learning process. It encourages students with an active learning experience that aims to simulate a "real-world" engineering experience.

Context

The Course

6522ENG Computational Statics and Dynamics is a third-year course in the Bachelor of Engineering (Honours) program and a core course for the Master of Professional Engineering program in the School of Engineering and Built Environment, Griffith University. There are approximately 60 students enrolled annually. 6522ENG is 12-week, 10 credit-point course that corresponds to one-quarter of the typical full-time load for the trimester. This course presents continuum mechanical basics and computational algorithms to analyse engineering components and structures under arbitrary loading conditions. The course is organised by PBL approach. Students also gain skills in using a finite element analysis package and deepen their knowledge via two group-projects and two individual exams.

Assessments for the course were as listed in Table 1. The project reports (15% and 25%) are directly connected to the project. Students worked in groups, but all students were required to submit individual project reports.

Table 1: Course Assessments

Assessment Item	Weighting
Problem-solving test (individual work)	15 %
Initial project report (group work)	15 %
Final project report (group work)	25 %
Final Exam	45 %

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The Project

The task for student is to work in groups of four to design a clip-on extensometer. Extensometer is a convenient tool mounted directly onto the specimen to accurately measure the average strain in the gage section of a material test specimen. The knife edges transfer extension from the specimen to the internal transducer are short and stiff, so there is practically no relative movement between the specimen and the extensometer, resulting in a high level of measurement accuracy. The elongation results in a ‘bending strain’ can be recorded by a strain gauge.

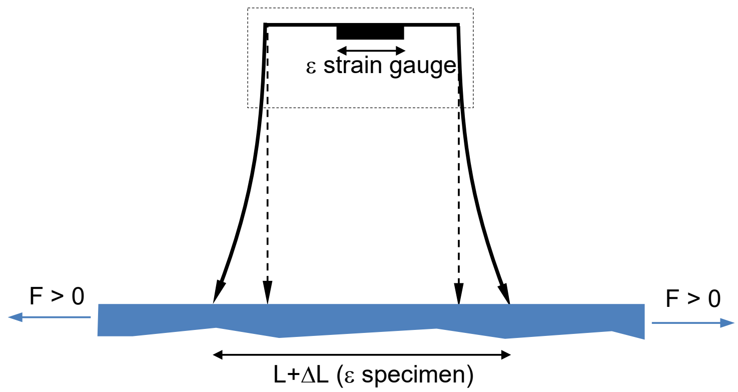

Figure 1: Extensometer design requirements

Student needs to design the extensometer based on both differential equation-based approach and the finite element method, and compare those results. The goal is to derive the relation between the specimen’s deformation/strain with those in the sensor. For the finite element approach, student will justify the selection of element type, mesh density and explain the chosen dimensions of the sensor. As an engineering project, a geometry optimisation process is required. The results also include a completed manufacturing drawings, assembly instructions, selection of sensor, manufacturing method, discussion on calibration protocol and estimated cost of the designed extensometer.

Pedagogy

We used various aspects of the project throughout the course. In particular, the concepts of material strength, partial differential equations, truss, beam, plane elements, were illustrated in connection with the project. The more fundamental topics provided the scaffolding required for understanding extensometer design via a weekly 2-hour lecture, a 1-hour tutorial and a 2-hour scheduled laboratory time for project work. The assessment plan is designed as a mixed-mode with four steps. The large project is divided into two phases, assessed at the fourth and eleventh weeks. Tests are individual work introduced before the first project assessment and after the second project assessment. These tests aim to monitor and promote student engagement. This mixed-mode assessment has been proven efficient in engineering education, and project-based learning has been demonstrated as a key component of engineering programs (Mills and Treagust, 2003). Additionally, each project is given a specified set of product requirements which will result in unique design and output of the project.

Methodology for analysis of initiative

We use four indicators to evaluate the effectiveness of this approach: feedback from students via student surveys, grade distributions, responses on the test, and the practical success of the proposed project. The survey results were the general university’ student experience of courses’ that students voluntarily complete. The survey consists of two open-ended questions and six statements (‘questions’) that quantify students’ respond. The survey also includes the students’ feedback on online experience during the pandemic Covid-19. Students can respond

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on a five-point scale ranging from strongly disagree (SD), disagree (D), neutral (N), agree (A) to strongly agree (SA). SD has a point value of 1 and SA a point value of 5. The questions are given in Table 2. Survey responses are done online before students take the final exam.

Table 2: University-wide Survey Questions (SEC)

Question (Statement)	Responses
Q1 This course was well-organised.	SD,D,N,A,SA
Q2 The assessment was clear and fair.	SD,D,N,A,SA
Q3 I received helpful feedback on my assessment work	SD,D,N,A,SA
Q4 This course engaged me in learning.	SD,D,N,A,SA
Q5 The teaching (lecturers, tutors, online etc) on this course was effective in helping me to learn	SD,D,N,A,SA
Q6 Overall I am satisfied with the quality of this course.	SD,D,N,A,SA
Q7 What did you find particularly good about this course?	Open
Q8 How could this course be improved?	Open

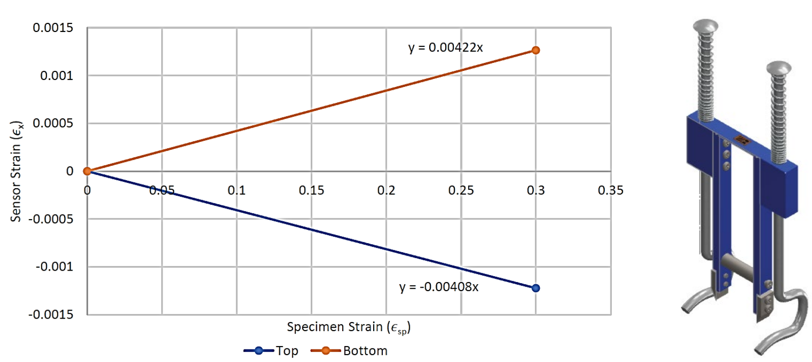
Approval was obtained from the ethics and integrity team at Griffith University to make use of the student data in this research.

Results and Discussion

Connecting theory and experiment – *a concrete and holistic experience*

All 22 student groups succeeded in designing, simulating, and validating extensometer, which yielded meaningful results of the engineering design process. Figure 2 shows a result from a student project. The graph is a typical calibration curve after performing the extensometer's dimension optimisation to reach the highest performance with minimal material cost. The mathematical background of the project is to solve partial differential equations with an analytical approach, and by finite element simulation (FEM approach) where students build their own stiffness matrix. These results are then compared with those of commercial package (ANSYS APDL). A script of simulating code and engineering design (e.g. detail drawing of Fig.2b) were submitted together with the report.

Overall, the practical implementation of the project can be judged a success. The student-designed extensometer all showed the deformation from the specimen is scaled down to those at the straingauge, which is well described in the report and reflected via 3D engineering design.



(a) (b)

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Figure 2: Typical results for extensometer design with (a) relation between speciment's strain and sensor' strain, and (b) a 3D CAD design.

Student perceptions of the course

The course was very well received by students. Figure 3 gives the distribution of responses to the first six questions listed in Table 2. 25 (39 %) of the 63 students enrolled in the course responded to the survey. On average, the students agreed or strongly agreed that the course was well organised, the assessment was fair, the feedback was helpful, the course was engaging and the teaching was effective. Although the question "engaged learning" had some negative responses at D or SD, 88 % of the response was positive (A or SA). In relation to the PBL component, it is difficult to differentiate between its effect and the other pedagogical methods employed in the course. However, the responses for Q4 (This course engaged me in learning) and Q5 (The teaching on this course was effective in helping me to learn) are encouraging since the main role for PBL in this course is to engage the students in learning.

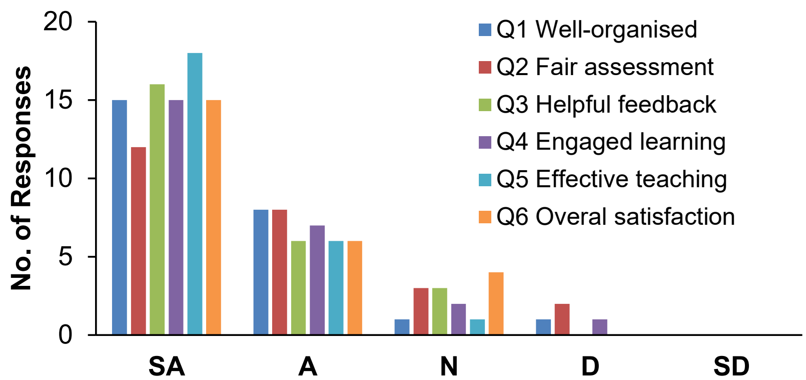

Figure 3: Distributions of responses to the six questions on the student survey

The responses to qualitative questions did not clearly indicate if the students particularly valued or even recognised the role of the project in the course. Figure 4 summarises the responses to the open questions (Q7 and Q8 in Table 2). In relation to 'what the students found particularly good about the course', students mentioned the "two stage assessment structure" and "industrial related content". However, the most common response is "well structure" of the course. Given that the project played an essential role in the content delivery, it seems reasonable that the embedded project with two-stage assessment contributed towards the positive feedback about course content and assessments.

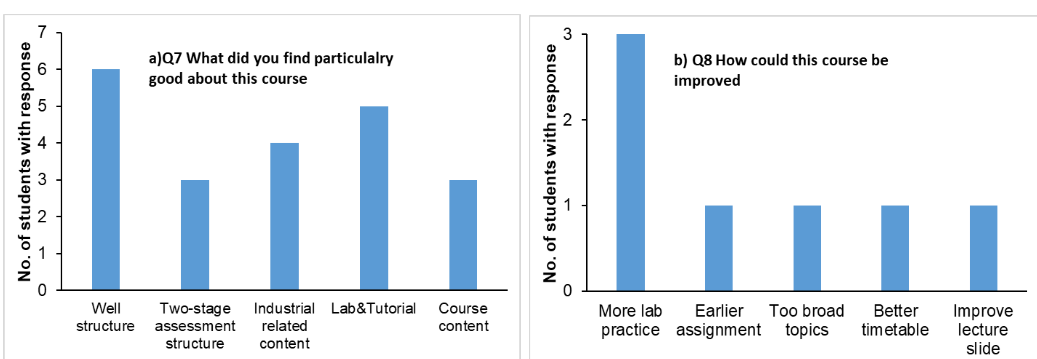

Figure 4: Summary of student responses to the qualitative questions

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Figure 4(b) presents the feedback that the students would like to have more lab practices and an earlier assessment. There was a lack of qualitative feedback directly connected to the project embedded in the course.

Learning outcomes

Figure 5 shows the grade distributions for the assessment items and the overall grade for the course. Students invested considerable effort into their project reports and did a commendable job. The overall grade distribution is also good, with a peak at the credit level. While the course was a success based on measured learning outcomes. It is difficult to say how much of the success can be attributed to the project-based learning component.

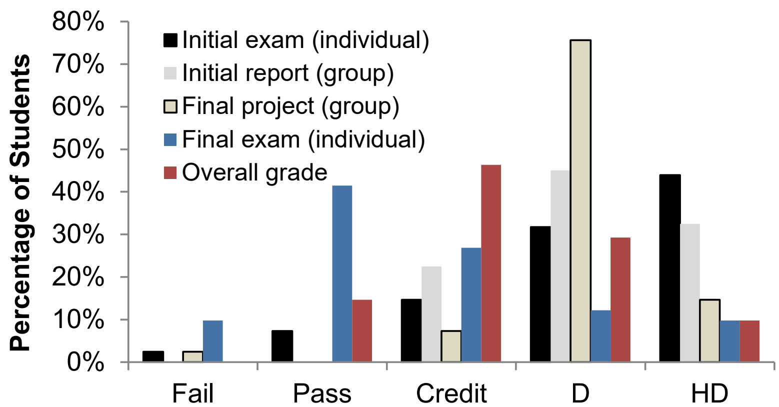

Figure 5: Grade distributions for the project report, the final exam and overall for the course

Conclusion

We were able to describe a successful implementation of a project-based learning component in an undergraduate course on computational statics and dynamics. The main merit of the embedded project was in providing hands-on experience of finite element method in design a real engineering structure. This served as scaffolding for introduction of new concepts within the course material. The extensometers, designed by students' project, were well-covered by design, analysis, simulation, and validation steps. Students demonstrated geometry optimisation using the finite element method by both commercial software and hand-calculation, validated results with analytical solutions. Students were able to discuss calibration protocol and the selection of electronics components necessary in real engineering design. Furthermore, students enjoyed the course, engaged well with the project and performed well on all assessment items and exam questions connected to the project's themes.

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Writing objectively: Functional grammar as a tool to improve engineering students' writing style

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ABSTRACT

CONTEXT

Professional writing skills are fundamental for engineers. Engineering degree program outcomes include the development of students' written communication ability as part of their professional competencies. The need to improve the effectiveness of curriculum in this area has been acknowledged for several decades, however, a gap remains between the expectations of employers and graduate ability. Making progress in this area remains challenging for both students and engineering academics and written assignments across the curriculum do not necessarily enable to students to master the skills required to write high quality engineering documents.

PURPOSE AND METHODOLOGY

Applied linguistics methodologies can offer robust strategies for making writing practices explicit so that students can learn to write effectively and appropriately for both academic and professional purposes. For example, analytical techniques drawn from Systemic Functional Linguistics (SFL) have been used to investigate how grammar is used to enact social relationships such as those between engineer and client. This paper investigates the writing style of professional engineering reports using methodologies provided by SFL.

RESULTS AND DISCUSSION

The results demonstrate clear differences in the use of particular aspects of grammar depending on the type of professional relationship between the engineer and their client. These results highlight the need to make the function of grammar explicit to students, to enable them to develop control of the appropriate professional writing style. Some suggestions are made in terms of integration of explicit functional grammar content in the engineering curriculum.

KEYWORDS
Professional Communication, Writing, Systemic Functional Linguistics

Introduction

Effective and appropriate written communication skills are essential in professional engineering practice (Australia, 2019; Yong & Ashman, 2019). As such, engineering degree programs place a high emphasis on graduating students who know how to write appropriately for the industry, along with possessing sound technical ability. However, an ongoing globally recognised 'skills gap' exists in terms of the communication abilities of engineering graduates and the expectations of employers (Clippinger et al., 2019; King, 2008; Male et al., 2015). This skills gap persists, despite several decades of acknowledgement of the need to improve the effectiveness of higher education engineering courses in developing appropriate professional writing skills in graduates (Conrad, 2017; Gwiasda, 1984; O'Brien, 2000).

The teaching of professional written communication skills varies from one course and institution to another, and includes a range of implicit and explicit pedagogic models and practices. Opportunities for practicing appropriate writing can be significantly limited, and little guidance may be given in terms of 'what or how to write, and for whom' (Goldsmith et al., 2019, p. 73) Engineering lecturers may limit consideration only to technical content (Smith, 2003, p. 73) or feel ill-equipped to support students in terms of their writing (Strauss & Grant, 2018, p. 4). Engineering lecturers may also feel that development of writing skills is not part of their role, or even that writing is not an area of knowledge that can be developed, leaving students with the view that writing is separate from actual engineering practices and only a component of academic study (Goldsmith et al., 2019, pp. 72-73).

Additionally, variable connections between engineering programs and the industry means that students may not be exposed to contemporary industry practice (King, 2008, p. iii), including appropriate writing styles. Engineering courses may expose students only to academic texts such as journal articles, which differ from industry writing, and writing instruction can encourage generalisation from the academic context into industry (Conrad, 2017, p. 68). There is also relatively little research into engineering writing or the literary practices actually used by engineers in the workplace (Giroux & Moje, 2017) on which to base teaching materials.

The style of professional engineering writing can be seen to be particularly challenging for a novice writer. Engineering documents need to use an objective style that foregrounds the detached presentation of evidence, be persuasive in order to convince the reader to agree with the findings or recommendations (Winsor, 2006), and also be framed specifically for the needs of the particular intended audience (O'Brien, 2000). Writing advice often offers such prompts as 'identify your readers' (van Emden, 2005, p. 3) to encourage consideration of the reader's needs and perspectives. However, the challenge for educators and students alike is how to translate the contextual requirements of a document into the actual words and sentences on the page.

Purpose

One successful approach to teaching engineering writing is to draw on Applied Linguistics methodologies to work with students and educators to deconstruct writing practices, so that students can be taught to analyse their own writing and that of professionals (Curry & Hanauer, 2014, p. 3). This paper draws on research methodologies from Systemic Functional Linguistics (SFL) to explicitly identify features of language which are important to the enactment of an appropriate writing style for professional engineering purposes. In particular, this paper presents an example of the use of grammar to enact the social relationship between the writer and reader (that is, the engineer and intended audience). This example is taken from the findings of a larger project.

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Methodology

This study investigates the writing style of 26 publicly available professional engineering reports using a combination of qualitative and quantitative discourse analysis, founded in SFL theory. The included texts were chosen on the basis that they were written by a professional engineer in the Australian context from 2010 onwards and were written for the broad social purpose of giving advice to a governing body or client on the need for engineering work or as part of the approval process for a proposed project. The types of reports include environmental impact statements, traffic impact statements, structural condition reports and a variety of investigation reports. Some shorter reports were analysed in full, while cohesive portions of longer reports were selected. The total amount of text analysed was 62941 words.

The reports were analysed using SFL linguistic methodologies. A key idea in SFL is that language is a system of choices, and that particular choices are made in order to fulfil a function. A strength of SFL in terms of researching writing style is that SFL conceptualises language as making meanings in a social context: language makes meaning concurrently at different levels and across different functions (Halliday & Matthiessen, 2014). The conceptualisation that language makes meaning on different levels at the same time is useful in terms of explaining the relationship between language and the context of the social reality in which it is used, for example, taking into account the relationship between an engineering writer and a client. Figure 1 demonstrates this conceptalisation: at the lowest level, sounds are organised into words and grammatical structures such as sentences. These are then organised into patterns of meaning at the level of a whole text, which enact the social context at the highest level.

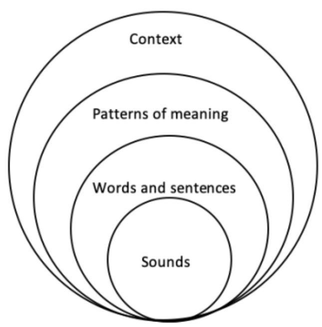

Figure 1: Concurrent meaning making on different levels based on Martin (2016, p. 48)

Additionally, the SFL model of language demonstrates how language makes different types of meanings at the same time, at all levels of realisation. The content, that is, the experiential objects, activities, places and people, of a document can be distinguished from its textual organisation, as well as the interpersonal positioning conveyed. These later two could be interpreted as 'how' the document is written in terms of its style. Figure 2 demonstrates this division of language into different functional domains.

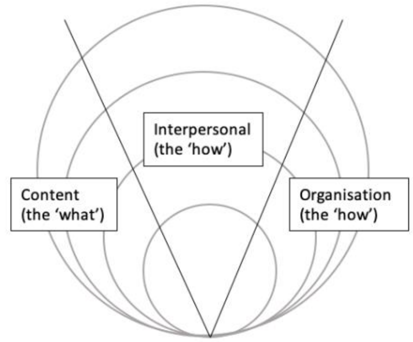

Figure 2: Concurrent meaning making across different functions based on Martin (2016, p. 50)

Separating these functions can be very useful for educational purposes. By explicitly identifying the area of language functionality most challenging for the students, writing instruction can be targeted to the area of most need. For instance, the technical terminology of a particular content area can be addressed separately from the structuring of a document. When it comes to achieving a desired style of writing in response to the needs of a certain audience it is often the interpersonal language choices which are of most concern.

One domain of interpersonal language resource is Engagement (Martin & White, 2005) which is used to create patterns of meaning related to the intersubjective positioning of the writer's voice in relation to other possible voices and perspectives. Choices in this area are concerned with the writer's choices in aspects such as how much they align with their envisaged reader, the extent of tolerance given to other viewpoints and how much authority they command in the relationship. Engagement resources include those of modality, which is the expression of degrees of obligation, likelihood, necessity and certainty through grammatical forms such as modal verbs (for example *should, may, might, need to, have to*), adjectives (for example *necessary, possible*), adverbs (for example *necessarily, probably),* verbs (for example *require)* and nouns (for example *necessity, requirement).*

Results and Discussion

This paper presents one example of the findings to demonstrate how functional grammar may be used to explicitly identify aspects of the appropriate writing style of engineering. As stated above, at the level of context the reports included in my study can all be considered to share a broad social purpose: giving advice to a governing body or client. However, a finer distinction of the context can be made in terms of the relationship between the writer (the engineer) and the intended reader. In some contexts, the engineer is writing on behalf of a company wishing to further a proposed project; the document forms part of the case put forward in support of the argument to grant approval to proceed with the project. Such documents include environmental impact statements, traffic impact statements and some investigation reports. In this context, it can be considered that there is an unequal power relationship between the writer and the intended reader as the reader is in a higher position of power with the ability to grant or deny the desired outcome. I name reports from this context 'seeking approval'.

In other contexts, the engineer takes the role of independent advice giver engaged to provide specialised advice which the decision maker needs in order to inform further action. For example, a report on the findings of an investigation into an electrical failure may advise electricity providers how to avoid repeating such a failure. A report on the structural condition of a building may be used by a council to decide whether to demolish the building or invest in repairs. In this context, the power relationship is the opposite of the 'seeking approval' reports. Putting aside any considerations of flow-on opportunities or reputation building, the engineer is not depending on the decision made as an outcome of the advice. The writer is engaged as an expert, a voice or authority, who presents findings and gives advice: therefore, reports from this context are named ‘giving advice’.

Determining contextual differences in the writer/reader power dynamic is useful to a limited extent. However, such a differentiation on its own does not necessarily lead to an understanding of how to adapt a writing style to these different contexts. Adaption of the writing style requires moving down a level to consider the patterns of meanings used to construct the writer/reader relationship.

The findings demonstrate clear differences in the use of engagement resources which correspond to the differentiated contexts of ‘seeking approval’ and ‘giving advice’. Specifically, there is a clear change in the explicit use of the modality of obligation- words such as *should, must, need* and *require*- being directed at the reader. In the ‘seeking approval’ reports, explicit expressions of obligation are mostly absent. Those that are present are mostly in relation to the obligations placed on the company proposing the project, as in this example from an environmental impact statement:

> *“[t]o achieve the State interest, Class A and Class B land should be protected from fragmentation, inappropriate development and land degradation” (AECOM 2016, p. xii)*.

Please note that modality is underlined in these examples. Occasionally, explicit modality is used in a ‘seeking approval’ report to emphasise a point in support of the argument, for example:

> *“It should be noted that this assumption of worst-case noise source to receiver wind direction is conservative” (Vipac 2017, p. 10).*

However, the reports identified to have a ‘seeking approval’ context avoid interpersonal language which may be interpreted as inappropriate for the power dynamic: they do not presume to tell the reader what to do.

Many of the ‘giving advice’ reports, in contrast, do make use of explicit expressions of obligation directed towards the reader. For example, a report on the findings of an investigation into a large amount of electricity outages is clear about what should be done to prevent repeat occurrences:

> *“DBs [Distribution Businesses] should assess their LV [Low Voltage] networks to identify the appropriateness of and the risks associated with the existing load diversification assumptions” (Energy Safe Victoria 2018).*

Another report investigating a generator failure states that a

> *“monthly testing regime needs to be developed that will allow the generator to be tested at full essential load capacity” (System Solutions Engineering 2016)*.

Similarly, explicit expressions of obligation are regularly used in reports on the structural condition of a building or structure:

“Timber decking should be replaced and further inspection of the lower headstock and pile components should be completed to confirm the condition” (GHD 2018, p. 33)

“Analysis of the design showed that the roof slab is structurally inadequate to support the current requirements and that this area should be immediately barricaded off to prevent human entry as this area serves as a potential of serious injury […] [t]he roof slab requires significant strengthening, structural components within the building require large quantities of concrete spalling and sections within the façade need to be rebuilt.” (Cardno 2018, pp. 17-18).

As a final example, a report into the geotechnical site preparation requirements of a proposed building repeatedly uses explicit modality of obligation, such as:

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“[a]llowance must be made for at least partial removal of the silty/sandy soils’ (Douglas Partners 2017, p. 5).

It can be concluded that the power relationship between the writer and intended reader in the context of a ‘giving advice’ report affords the writer the ability to take an unambiguously authoritative stance.

These findings illustrate a key difference in interpersonal language choices to construct the writer/reader relationship in response to the identified contextual variables, and that this area of grammar is one crucial component of presenting an objective style and persuasive stance. Figure 3 illustrates the difference with reference to the different layers of the realisation of language.

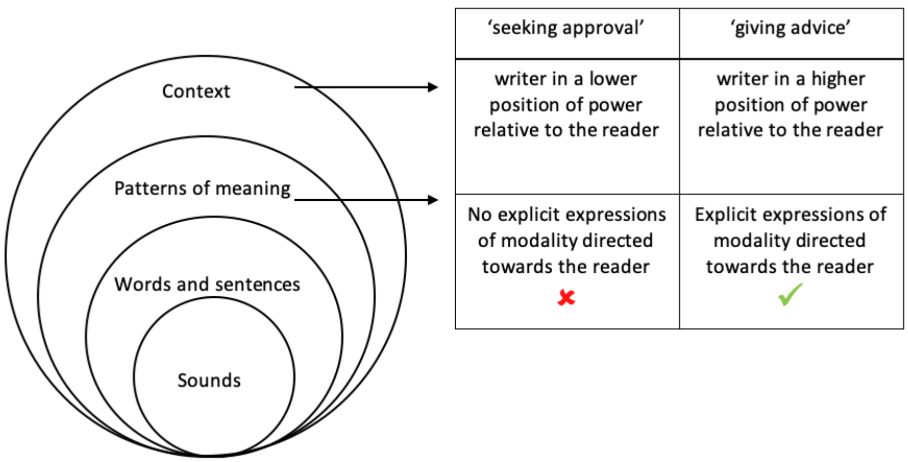

Figure 3: Modality of obligation differences between ‘seeking approval’ and ‘giving advice’ contexts

It can be surmised that the use of explicit modality in a ‘seeking approval’ context would undermine the persuasiveness of the argument, potentially eliciting a negative response from the reader. If the intersubjective positioning is interpreted as inappropriately powerful, the objectivity of the style could also be undermined. It should be emphasised here that the illustration of the use of modality of obligation is just one aspect of the linguistic construction of the style of these reports, chosen to demonstrate the usefulness of functional grammar in an educational setting.

Conclusion and Recommendations

This paper has demonstrated how SFL analysis can make explicit connections between context and language choices, which can be applied in educational materials. The initial identification of the contextual differences between the two groups of reports can help students in terms of the nature of the role of their intended audience, and consider the interpersonal stance they should therefore take as the writer. For some students, this may be sufficient for them to adapt their writing style to the different contexts. However, to do so, such students are likely to have an existing implicit understanding of the appropriate language choices associated with different levels of power, that is, that it would be inappropriate to use explicit expressions of obligation when the reader is in a higher position of power than the writer. Not all students necessarily have this implicit understanding. Identifying the patterns at the next level down on the model of language, and linking them to the context at the higher level, enables students to explicitly understand the choices that are considered appropriate in the different contexts.

There are a variety of ways in which teaching materials using functional grammar can be incorporated into higher education programs to improve students’ ability to adopt the

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appropriate writing style for a particular context. A common approach is to offer supporting or preparatory writing workshops separate to the main curriculum, and functional grammar can be used successfully in such workshops. However, such workshops are limited by the fact that they are not contextualised (Wingate, 2006). Similarly, online resources (Drury & Mort, 2012) and support from learning advisors or writing consultants (Walker, 1999) can make effective use of functional grammar concepts, but can face the same issues of separation from a realistic context.

Because adapting writing style to contextual variation is crucial, embedding writing instruction across the curriculum in a way that helps students to understand the connections between context and language choices may provide the most effective approach. Embedded instruction of communication skills in engineering modules, with an emphasis on creating realistic contexts, has been shown to be successful in many instances (Beck, 2004; Bodnar & Kadlowec, 2018; Breeze & Guinda, 2017; Yu, 2008). As an example, many engineering programs already use project based learning (Graham & Crawley, 2010) or similar approaches that simulate a professional context. Functional grammar can be used as a learning tool in such a project through the writing tasks involved. The role of a writing task can be the focus of discussion between the educator and students, with consideration at the contextual level in relation to the project milestones, the purpose of the document, the intended audience and their relationship to the writer. This context can then be explicitly linked to appropriate language choices such as modality through the deconstruction and reconstruction of model texts. This embedded approach relies on the language awareness of the engineering educator; therefore, raising the levels awareness of functional language choices among engineering educators is necessary in order for successful integration.

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Preparing Chemical Engineers for Industry 4.0: An Interactive Education Approach

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ABSTRACT

CONTEXT

With the emergence of predictive data analytics and advanced technologies such as digital twins and artificial intelligence, the potential exists to transform the chemical industries over the next two decades. In this pivotal time, it is crucial to equip future engineers with such skillsets to address the current need of the industry. However, the core of industry 4.0 mainly concerns computer science and IT disciplines, and as such, these concepts have hardly been addressed in chemical engineering education.

PURPOSE

While it is expected that in the coming years, incremental changes apply to the engineering curriculum by including digitisation, it is important to design courses to prepare the chemical engineering graduates for the transition of chemical industries from 3.0 to 4.0. To this end, we designed a master-level course, which is also an elective for 4th-year undergraduate learners. This unit of study aims at developing an understanding of the available means (e.g., advanced sensors, industrial internet of thing (IIoT), digital twin, and deep learning algorithms using Python) and their implementation within chemical processes. It is expected that the designed projects and hands-on activities in this educational package provide a valid basis for the current transitioning phase of industries from 3.0 to 4.0 while allowing practising and developing transferable professional skills.

APPROACH

The learning and teaching activities presented in this article were spanning across multiple components of industry 4.0 as well as learners' creativity in the enhancement of chemical processes. To transfer the Industry 4.0 topics to the learners within the framework of chemical engineering, we benefited from various teaching practices, including recent industrial case studies and hands-on activities (e.g., making a neural network predictive temperature control system with Arduino microcontroller and wireframing a mobile app for a chemical process unit). Three capstone projects were designed: 1) to propose a solution for the digital transformation of a chemical process using the concepts of industry 4.0, 2) to apply deep learning for big data analysis of a chemical process using Python, and 3) building a digital twin for neural network predictive control of a DC heater/fan system using Arduino microcontroller.

ANTICIPATED OUTCOMES

The activities are designed to provide opportunities for students to understand advanced digital technologies and apply them in real-world engineering scenarios. It is expected that students develop skills in big-data analytics and real-time data processing using sophisticated data-driven approaches, including deep learning. Students gain hands-on experience working with Arduino lab kits in wiring up a heater/fan system and applying process control theory into practice by programming a neural network predictive controller in Matlab/Simulink for real-time temperature control. Such practical skills in real-time data acquisition and processing are identified as critical attributes for engineering graduates, according to experts from the industry.

SUMMARY

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A novel teaching and learning package including hands-on activities was designed to prepare chemical engineering learners for the digital transition to industry 4.0. The importance of hands-on activities and engineering laboratories are not hidden to the engineering educators. Thus, there are numerous opportunities in transforming the conventional chemical engineering laboratories to their 4.0 versions. The students' feedback has been positive, suggesting engagement and overall satisfaction with the course. However, a comprehensive pedagogical survey will be carried out in the future to gain more insight into the educational offer of different components of this unit of study.
KEYWORDS

Industry 4.0, Chemical Engineering Education, Arduino microcontroller, Big-data analytics.

Introduction

With the success of the digital revolution, and the rise of technological developments on cybernetics, distributed physical devices with built-in computing and communication capabilities, new sensor technology, sophisticated IT infrastructures (e.g., cloud storage and computing), the industries are evolving rapidly – creating what is referred as smart industry and smart manufacturing. The industrial plant (physical world) synergistically combined with the cyber world in a way that they can communicate and affect each other has been labelled as industry 4.0. Whether industry 4.0 is merely an "old wine in new bottles" (Köbsell, 2015), or a completely shaped landscape (Pfeiffer, 2017), it is axiomatic that it is the biggest paradigm change that the industry is currently experiencing.

In a survey performed by PWC from 222 chemical company executives in 26 countries (PWC, 2016), it was inferred that while most companies were expecting to strengthen their digital offering either by using big data analytics or by digitising their existing products and processes; they believe lack of digital culture and training is the biggest challenge facing them. Hence, it is most appropriate that the educational organisations respond to the knowledge gap of their graduates for addressing the new technological and training challenges.

Most elements of industry 4.0, such as digital twin, advanced sensors, internet of things, augmented reality (AR), virtual reality (VR), big data analytics and machine learning, are originated from computer science, information technology (IT) and to some extent electrical engineering. Hence, they are fundamentally new to other engineering disciplines, particularly chemical engineers. Many educators have recently emphasised on creating graduate programs or updating the whole curriculum of undergraduate programs to include industry 4.0 topics. Hernandez-de-Menedez et al. recently reviewed the established programs in engineering education for industry 4.0 (Hernandez-de-Menendez et al., 2020). Despite building momentum in updating the chemical engineering curriculum, adopting industry 4.0 in courses is still challenging – mainly due to the lack of knowledge of the use and implementation of industry 4.0 components within chemical processes (Kakkar et al., 2021).

Teaching students the unusual topics to their background whilst keeping them engaged to the topic is of most importance. Interactive methods of training such as case study (Shallcross, 2013a), peer feedback (Rodgers, 2019), project-based learning (Ballesteros et al., 2019), game-based learning (Ghadi et al., 2020), storytelling (Smyrnaiou et al., 2020), and basket and action learning methods (Guimarães et al., 2021; Yakovleva et al., 2014) have been successfully used for students engagement in contemporary higher education of chemical engineering. It should be noted that some interactive methods have proven to be more successful and well-received by students in certain areas of chemical engineering. For instance, case studies could be very effective in educating process safety, risks assessment, and cybersecurity (Shallcross, 2013a, 2013b; Wu et al., 2018). The inclusion of real-world cyberattacks to chemical processes presumably enhance the course relevance and subsequently encourage the students to be more proactive in the course. However, Wu et al. reported that, based on their experience, technical writing as well as generating solutions to

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“open problems” were challenging to the students while doing cyberattack case studies in their process control course (Wu et al., 2018).

Industry 4.0 can provide opportunities in process system engineering. For instance, deep neural networks have been used to predict the adsorption equilibrium using Artificial Neural Network (ANN) and MATLAB in a bioprocess engineering course in the last year of undergraduate level (Kakkar et al., 2021). The lecturers provided the MATLAB codes to the students in the classroom and encouraged them to modify them (Kakkar et al., 2021). While Kakkar et al. received positive feedback from the students, they cautioned that their approach could potentially make the students take neural networks as purely “black box” modelling, thus, hindered students’ ability in understanding the mathematical aspects of neural networks (Kakkar et al., 2021).

On another note, there have been recent discussions arguing if the chemical engineering students possess the “programming skills” required to answer the new problems, particularly those problems that were defined in the framework of digitisation of the chemical industries (Pfeiffer, 2017). In a survey from students performed by Cano del las Heras et al., students stated that the presence of programming content with the whole curriculum is insufficient, and they favoured Python over other programming languages (de las Heras et al., 2021).

It should be highlighted that the ratio between demonstrations and hands-on activities must be well-balanced to answer the goal of the learning industry 4.0. A great initiative that recently applied is using digital twins for the education of engineering sciences, particularly within laboratory experiments (Zacher, 2020). The main advantage of such method is adaptability and expandability depending on the training need. However, building such medium-to-high fidelity digital twin still involves high costs. Recently, innovative microcontrollers for process dynamics and control have been developed using Arduino and Raspberry Pi (Park et al., 2020; Škraba et al., 2020). The engineering students appreciate the low cost of prototyping devices such as Arduino, Raspberry Pi, and BeagleBone Black and become motivated by their own creativity using such devices (Jamieson et al., 2015).

Building on the literature, we propose a combination of interactive methods for introducing different components of industry 4.0 to chemical engineering students within one unit of study. This article summarises the development of a lecture resource package for preparing the learners for industry 4.0 in the final year of an undergraduate chemical engineering program. The work contributes to a new course designed and delivered in 2020 and 2021 at the School of Chemical and Biomolecular Engineering, The University of Sydney, Australia. The learning and teaching activities presented in this work incorporate a combination of different elements of interactive teaching and are a framework for sharpening students’ soft skills such as thinking and creating in industry 4.0, understanding and applying predictive data analysis using deep learning and ultimately building a digital twin using an Arduino kit and predictive control. We hypothesise that using multiple interactive approaches tailored to the industry 4.0 components not only prepare the students for their future career in an emerging digitised industry but also engage them effectively throughout the course.

Context of the course

In designing the course contents, the following three main areas were targeted: (i) safety of chemical processes (e.g., HAZOP review, and cybersecurity), (ii) training of new personnel (including safe operator experimentation, process unit start-up and shutdown), and (iii) process system engineering (PSE). At the beginning of the course, major components of industry 4.0 (e.g., augmented reality, digital twin, sensors, IoT and cybersecurity) within the framework of chemical and biochemical engineering were introduced and discussed through examples and case studies from industry. Students were encouraged to reflect on the demonstrated examples in groups and then apply similar concepts to new processes. Group members brainstormed and presented their ideas to the rest of the class and received feedback from their peers and the teaching staff. This provided students with the opportunity to exercise idea

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generation and innovation within the context of industry 4.0 transformation while practising teamwork, giving/receiving critics and engaging with risk-free and open-ended scenarios. To further consolidate the acquired knowledge and skills, a capstone project was designed for the students to write a proposal for updating a chemical process from industry 3.0 to 4.0. To carry out the design activity, students followed “design thinking” principles, including (1) research, (2) empathise, (3) define the problem, (4) ideate, (5) prototype, and (6) test (Dym et al., 2005; Santos et al., 2017). Students conducted research on a chemical process to identify the areas that they could improve the process using digitisation. They were also encouraged to empathise with the client by considering the client’s needs when including the components of digitisation (e.g., AR, digital twin, sensors and IoT). They were also asked to provide a general discussion identifying the overall recommendation for implementing their proposal as well the risks associated with their plan. The overall goal of this capstone project was to encourage students in (i) understanding the process and the role of digitisation, (ii) ideation by designing innovative solutions to enhance the overall performance of the process, (iii) empathising with the client, (iv) avoiding the digitisation-hype, (v) planning for risk mitigation, and (vi) practising professional writing. Feedback was provided to the students based on meeting the aforementioned items.

As stated above, the application of industry 4.0 topics (e.g., cybersecurity, AR/VR, machine learning, sensors, IoT and digital twin) within the context of safety, training personnel, and PSE were taught with different interactive teaching methods as depicted in Figure 1.

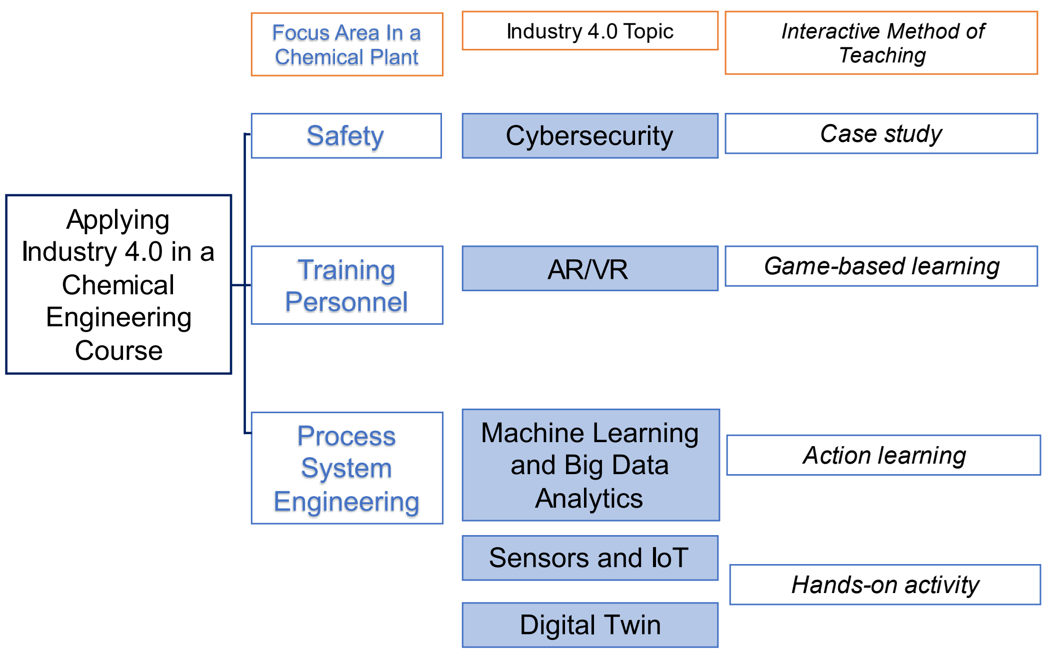

Figure 1: Teaching industry 4.0 topics via interactive teaching methods in a chemical engineering unit

Cybersecurity via a case study

A list of cyber incidents cases in chemical processes and control systems was adapted (INL, 2018) and provided to the groups of students to choose from prior to the session. Students had the chance to review the list and be exposed to multiple scenarios. A worksheet (Table 1), similar to what was presented by Wu et al. (2018), was designed and provided to the groups. Each group was asked to fill the worksheet while brainstorming and discussing various sections of the worksheet, including “knowing”, “investigating”, “engineering”, and “designing”.

Afterwards, each group presented their completed worksheet to the rest of the class and received feedback from their peers as well as the lecturer.

Table 1: Cybersecurity case study worksheet

Section	**Questions (point allocated)**
Knowing	Briefly describe the process that was targeted
Investigating	Describe in technical terms how the cyber-attack happened.
Engineering	If you were the engineer responsible for this plant, a) What would you do to promptly detect if your process/control system was under attack? b) What actions would you take to stop the adverse effects of this security bridge?
Designing	Design a system to protect your plant from a similar attack in future. Explain how your proposed plan would protect this chemical plant.

Augmented Reality (AR) via game-based learning

Game-based learning was applied to educate the learners on the concept of augmented reality (AR) and its application in training personnel. For this activity, groups of 3-4 students were asked to wireframe a mobile app to (i) navigate the trainee to the bubble column unit in the laboratory in our school via university map; (ii) provide step-by-step safe operational training and navigation to the trainee using augmented reality with arrows popped up on the screen upon turning on the camera; (iii) build features in the app to access the manual and submit the report at the end. The activity was performed in a hackathon manner using a game-based learning approach as an effective pedagogy in boosting creativity, motivation, engagement, and retention of the subject matter (Cojocariu et al., 2014; Heininger, Prifti, et al., 2017; Heininger, Seifert, et al., 2017).

The bubble-column operational manual was provided to the students. Several photos taken from different parts and different angles of the bubble column were also provided. Students were familiar with this educational laboratory equipment as they operated this unit in the past. Interestingly, many students were inspired by PokemonGo mobile game and IKEA app interfaces – common mobile apps using AR. A score was awarded for a reasonable app design where all the required questions were addressed reasonably and relevantly within the allocated time frame. Scores varied according to the compliance with design objectives while avoiding overdesign of the application, i.e. including other laboratories map or other units in the same lab within the app design. In the next stage, they started prototyping by wireframing their mobile app based on augmented reality. Students then presented their completed wireframe to the rest of the class. The lecturer promoted discussions among groups and made notes of each group's interesting design points on the screen.

Artificial intelligence (AI) and machine learning via hybrid action learning

Perhaps one of the most applicable components of digitisation is artificial intelligence. As discussed earlier, educators commented on how students took the pre-existing computing packages as a "black box", in which the math behind these algorithms, e.g., Artificial Neural Network (ANN), was a great challenge to them (Kakkar et al., 2021; Samek et al., 2017). We avoided this issue by first covering the fundamental mathematics behind the neural network algorithms and, hence demystifying them. Several exercises were defined, and students were asked to use hand-calculation to solve a simple perceptron model. Next, Python codes (in Numpy and Panda) were provided to the students. Students inserted each line while the lecturer explained them. It should be noted that pre-existing black box packages for the neural network, such as TensorFlow and Keras were not introduced to the students at this stage.

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Students were encouraged to code and to fix the errors. The aim of this step was to introduce Python as well as avoiding the “black box” perception of deep learning in Python.

In the next step, we applied action learning which is a favourable approach to operate within the context of a real and complex project (Stappenbelt, 2010). The groups of students received a big data set that included physicochemical properties of red and white wine (Cortez et al., 2009). The students were asked to develop an ANN model to predict the wine quality, which is often assessed by sensory testing based on the physicochemical properties. Since students developed a good understanding of the math and fundamental coding for neural networks by this stage, the Keras package was provided to the students with descriptions. However, the codes regarding optimising functions were excluded. Students were then asked to run the code and check the accuracy of their predicted model. Through this process, the learners were encouraged to reflect on the math that they learned in the first step and suggest improvement in their models. Almost all students asked how they could include modifications such as various optimisers in their codes. Through the process of running the code, checking the accuracy, reflecting on the change, and planning the next modification (a classic do-check-act-plan cycle), the groups of students built a robust ANN model. They have then drafted a professional report and discuss their outcomes and submitted their work for assessment.

Heater/fan set-up using Arduino microcontroller for predictive temperature control

Students participated in a hands-on activity in which they wired up and programmed a 12V heater/fan system using an Arduino microcontroller, thermocouple sensor, and electronic parts. Figure 2 presents a photograph and schematic diagram of the heater/fan set-up. Students were exposed to the working concept of MOSFET transistors, resistors, diodes, analogue/digital input/output, and pulse-width modulation (PWM) to build circuits on a breadboard to control the electrical loads of the heating element and the fan.

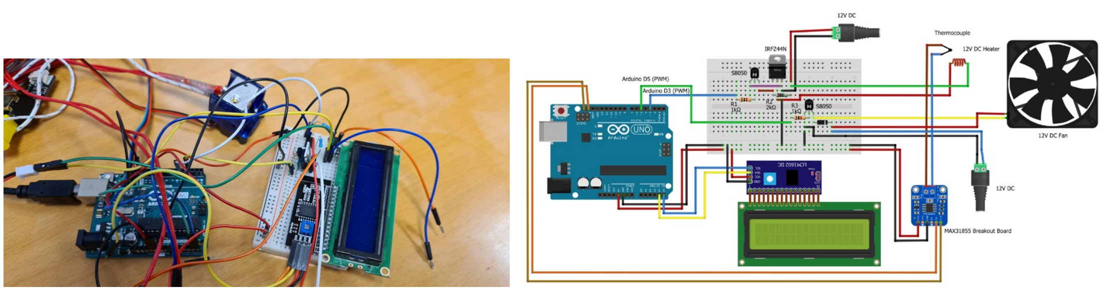

Figure 2: Photograph and schematic diagram of the Arduino heater/fan set-up

The Arduino set-up provided the context and practical motivation to consolidate their learnings about industry 4.0 and machine learning and to exercise programming using Arduino software, Python, and MATLAB/Simulink. Students used libraries such as “pyfirmata” in Arduino and “serial” in Python to control the PWM outputs of digital pins 3 and 5 corresponding to the heater and fan outputs, respectively, and read/plot the temperature measured by the thermocouple. Students also took advantage of the MATLAB Support Package for Arduino Hardware to write PWM signals and read the temperature sensor using I2C communication protocol through the Arduino board. The “in-house” built Arduino set-up was used as a “physical asset” for real-time data processing and to exercise neural network predictive temperature control along with its “digital twin” programmed in Matlab/Simulink. Figure 3 shows the block diagram of the feedback control system developed in Simulink to control the Arduino microcontroller using a Neural Network predictive controller. Through this design-and-build activity, students gained practical experience in predictive control via data-driven techniques such as model predictive control (MPC) using ANN-based models, which is the current trend in process system engineering.

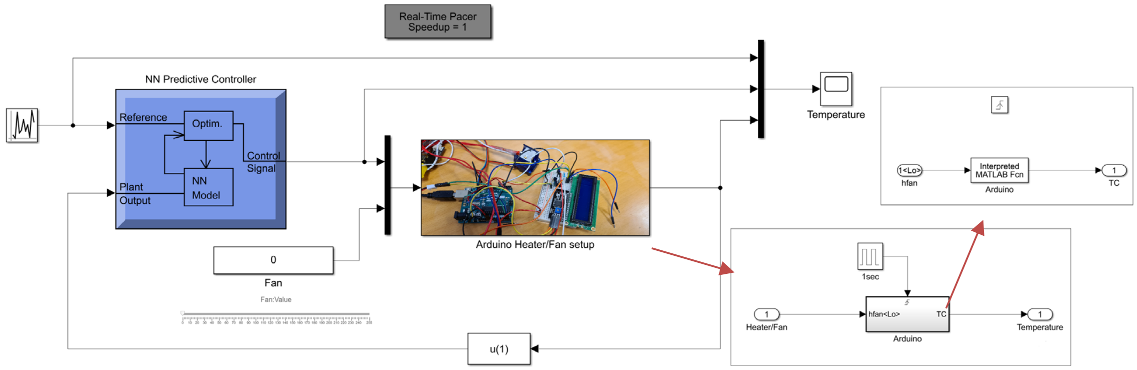

Figure 3: The feedback control system block diagram used to control the Arduino microcontroller using Neural Network predictive controller in Simulink. An Interpreted Matlab function was written to control the PWM pins outputs. I2C communication protocol is used to transmit the measured thermocouple output back to the computer.

Students' feedback

In anecdotal conversations throughout the semester, students expressed their views of the individual activities and their overall experience with the course. There were many positive comments about the course being challenging, innovative and intellectually rewarding. Students commended the authenticity of the learning experience and how they can see the acquired skills are applied in the evolving industry. They appreciated the interdisciplinary nature of the course introducing them to digital technologies, Data Science, programming, and basic electronic concepts and how they can interface with the emerging Chemical Engineering discipline. The hands-on experience of working with Arduino and programming with Python was also suggested to be fun, engaging, and informative. Nevertheless, they suggested they needed more time to work on the Arduino and understanding the concepts behind the electrical circuits, which will be taken into consideration in the future.

Conclusion

An educational initiative in transforming the chemical engineering curriculum in response to the new training needs regarding digitisation and industry 4.0 has been presented. The learning and teaching activities aim to develop an understanding of the role of various components of Industry 4.0 in chemical industries as well as applied skills in programming (e.g., Python and Matlab), data-driven modelling, digital twins, predictive data analytics, data wrangling, artificial intelligence, and deep learning. Various teaching methods, including game-based learning applying design thinking approach, action learning, and hands-on learning (Arduino set-up and wireframing activities), have been successfully implemented to address the diverse nature of the industry 4.0 components and maintain high students' engagement. Anecdotal feedback from students and observations from the teaching staff suggested high students' engagement and satisfaction with this unit of study. The successful implementation of this initiative has inspired us to explore opportunities in transforming some of our conventional chemical engineering laboratories to their 4.0 versions as potential hands-on activities for the next academic year. The effectiveness of this educational intervention in achieving the intended learning outcomes will be assessed through a combination of targeted survey questions, student reflections, feedback from academics, and unit of study evaluation responses.

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Developing 21st Century Graduate Attributes: Designing Learning Environment through Cooperative Experiential Learning (CEL) Approach

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ABSTRACT

CONTEXT

The issue of unemployment among graduates is a global issue and is mostly associated with the inadequacy of employability skills and generic skills in graduates during their time in university. Employers have often complained that graduates lack the necessary soft skills which is vital for the organisation. A highly competent candidate with strong foundational literacies alone will not guarantee its organisation will achieve its goal, especially in the 21st century workforce. Generic attributes and strong character qualities are the vital attributes for organisations that ensure a productive, collaborative, and healthy work environment in an increasingly competitive world.

PURPOSE OR GOAL

To ensure that students can attain the required 21st century graduate attributes, a change of approach in their learning experience is essential. It is conjectured that the implementation of experiential learning with cooperative learning principles will facilitate the development of 21st century graduate attributes among undergraduate students. The paper aims to describe the first attempt of designing and implementing a learning environment that infuses cooperative learning principles into the experiential learning framework to help develop these attributes.

APPROACH OR METHODOLOGY/METHODS

A general university course is designed by incorporating the principles of Cooperative Learning in Kolb's Experiential Learning Cycle to explore the development of 21st century graduate attributes among undergraduate students. Students went through five (5) cycles of the cooperative experiential learning (CEL) approach in class-based learning and field-based experience. In the CEL approach, abstract conceptualization mainly happens during mini lectures and briefings for team tasks and team projects. Active experimentations are conducted via team activities and a team project to promote cooperation and create meaningful learning experiences for students. Students are also provided with time and space to think individually during each CEL cycle (concrete experience stage) before discussing with respective team members to reach team consensus (reflective observation stage). To study the impact of the CEL approach, thematic analysis was conducted on the students' reflections - what they have learnt and experienced throughout the course implementation, focusing on the 21st century graduate attributes

ACTUAL OR ANTICIPATED OUTCOMES

From the students' reflections, three main attributes were identified: teamworking & leadership, communication and thinking skills. In several deep reflections, the characteristics of cooperative groups emerged which includes accountability towards team members, shared leadership, developed interpersonal skills and positive interdependence among team members.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
These initial findings indicate that the implementation of cooperative experiential learning in an introductory course allows students to be engaged in team activities and helps promote positive development of required graduate attributes among engineering students.

KEYWORDS
Experiential learning, cooperative learning, 21st century graduate attribute

Introduction

Today, the pace of change is accelerating, especially in technology, manufacturing, and marketing, which have resulted in an increasingly competitive borderless world. Competition for the right talent is aggressive and the demand for well-educated graduates exists everywhere. Inevitably, employers do not have the luxury of resources, especially time to train and improve graduate competency that can meet industry demand. What is needed are dynamic and highly versatile graduates that are capable of fitting in quickly to embrace a broader vision of professional role to respond to global challenges. Several skills highly valued by employers are communication skills (Levy & Cannon, 2016 and World Economic Forum, 2020), thinking skills (Floyd & Gordon,1998 and World Economic Forum, 2020), scholarship, leadership and teamworking skills, adaptability, global citizen and enterprising skills (Mason & Arshed, 2013 and World Economic Forum, 2020). While hard skills are relatively easier to master, it is these soft skills that are more difficult to learn (Raj, 2008). Graduate attributes including generic attributes and personal traits, play a significant role for graduates to gain employment. In addition, graduates need not only to adapt to workforce change, but be willing to acquire new skills and to embrace a positive attitude towards life-long learning.

For this reason, higher education institutions have a crucial responsibility to undertake transformation, aimed at producing knowledgeable and high-quality graduates to fulfill the market needs. Therefore, holistic approaches at the institutional level are needed to ensure that graduates' competencies are assessed based on the current industrial market needs. Curriculum has been revised and designed to inculcate the important attributes among graduates. In Universiti A, the Graduate Success Attributes (GSA) course is designed with the aim to introduce students to the desired 21st century graduate attributes, and the need for competent graduates, especially in facing the challenges of the 21st century. The GSA course is designed to have a supportive student-centered learning environment that allows students to develop important skills to learn, as well as understand and develop abilities required to be highly competent graduate. To attain the course outcomes, student-centered learning approaches are implemented by introducing simple active learning activities in interactive class, cooperative learning through team-based activities leading up to experiential learning via team-based project.

Students need to be engaged in learning through variety of ways, and cooperative learning has been identified as a necessary skill for success in the 21st century. Cooperative Learning (CL) is an instructional strategy that involves students working together to accomplish common and shared goals. It is this sense of interdependence that motivate team members to help and support each other which enable them to maximize their learning experience. According to Johnson and Johnson (1999), CL comprises five elements, which are positive interdependence, face-to-face promotive interaction, individual and group accountability, social skills and group processing. Research shows that CL has been proven to enhance academic performance (Gull & Shehzad, 2015), guide in shaping student creativity (Elizabeth & Meera, 2014) and critical thinking (Sadeghi, 2012) and promoting soft skills (Mohd Azmir et. al., 2011). According to Johnson and Johnson (1990), placing students in small groups and telling them to work together does not guarantee that they will work cooperatively and produce positive social outcomes. Groups need to be structured to ensure that team

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members will work interdependently if they are to reap the academic and social benefits widely attributed to this approach to learning. With cooperation and social interaction playing such a critical role in the success of individuals, students learn to listen to what others have to say, give and receive help, reconcile differences, and resolve problems democratically.

To attain deep understanding of graduate attributes among the undergraduate students, the learning environment for the GSA course is also designed based on Experiential Learning Theory (ELT). According to Kolb (1984), learning is the process whereby knowledge is created through the transformation of experience. Experiential learning focuses on learners reflecting on their experience of doing something, to construct knowledge. Kolb's experiential learning model suggest four stages in a cycle: active experimentation, concrete experience, reflective observation and abstract conceptualization (Kolb, 1984).

According to Lewis and William (1994), experience-based learning in the classroom can take many forms, including role playing, games, simulations, case studies (Gadola, M., & Chindamo, D., 2019), presentations and various types of group work (Musa et. Al., 2012). Effective and safe learning environment is vital for students to be able to perform analysis, exploration, and working on their own self-discovery process (Chapman, McPhee, & Proudman, 1995). In addition, classroom activities should build students' ability to see relationships in complex systems and find ways to work within them. Students should be able to reflect on learning, and gain insight about themselves and their interactions with the learning environment.

There is evidence that proved experiential learning, when properly designed, is highly engaging for students and leads to improvement in academic performances (Rodríguez & Morant, 2019). Research also claims that it leads to developed skills such as problem-solving (Miller & Maellaro, 2016), critical thinking (Suanto et. al., 2019) and improved communications skills. It enables learners to manage better highly complex situations that cross disciplinary boundaries, and subject domains where the boundaries of knowledge are difficult to manage.

Cooperative learning fits the experiential learning model perfectly to implement effective learning environment that can help students to learn the essential skills that will enable them to adapt to the workplace environment. Therefore, based on the principles of cooperative learning and the theoretical framework of experiential learning model, the GSA course is designed and the impact on students' attainment of 21st century graduate attributes is the focus of investigation.

Application Design

Course Description & Implementation

The Graduate Success Attribute (GSA) course is a university general course that is compulsory for all undergraduate students. The course is a two-hour weekly course which is designed to be offered in the second semester of the first-year undergraduate studies. The course aims to serve the need of students to understand and apply the holistic seven (7) graduate skills and attribute inspired by the university. The course guides students in developing the 21st century skills which consist of communication, thinking, scholarship, teamwork & leadership, adaptability, global citizenship and enterprising skills. The course also prepares them to face the real challenging world.

In class, forty-nine (49) students are divided into teams of five (5). The heterogenous teams are formed by considering various factors that include race, gender, cultural background, and academic achievement. Having a heterogenous team promotes diversity in thinking and provides opportunities for students to adapt with others of mutual concerns (Valls & Kyriakides, 2013). The teams are formed since the early session of the course to promote initial bonding among team members. Each team are required to identify a suitable team name and agreeing on mutual team rules to commit.

In support of transforming to student centred learning approach, the GSA course is designed by integrating CL principles into the experiential learning framework (Kolb, 1984) as shown in Figure 1. Students went through five (5) CLE cycles in two main settings: the classroom-based learning and the field-based experience.

Classroom-based Learning

In the classroom-based setting, students went through the abstract conceptualization (AC) stage through mini lectures which introduced students to each graduate attributes, its basic principles, good practices, and related examples. Following the mini lectures, students underwent the active experimentation (AE) stage through different in-class activities related to the graduate attribute introduced for the session. All in-class activities were conducted in teams to help build trust and develop cooperative team characteristics among the members. However, in the concrete experience stage, students identified the required tasks for team-based activities individually first (concrete experience - CE). This provided students the space and time to think on their own before discussing with their respective team members and reaching a consensus (reflective observations). In the classroom- based setting too, students were introduced to SD challenges and global issues and provided with the requirements for poster presentation of the selected sustainable development (SD) that they decided to highlight. Students also presented to the overall classes on the selected SD challenges and were encouraged to use as much recycled items as possible.

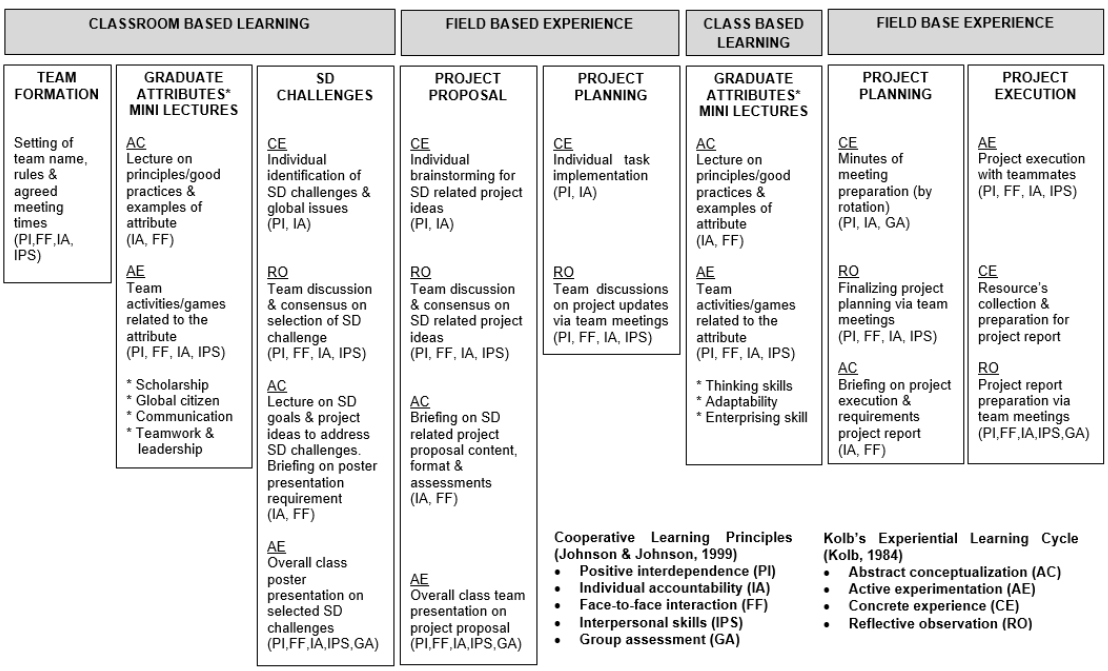

Figure 1: Cooperative experiential learning (CEL) framework

Field-based Learning

The field-based experience involves a complete cycle of a team project that addresses one of the sustainable development goals (SDG) by the United Nations (UN) (United Nations, 2015). The project cycle involves the proposal, planning and execution stages. In the concrete experience stage of the experiential learning, students worked on their own to brainstorm about SD related project ideas before sharing them with the team members. This promotes positive interdependence (PI) and individual accountability (IA) in each team members. During the reflective observation (RO) stage, team members brought forth their

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ideas, discussed and agreed on the final project idea. Through the team discussion, students develop their interpersonal skills (IPS) and promote face to face interaction (FF). Student teams then presented their SD related project proposal to the overall class cycle. After getting feedback on their project proposal, students now work on their individual tasks, depending on their role in their respective teams. Team meetings were expected to happen regularly as each team members were expected to take turns in submitting the team minutes of meeting. Prior to the project execution, a briefing on the project execution & project report was conducted. During project execution, students were required to record evidence of the event and to conduct a survey from participants to analyse on the current condition related to the SD challenges they were working on. Finally, students worked together in preparing the final report before submitting it as

Students were assessed based on the team deliverables which include sustainable development (SD) challenges poster presentation, project proposal presentation as well as minutes of meeting and final project report. Continuous group assessment (GA) was also conducted at the end of major team activities in each cycle of the AE stage. To ensure that students are able achieve the intended learning outcomes, feedbacks were given at the end of every in-class activity and after every team project presentation (poster presentation & project proposal). These serves as scaffoldings for students to improve in their next task together. Addition to that, students were also provided with guidelines for poster presentation, project proposal and the final report as well as a template for minutes of meeting as an example to record their meeting activities in an organised way. To support students working in team, the instructor was included in all team channels which used an instant-messaging platform for social interaction among team members.

Analysis method

To study the impact of the CLE approach, an analysis was conducted based on the information gathered from students' reflective journals. The reflections were collected twice in the semester. Earlier in the semester, students were asked to write a brief reflection on their learning experience during their individual case study assignment. Students were asked to reflect on what they learnt, the challenges that they encountered and the steps that they did to overcome the challenges when preparing the case study assignment. At the end of the semester, students were requested to submit a reflective journal related to the project they were involved in. Students were asked to identify the graduate attributes that they have developed and explain on how they developed the attributes throughout the field-based experience. Students were also required to assess their peers and reflect on the team performance four (4) times throughout the semester.

Once the reflective journals are collected, a qualitative data analysis technique recommended by Miles and Huberman (1994) was employed. The thematic analysis stages include data reduction, data display, conclusion drawing and verification. Keywords and phrases that are related to the reflection questions were highlighted and categorized into different graduate attributes.

Results & Discussion

There were eleven (11) teams that were involved in the implementation of the CEL approach. Through in-class team activities, students got the opportunity to get to know their team members gradually to prepare working together in a project in the field-based setting. In the CEL approach, students were introduced to the SDG outlined by the UN. Students worked in teams to highlight global issues that are related to the SDGs and their role as a global citizen through poster presentation. This is to provide background information for students during their research in preparing the poster. Among the issues presented include issues related to the effects of Industrie 4.0, solid waste management, pollution (air, water contamination, carbon emission), obesity and climate change. From the issues presented, students progressed into proposing a project to address these global issues. Some teams pursued projects which were related to their poster presentation while the others decided to propose projects which were different from their poster presentation but were still within the scope of global issues that are related to UN's SDG. During the project planning, the dynamics of the team can be observed as the instructor was included in every team channel via an instant messaging platform. The instructor was able to provide guide, advice and also resources for financial support for the proposed project. Since the project started in the middle of the semester, all projects were conducted within the university. Participants involved mostly students in campus except for one project that involved children's participations. Examples of projects are Youth Mental Health Seminar, Waste Management Campaign, Recycling Awareness Game, STEM Fun Day, Run for Water and Good Morning - Free Breakfast event.

Graduate Attributes

The paper explores the development on competencies and character qualities of 21st century graduate that student perceived to achieve in the GSA course. Table 1 shows the graduate attributes mentioned in the students' reflections based on ranking. The number in the table represent the number of students who mentioned the attributes in their reflections and also presented in the form of percentage.

Table 1: 21st century graduate attributes mostly mentioned by students in reflective journal

Graduate Attributes	Frequency	Percentage
Teamwork & leadership	42	86 %
Communication	39	80 %
Thinking Skills	33	67 %
Adaptability	23	46 %

From the reflections, the top four attributes that students perceived to develop through the learning activities are teamworking & leadership, communication and thinking skills. The other four graduate attributes (adaptability, scholarship, enterprising skills & global citizen) were also mentioned in the reflections, but the frequency was less than 25%. – scholarship (24%), enterprising (20%) and global citizen (16%).

Table 2 displays samples of the students quotes mentioning the three main attributes that were perceived to develop throughout the course. Analysis of the reflective journals show that student acknowledged the importance of each members' contribution and commitment in making the assigned task a success. For example, the tower building activity in one of the in-class team activities provides a cooperative environment in which teams are required to build a tower using the limited materials provided and at the same able to withstand the weight of the load. It also requires each student to think creatively and analytically to fulfill the required goal of the activity before coming to a team consensus on what is agreed upon. As for the team project, students demonstrate that they were able to work with others from different backgrounds. Some teams highlighted their experience in managing conflicts during project planning. By incorporating CL principles throughout the course, students stay in the same team for the whole semester, and this promotes greater teamwork skills gradually with time. The CLE approach also encouraged students to work individually,

These findings agree with previous research that claims experiential learning improved communication skills and lead to develop thinking skills, namely problem-solving skills (Miller & Maellaro, 2016) and critical thinking (Suanto, et al, 2019). Compared to students taught traditionally, students taught in small group learn at a deeper level, retain information longer, acquire greater teamwork skills, and gain a better understanding of the environment in which they will be working as professionals (Barbara et al., 2004). A study by Espinosa et. al (2020) proved that experential learning had increase student-to-student and student-to-instructor

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interaction, proving that going through experiential learning cooperatively within a small team promotes reflection, conceptualization, and experimentation in engineering courses.

Table 2: Samples of quotation for attributes found reflective journal

Graduate Attributes	Excerpts of Students' Quotation from Reflective Journal
Teamwork & leadership	*In our group, there is no leader as each one of us at some point, discovered our own capacity for leadership. We are all very good listeners for what is needed in the moment and expressed ideas such that they occur as opportunity for others. When five of us conducting our project, the questions of how to organize our event, how to relate our topic to global issue, and how to make our presentation as successful as the other groups are always our top concerns. Other than that, teamwork and leadership skills also give a lot of impact in myself. In a team each of us is expected to contribute. Each member must fulfill our own obligations for the team to succeed. From the team project, I learn that having the right people in the correct roles is an important factor in measuring the success of a team, where we are united to complete our main goals. Every member of our team is a leader in some way. We attend group meetings where we discuss any challenges, issues and problems. Part of being a good leader is knowing how important it is to receive the best ideas from each member of our team. We are all good communicators seeing as how everyone takes notes on team progress that need to be completed. At every meeting, we often exchange ideas or brainstorm new ones with each other and come up with the best team solutions to those perceived problems. For example, we had problem with our event location and one of our member suggest a place where we can get much people to participate our event. We also had problem with our free gifts where the parcel did not arrive yet but fortunately we manage to get them at very last moment before our event started. Now, I know teamwork can often achieve higher levels of performance than individuals because of combine energies of the members.*
Communication	*Communication is one of the obvious skills that I manage to develop during team project. I learn how to communicate with guys as all my team members are guy except me. Before this I'm quite awkward and shy to talk with a guy but to be professional I have to overcome that weakness and also for work purpose. During team project, I found that teamwork projects help me to work on my communication skills. Communication skills required in group projects include speaking in turn, speaking up when I have ideas, actively listening to other team members' contributions, and crucially making compromises for the good of the team. Communication is not only about speaking to and hearing from people, it's also about understanding the complete message. When I start to speak to my team members, they give full respect on my opinions and sometimes they agree with my suggestions. That what makes me become more confident to speak up my ideas. Also, during the event I learn how to talk with strangers where we have to approach people and entertained them to participate in our event. I feel so excited and happy because I had overcome my shyness towards people, and I realized somehow talk to people especially strangers can boost up our self-confident. So, a successful project manager can only maximize the effectiveness of communication within the team by being prepared to lead*
Thinking Skills	*There are many types of thinking skills such as analytic thinking skills, creative thinking skills, and critical thinking skills. During the preparation of the event, there is many aspects need to be considered so that the event can be carried out more efficiently. For instance, the effectiveness of the event, the venue that has a certain number of respondents, the distribution of tasks according to the ability of each team member, the method to collect the data regarding the mental health* *condition of the respondents, the method of analysis of the data and the presentation of the final report. Throughout the event, my critical thinking skills have improved a lot compared to the previous me. Common steps of critical thinking skills that I had taken in the event are identified a problem or issue,*

	create inferences on why the problem exists and how it can be solved, collect information or data on the issue through research, organize and sort data and findings, develop and execute solutions, analyze what solutions worked or didn't work and identify ways to improve the solution. Thinking skills are important for me as it can help me to become a more organized person and also more analytical people. Thinking skills are also important as they can help me to reflect on the mistakes that had been made and make me a better person.
Adaptability	*The biggest challenge I face is task distribution. As there is one member in my group is unable to present physically in the event and also the meeting due to some health reason. It is hard to give him a task. Therefore, I come out with the idea to give him the task that he is able to do it online such as designing posters, google forms, proposal and others. Even though he is unable to participate in this event physically, but he had shown his effort in doing the job that is assigned to him.*

Cooperative Group Characteristics

In several reflections, the emergence of cooperative group characteristics was found. These characteristics were the results of embedding cooperative learning principles in the experiential learning approach. Among the characteristics that emerged in the students' reflections are:

- Accountability towards team members in achieving team goal

Although there are two members of the group who are slow and inexperienced in doing their given task, it is not a good reason for me to relinquish my responsibility as a member of the group to working in the group because if I do not carry out the group assignment given by the lecturer, it would have a detrimental effect on our team marks

- Shared leadership

Leadership skill also very important skill as not everyone can be a leader in any situation. So, anyone have to stand up can take the responsibility to be a leader when the situation need you. This is why leadership skill and team working skill are put together to be a skill that we need to develop and improved. Leadership and team working skill can help me to be a good and team working member and also a leader when the situation need me in my life.

- Developed interpersonal skills

I saw that my confidence in communication skills especially my talking skill has been boost up. Before this, I don't know how to talk to the public. But after being taught by lecturers and encouragement from friends, I felt that my communication skills were improving and I was more open to talking to people I didn't know. It's an advantage that I get and I think I will value it. Communication skills are very important because they are a key step in starting a business with others. If we have a high of communication skills, we will be able to attract their attention and easily ensure that they are very confident in us.

- Working & supporting each other academically & personally

Throughout the preparation, we had discussed and distributed all the tasks to make sure the event can be run on the date. This attribute is important as it helps me to lead and work with other people from different backgrounds to achieve a common goal. I will be able to comprehend and assume the interchangeable role of leaders and follower as well as take action to get others engaged. One with a good teamworking skills able to recognise and respect others' opinions and ideas as well.

- Team goal includes maximizing each member's learning

Now, I know teamwork can often achieve higher levels of performance than individuals because of combine energies of the members

This is because the ability of a person is limited but the ability of a team is infinity

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- Members relieved that they have been assigned to work together

Everyone sacrificed their time to prepared and organized this event and I am blessed that I have them as my new friends and teammates.

These characteristics were inline with previous research that reported the implementation of CL not only promote learning but also help develop team members to attain characteristics of a cooperative group member. These characteristics are valuable for graduates to possess when they enter the challenging 21st century workforce. Extensive research has shown that properly implemented cooperative learning leads to greater learning and improved communication development and teamwork skills which include leadership, project management and conflict resolution skills (Felder & Brent, 2007). Students learn to organize themselves within the team, to divide tasks equally among team members and relying on each other before deciding on a final successful product (Patesan et. al., 2016)

Conclusion

The inculcation of 21st century graduate attributes among engineering students can be attained through proper design of learning environment. The proposed cooperative experiential learning framework provided support in promoting the development of required competencies and character qualities in engineering graduates. It serves as a particularly valuable career preparation experience for the students. Integrating CL into the Kolb's experiential learning framework encouraged students to understand the theoretical principles and good practices of these 21st century graduate skills, experiment them in small scale via in class activities and helped them to project their learning into applications in the field-base setting via a team project.

The implementation of the framework requires detailed planning from instructors as well as continuous tracking on teams and student's performance. Despite the required efforts, the framework and its implementation can be custom-designed and applied in other courses that suits the course requirements. As the course is an introductory course to students, it is essential to have a continuous learning environment that help further develop these important and desirable graduate attributes to prepare them for the challenging future

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Moral judgment into moral action: Enhancing the teaching of engineering ethics

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ABSTRACT

CONTEXT

A recent review of the Australian Qualification framework (AQF) identified ethical decision making as a key capability for future graduates at AQF level 8. Further, ACED Engineer 2035 report also identifies ethics, trust, and ethical decision making as key for the future engineer. While most Australian universities incorporate Ethics as part of their engineering curriculum, very little consideration is given to models of ethical decision making. This paper makes recommendations for improving the current teaching practice of engineering ethics.

PURPOSE

The purpose of this paper is to examine and enhance current teaching practices of engineering ethics using ethical decision-making models as a basis for the improvement.

APPROACH

The approach consists of 1) analysing current teaching practices for engineering ethics as described in the literature, against models of ethical decision making, 2) identifying gaps that would better prepare students for ethical decision making, and 3) making recommendations to enhance current teaching practices.

OUTCOMES

The analysis of the literature highlighted that current teaching practices focus on ethical judgment making rather than ethical decision and action taking. Using models of ethical decision making, the analysis focused on two areas that would better facilitate judgment turning into action. They are 1) the situational context of the ethical issue, in particular the organisational context, and 2) the moral capacity of individuals.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This paper offered recommendations to supplement existing teaching practices of engineering ethics by considering two important moderators of ethical decision making, the situational context and individuals' moral capacity to carry a judgement into action. The two moderators are components of a widely used ethical decision-making model and are not currently considered in existing engineering teaching practices.

KEYWORDS

Ethic decision making, ethics in engineering practice, ethics education.

Introduction

In September 2015, Volkswagen received a notice of violation of the Clean Air Act from the American Environmental Protection Agency. Volkswagen used “defeat devices” on millions of its diesel cars to falsify car emissions. Software was embedded in the devices and used steering wheel position, speed, engine operation and air pressure to determine whether a car was in test mode, in which case emissions control would be switched on. Under normal driving conditions, the car would operate “normally” which would result in 40 times more nitrous oxide being released. Allegedly, engineers designed and implemented the software in the “defeat devices”, raising concerns around ethical practice in the engineering profession (Rhodes, 2016).

A recent review of the Australian Qualification framework (AQF) identified ethical decision making as a key capability for future graduates (Noonan et al., 2019). The Australian Council of Engineering Deans (ACED) recently released its Engineer 2035 report, and also identified ethics, trust, and ethical decision making as key for the future engineer (Crosthwaite, 2019).

Most Australian universities incorporate Ethics as part of their engineering curriculum, however, there is great diversity in the way Ethics is delivered. There is often great reliance on the Engineers Australia Code of Ethics (Engineers Australia, 2019). The Engineers Australia Code of Ethics makes four broad recommendations, with further specifications under each recommendation (Figure 1).

Figure 1: The Engineers Australia Code of Ethics

It clearly states that engineers need to act with integrity, practice competently, uphold the reputation of the engineering profession, and serve the community to foster health and wellbeing. It doesn’t tell engineers, however, how to handle ethical dilemmas when they present themselves. This is the realm of Engineering Ethics Teaching practices that primarily focus on reasoning through ethical dilemmas to achieve sound moral judgments (Magun-Jackson, 2004; Hamad, Hasanain, Abdulwahed & Al-Ammari, 2013; Baligar & Joshi, 2017).

Traditionally, when teaching ethics is part of the engineering curriculum, students are given a fictional or real case study (for example the VW case), discuss the different possible ethical judgments related to the case study, and justify their judgments in terms of existing ethical theories (Hersh, 2015). Depending on the teaching practice undertaken, some students would be encouraged to engage in an exercise of perspective taking and metacognition, which was shown to positively promote students’ moral reasoning and judgment capabilities (Hess et al., 2017; Hess et al., 2019).

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Students' moral reasoning is traditionally framed around Kohlberg's cognitive stages of moral development (CMD) (Table 1) (Kohlberg & Hersh, 1977). The most common tool for assessing moral judgement is the Defining Issues Test (DIT) and is based on Kohlberg's CMD (Bebeau, 2002). Engineering and Science Issues Test (ESIT) for Ethics instruction was more recently developed specifically in the context of engineering practice (Borenstein, Drake, Kirkman, & Swann, 2010; Kerr, Brummel, Daily, 2016).

Table 1: Kohlberg Stages of Development (Kohlberg & Hersh, 1977)

Level1: Preconventional	Stage1	*Punishment and Obedience Orientation* This stage involves total obedience to power figures and avoidance of punishment.
	Stage2	*Instrumental-Relativist Orientation* This stage is based on satisfying one's own needs. Reciprocity is in terms of "I'll help you if you help me".
Level2: Conventional	Stage3	*Interpersonal Concordance Orientation* This stage is around pleasing others and seeking approval by being "nice"
	Stage4	*"Law and Order" Orientation* This stage involves respecting authority, following rules, maintaining social order and doing one's duty
Level3: Postconventional	Stage5	*Social Contract, Legalistic Orientation* This stage aims for social utilitarianism, where individual rights are approved by society as a whole.
	Stage6	*Universal-Ethical-Principle Orientation* In this stage, there are no predefined rules. Right is defined according to one's own ethical principles.

Unfortunately, while the DIT and other measures are good predictors of moral judgment, they only account for 20% of moral behaviour (Hannah, Avolio & May, 2011). This means that while individuals may make good moral judgements, their actions may not follow. For example, the VW engineers may have come to a moral judgement that the "defeat devices" were unethical, but they still implemented the software that allowed for extensive release of nitrous oxide.

This paper addresses the limitation of existing engineering ethics teaching practices by making recommendations to turn moral judgment into moral action. The recommendations are supported by a widely accepted ethical decision-making model; they highlight important aspects of the model that are currently not incorporated in the teaching of engineering practice, namely the situational context and the individuals' moral capacity to go beyond judgment and into action.

Models of Ethical Decision Making

Engineering professional practice involves continuous engagement in judgement and decision making. Figure 2 depicts the life cycle of an engineering project from conception to operation (CDIO framework). The process of judgement involves critically evaluating alternatives based on available information, while decisions involve selecting preferred options from alternatives. Judgements and decisions tend to rely of executive functions for planning and control, as well enabling cognitive capabilities such as working and long-term memory, attention, and existing schemas from prior experiences.

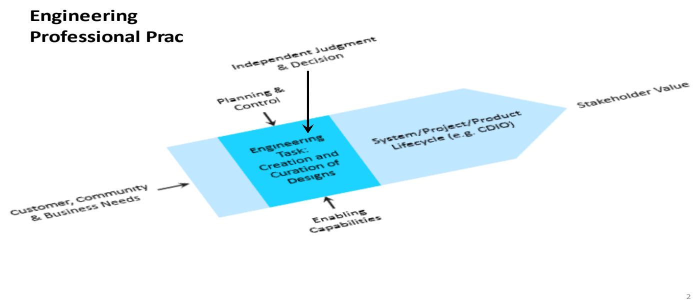

Figure 2: Concept of Engineering Professional Practice

Most of the time, engineers engage in judgement and decision processes that do not involve a moral issue. Sometimes, however, engineers will face a situation affecting the interest and welfare of the community they are serving in a way that conflicts with their personal, organisational or societal moral standards (Schwartz, 2016). These engineers will then engage in Ethical Decision Making (EDM).

Several models of EDM have been proposed in the literature, all serving various professions. They generally fall into two broad categories, 1- Reason-based models which assume that judgement and decisions follow a moral reasoning process (Kohlberg, 1973; Rest, 1986) and 2-Intuition and Affect based models which assume that both intuition (a cognitive process) and emotion drive ethical judgements while moral reasoning play a secondary role (Haidt, 2001). This paper will focus on a recent EDM model which incorporates both cognition and affect, the Integrated Ethical Decision Making (I-EDM) model (Schwartz, 2016) depicted in Figure 3.

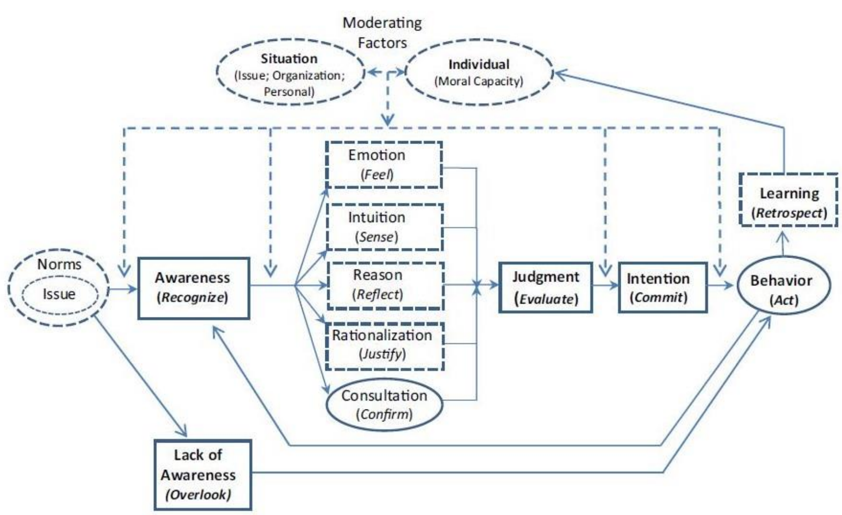

Figure 3: The Integrated Ethical Decision Model (I-EDM) (Schwartz, 2016)

The model's starting point is "The Issue". This is where conflicting norms and values first appear, creating a dilemma that needs to be resolved. Norms refer to "prevailing standards or expectations held by a particular group or community" (Schwartz, 2016). Engineers may have different sets of values from that of the organisation where they work or from the society where they live. They may be working for an organisation where engineering processes do not need to be strictly followed or living in a culture where bribes are the norm.

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The model allows for the possibility of lack of awareness of the issue, in which case no dilemma arises, but engineers are unaware of their unethical judgement and decision making. Lack of awareness depends on the individual's *moral sensitivity* (Reynolds, 2008). It has also been attributed to a process of self-deception (often unconscious) that is exacerbated when the organisation tends to prioritise profits over ethical considerations (Reynolds, 2008). The I-EDM model also has a feedback loop at the end of its processes, allowing for an opportunity to learn, for example if the ethical issue that was once ignored is amplified to a level where it can no longer be ignored.

Assuming individuals are now aware of the moral dilemma of a given situation, they engage in cognitive and affective processes that lead to a judgment, decision, then behaviour. Ethical decision making involves choosing from a set of possible outcomes, and generally, no outcome is entirely satisfactory (Mattison, 2000).

Moral reasoning (reason) involves reflecting and weighing various alternatives using ethical criteria as support. For example, fairness and consequences of various decisions could be compared, and the comparison would lead to an optimal ethical decision. This is the area of focus of most engineering teaching practices. Beyond reason, emotions are also often involved and can strongly affect moral reasoning. For example, in the presence of fear, the brain's executive functions and therefore moral reasoning tend to be bypassed. Engineering ethics studies are starting to consider emotions as playing an important role in ethical reasoning and moral judgment (Sunderland, Ahn, Carson, & Kastenberg, 2013). Intuition refers to a cognitive process that is automatic and that leads to an initial "gut sense" and generally precedes more reasoning (Haidt, 2001). It may be based on existing experience. The model also allows for consultation, for example with peers, to support their decision making. Moral consultation may or may not lead to better ethical outcomes. Importantly, the model allows for judgements and decisions to be moderated by individual and situation characteristics.

Individual characteristics relate to the individual's *moral capacity* to judge, decide and act when morally conflicted. Moral capacity is a combination of their *moral character disposition* as captured, for example, through Kohlberg's Cognitive stages of Moral Development (Table 1), and their *integrity capacity*, that is their ability to uphold their ethical behaviour in the face of adversity (Hannah et al., 2011). Individual moral capacity is influenced by demographics (gender, age, education level, …), personality, as well ethical training and experience (Schwartz, 2016).

Situational characteristics comprise 1) the issue that is at the source of the ethical dilemma, 2) the organisation, and 3) personal factors at the time of the ethical dilemma not related to moral capacity.

The issue needs to have a high enough *moral intensity* and *importance* to raise the engineer's awareness. As mentioned earlier, there is an element of subjectivity depending on the *moral sensitivity* of the engineer. Issue *complexity* is another important element that could prevent an engineer to engage with an ethical dilemma. The VW case is an example of a complex issue where whistleblowing on the organisation's unethical behaviour can be perceived as a complex decision with difficult consequences for multiple stakeholders (Schwartz, 2016).

The organisation, in particular its ethical infrastructure can play an important role in moral judgment and decision making. Ethical infrastructure refers to ''…the organizational elements that contribute to an organization's ethical effectiveness'' (Tenbrunsel et al., 2003), and forms part of the organisation's governance. This topic will be addressed in further details in the following section

Finally, individuals' personal situation at the time of the ethical dilemma, regardless of their moral capacity, can also affect their ethical decision-making process. Are they facing personal issues at home or in the workplace? Are they in a weak financial situation? These personal issues, regardless of individuals' moral capacity, carry an emotional load which could alter the

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judgement and decision process towards unethical outcomes, particularly if there is a perception of gain (Schwartz, 2016).

Recommendations for improving the teaching of Engineering Ethics

An important shortfall of existing teaching practice is that they focus on a small portion of the I-EDM model (Figure 4), that is “moral reasoning leading to moral judgement”.

Figure 4: Current practices focus on this small portion of the full I-EDM model (Figure 3)

As mentioned earlier, more often than not, moral judgment does not always lead to moral behaviour. In other words, the portion of the I-EDM model shown in Figure 6 below is not, to the best of our knowledge, addressed by current engineering teaching practices.

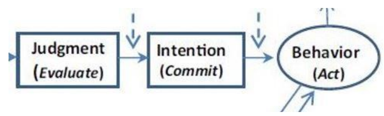

Figure 6: Current teaching practices do not address how judgment translates to behaviour

This incongruence between moral judgement and moral behaviour is addressed by considering two important factors, depicted as moderators in the I-EDM model, 1) the *situational context*, and 2) the individuals’ *moral capacity* to uphold ethical judgements (Figure 5). This section makes recommendations around incorporating these 2 factors into engineering teaching practices.

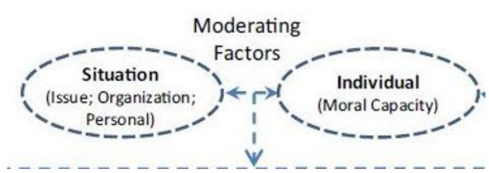

Figure 5: Teaching practices need to incorporate this portion of the I-EDM model (Figure 3)

The following psychological experiment illustrates the importance of these two concepts.

Milgram’s experiment (McLeod, 2007). Stanley Milgram was a professor of psychology at Yale University, and the son of Jewish immigrants. Following the Nuremberg trials where the main defence for holocaust crimes was that nazi officers were just following orders, Milgram decided to investigate the extent everyday citizens were willing to hurt others just because they received an order from a higher authority. The experiment Milgram designed involved a teacher, a learner, and a researcher. The teacher was a participant unaware of the real intent of the experiment. Participants were told that the purpose of the experiment was to investigate the extent punishment would improve learning, and punishment consisted of administering electroshock of increased voltage intensity (up to 450V) every time the learner made a mistake. The learner was an actor strapped in electrodes and was pretending to be hurt when electroshocks were administered by the participants. Participants were deceived in believing they were administering actual electroshocks, and the learner (the actor) would scream and pretend to be hurt to the point of heart failure. The researcher, who was part of Milgram’s team, dressed in a lab coat, represented authority and was the one giving the order to administer higher and higher voltage shocks. All the participants continued to obey orders and administer electroshocks up to 300V. Two-thirds of the participants continued to the highest voltage value of 450V where the actor would pretend to collapse. The experiment (later deemed highly

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unethical) showed that ordinary people, while highly conflicted, would still obey orders even if it involves hurting an innocent person to the point of collapse.

This is an example of how the situational context, in this case the researcher's authority, and individuals' moral capacity could impact ethical judgment. The participants' moral judgment probably dictated that they should not hurt the learner, but their capacity to act in alignment with their judgement was jeopardised by the authority of the researcher. The organisation can represent authority, and as in the VW case could put pressure on engineers to undertake unethical actions that could potentially have harmful consequences to the community. Should the VW engineers object to the directive of falsifying emission reports and as a result betray their organisation, their work colleagues, and their ability to support their family through potentially losing their jobs? In this context, the engineers are weighing individual values against organisational and societal values and pressures, and the answers are not easy.

Interestingly, in the Milgram experiment, when participants went back home and talked to their partners about the experiment and the choices they made, all partners stated that they would not have obeyed orders. This last point demonstrates how, when the situational context is removed, people may believe their behaviours would be aligned with their judgment, which is not necessarily true and heavily depends on their moral capacity in a given situation. Similarly, when engineering students make a moral judgement unaware of the situational context (in particular the organisation), they are unable to reflect on their moral capacity.

Recommendation 1

The situational context (Organisation)

Over-reliance on individual moral reasoning without situational context has already raised a number of concerns when it comes to teaching engineering ethics (Zhu & Jesiek, 2017; Lawlor, 2021). As mentioned above, individuals outside the organisational context tend to believe that their moral judgments and actions will be aligned. In context, judgements, intentions or decisions and behaviours may not be congruent. The organisation culture may affect individuals' capacity to take action on their moral judgement. This first recommendation is to bring the organisation into the case study presented to the students. This will raise their awareness around corporate governance and its importance in ethical decision making.

Corporate governance sets the organisation's goals, direction, limits, policies, structures and accountability frameworks, which together provide the principles for organisational decision making. Through these means, governance shapes the corporate culture and values, including a moral compass that influences employees' ethical behaviour. This is consistent with prevalent ethical decision models that suggest that individuals make decisions based on personal aspects, group variables, environment factors and situational aspects, such as severity of the consequences, rewards or punishments (Craft, 2013). Previous research highlights the importance of awareness of the corporate culture and values, seen as the personality of the organisation, to guide employees ethical decision making (Knouse, Stephen & Giacalone, Robert. 1992) and the integral role of ethical accountability in the organisational culture (Potts, & Matuszewski, 2004).

An enterprise will define an Engineering Management System (EMS) as a subset of its corporate Quality Management System (QMS). The EMS outlines the principles, processes and procedures by which the engineering organisation will achieve management and technical control over its engineering operations. Corporate guidance on social responsibility (regulatory compliance, safety and environment, etc) will be flowed down to the EMS. In a large enterprise the EMS may comprise many hundreds of artefacts. A large project or program within an enterprise may develop its own management system, often called an Engineering Management Plan, tailored to its specific needs, using the enterprise EMS as its basis. With this approach, guidance on social responsibility will be flowed down from the enterprise level to the operational level; its effectiveness at that level will be dependent on operational managers.

The purpose of the EMS is to achieve proper control, coordination, consistency and standard of engineering services. A properly implemented EMS will ensure that no individual engineer can operate in isolation of these control and coordination processes. Error reduction and risk management processes are integral to the EMS and are implemented through extensive independent review of designs at specified gates, as well as through independent review and approval at the level of engineering documents. With careful implementation, potential ethical failures which present as errors or risks can be detected by these EMS processes.

Recommendation 2

Moral Capacity

As mentioned in the introduction, the most common tool for assessing moral judgement and decision making is the Defining Issues Test (DIT) (Bebeau, 2002), even though in was reported to account for only 20% of the variance in ethical behaviour. The main reason is that moral judgement is not always carried through to action, often because of the situational context (Bebeau, 2002). The ability to act on a moral judgement is referred to as *moral conation capacity* and consists of three components, *moral ownership*, *moral efficacy* and *moral courage.* For individuals to carry through a moral judgement into moral action, they need to take responsibility (moral ownership), feel they have the capacity to take action (moral efficacy), they find the courage to carry through (moral courage) (Hannah et al., 2011).

Moral ownership involves some sense of responsibility over the decision and action that needs to be undertaken. If the authority exerted by an organisation is such that individuals feel that they have no choice but to obey orders, they will have little moral ownership regardless of their moral judgement.

Moral efficacy refers to the individual's perceived capacity, capability, and available resources to act following judgment. It depends on both the situational context and the perceived magnitude of the task ahead

Moral courage has been identified as critical in taking action against perceived and actual barriers and threats within organisations. Even when individuals feel a sense of ownership and feel that they have the capability and resources to act, they may lack the courage and strength to follow through with their judgment (Hannah et al., 2011).

It is therefore important when teaching ethics to future engineers, to not only focus on developing students' moral reasoning, leading to ethical judgment making, but to also invite them to reflect on their moral capacity to take action on their judgment by investigating their sense of ownership, efficacy and courage in a given situation.

Conclusion

This paper offered recommendations to supplement existing teaching practices of engineering ethics as described in the literature, by considering two moderators of ethical decision making, the situational context and individuals' moral capacity to carry a judgement into action. The two moderators are components of a widely used ethical decision-making model and, to the best of the authors' knowledge, are not currently considered in existing teaching practices.

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Evaluating Outcomes in Two Engineering ‘Clinic’ Subjects

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ABSTRACT

CONTEXT
Project-Based Learning (PBL) is seen as a key pedagogical approach to address a widely acknowledged skills gap existing between the capabilities expected by employers and what is seen in engineering graduates. This enthusiasm stems from an understanding that PBL provides authentic learning experiences where students perform the very activities in which they will engage after graduation, as well as opportunities for “dual-impact” learning activities to build technical and professional skills simultaneously (Crawley et al., 2014). Moreover, open-ended projects can encourage students to develop capabilities for self-directed learning and application of knowledge, and the independence and initiative needed for a successful career.

PURPOSE
This paper details the creation of two project-based ‘clinic’ subjects within a traditionally taught Electrical Engineering master’s program. Both subjects revolve around open-ended, semester-long design projects addressable through many plausible solution paths. The primary purpose of this paper is to evaluate the extent to which students were able to simultaneously integrate knowledge from prerequisite subjects and develop their professional engineering skills through dual-impact learning activities.

APPROACH
The design and implementation of the clinic subjects is informed by literature on project-based learning. In lieu of pending survey results, the approach taken to assess the success of students achieving defined learning outcomes is through observations of the instructors and analysis of recurrent themes expressed in self-reflection essays submitted by students.

OUTCOMES
Observations indicate students were highly motivated by the open-ended nature of the projects and considered gaining practical experience with hardware and software tools to be their most significant achievement from undertaking the subject. These experiences were indeed gained simultaneously with the development of professional skills; however, the instructors observed a deficiency in the rigorous application of theoretical engineering concepts from prerequisite subjects.

RECOMMENDATIONS
The next iteration of the subject will address the perceived lack of engineering rigour by exemplifying the expectation, while ensuring that such an example does not degrade the open-ended nature of the project. To that end, an adaptation of the project scope will be used to ensure that an off-the-shelf solution to the project does not exist and hence achieve the same ownership and engagement that was observed to drive students’ skill development.

KEYWORDS
Project-based learning; integrative learning; professional skills.

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Introduction

It has long been recognised that successful engineers possess not only solid theoretical knowledge but a strong aptitude in the practical application of that knowledge accompanied by numerous professional attributes that are non-technical in nature. Such professional attributes include generic and transferable competencies such as written and verbal communication skills, teamwork, self-management, innovation, and ethical conduct. It is common for studies on the attributes required of engineering professionals to report these non-technical and attitudinal competencies to be as important as technical competencies (Male et al., 2011). In its current phase (Crawley et al., 2014), engineering education has been on a path of continuous evolution to better deliver graduates with these attributes, as is clearly reflected in an increasing emphasis on such capabilities in accreditation standards (Engineers Australia, 2021).

The shift in emphasis in graduate attributes has naturally required a corresponding shift in pedagogical approaches and design of curriculum within engineering programs. Project-based Learning (PBL) is one approach widely promoted and deployed to better prepare students for the realities of the engineering workforce (Mills and Treagust, 2003). The enthusiasm for PBL, and its central role in many reform initiatives (CDIO, 2021), derives from its ability to provide authentic learning experiences where students perform the very activities in which they will engage after graduation. These activities can be 'dual-impact' in nature, simultaneously and efficiently allowing the development of both technical and professional skills (Crawley et al., 2014). Furthermore, the potential open-ended nature of project work encourages students to develop capabilities for self-directed learning and the application of knowledge while fostering greater independence and initiative, which is aligned with notions of life-long learning and sustainable assessment (Boud and Soler, 2016).

In this paper we reflect on the initial offering of two 'clinic' subjects within a Master of Electrical Engineering program which are structured around semester-long design projects in the areas of autonomous systems and communication systems. Here, the 'clinic' label is inspired by its use within the medical community to denote practical instruction and experience in the treatment of real patients. In a similar manner, we envisage an engineering clinic to be

> *a class of engineering students which takes place predominantly in a workshop setting where skills, knowledge, and understanding are gained through practical instruction in analysing and implementing solutions to a team-based design project.*

These subjects afford students the opportunity to integrate prerequisite knowledge, practice engineering design principles, and develop important professional attributes.

It is common to find PBL employed in engineering curricula, particularly within introductory engineering subjects (Dym et al., 2005) and final-year capstone design projects (Heitmann 1996). It is less common to find PBL widely employed across a single master's degree program, although there are examples (Kjersdam, 1994). PBL is not without its associated challenges; many of these issues have been identified or studied in the literature, including topics such as the hierarchical nature of engineering knowledge (Mills and Treagust, 2003), team formation (Rasul and Mandal, 2019), the assessment of individual contributions within team-based work (Holgaard and Kolmos, 2009), and the high time commitment for project-based work (Bédard et al., 2010).

In the remainder of this paper, we first describe the design and implementation of these two subjects. We then offer reflections based on instructors' perceptions of student performance and attitudes. When relevant, we comment on how awareness of PBL-associated challenges informed design and implementation decisions and discuss how observations in our reflection may be related.

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Subject Design

The primary motivation behind introducing the clinic subjects was to give students additional opportunities for completing domain-specific design projects, further developing important professional attributes, and integrating knowledge across prerequisite subjects. Both subjects are taught as electives and have master's level prerequisites as depicted in Figure 1. A key anticipated benefit of the subjects was that, by requiring students to draw on knowledge from multiple prerequisites, the 'silos of knowledge' that often exist between separately taught technical areas could be eroded. These silos are the unintended consequence of the semester structure and subject division within university programs and can conceal from students how closely related many subdisciplines are within practical engineering applications.

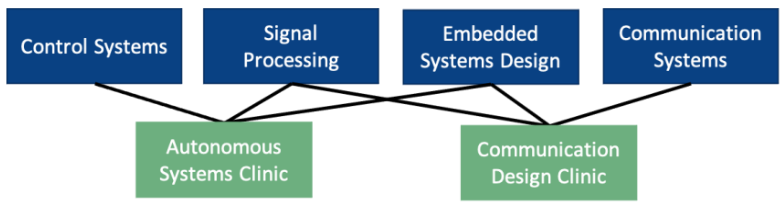

Figure 1: Prerequisite subjects (blue) for engineering clinic subjects (green) within the Master of Electrical Engineering program

Intended learning outcomes (ILOs) were formulated for the two clinic subjects to codify the high-level conceptual goals. ILOs for the clinic on autonomous systems are reproduced in Table 1 along with their mapping to Engineers Australia (2021) 'Stage 1 Competency Standard for Professional Engineer'. The 16 mandatory elements of competency are grouped into three categories, and from the mapping it can be seen the stated learning outcomes heavily focus on categories *2. Engineering Application Ability* and *3. Professional and Personal Attributes*. Less emphasis is placed on instructing students in new theoretical knowledge, as will be further evident in the discussion on subject implementation. Rather, the focus is on students applying prior theoretical knowledge and self-directing their study of advanced topics they identify as relevant to their proposed solution. This focus is similar to the year-long, team-based capstone design project completed by all students in the degree. In this way, the clinic subjects are intended to be 'mini-capstone' experiences and provide preparation and skill development relevant to students' future capstone efforts.

Following the well-established educational best practice of constructive alignment (Biggs and Tang, 2011), learning activities and assessments were designed with the outcomes of Table 1 in mind. We defer discussion of learning activities to the next section, but a summary of assessments employed is provided in Table 2. These included a mix of both individually and team assessed tasks with a heavy focus on the use of authentic assessments related to project work. A series of guided workshops, completed as a team but assessed individually, familiarised students with the software and hardware platforms used within the projects. A mid-semester exam was used to assess individual achievement of concepts relevant to the area of the respective design project.

Table 1: Intended learning outcomes for clinic on autonomous systems

	Intended Learning Outcome	EA Competencies
1	Apply established engineering design methodologies to assist in the design and implementation of autonomous systems.	1.5, 2.3
2	Analyse and devise solutions to autonomous systems design problems, drawing upon fundamental principles underpinning autonomous systems from areas such as embedded systems, control systems and signal processing.	1.3, 2.1, 3.3
3	Determine the integrity and reliability of structures, circuits, and algorithms, in order to robustly design against failure.	2.2
4	Demonstrate competency with modern hardware components and software frameworks for autonomous systems through hands-on engagement.	2.2
5	Apply systematic approaches to the conduct and management of a relatively complex electrical engineering design project in a small team.	2.4, 3.5, 3.6
6	Communicate effectively with professionals across different engineering disciplines, through media such as concise technical reports and informational videos.	3.2

Table 2: Assessment structure for engineering clinics

Assessment	Type	Weight	ILOs
Guided Workshops	Individual	12.5%	3
Mid-semester Exam	Individual	10%	1-3
Project Plan	Team	10%	2, 3, 5
Project Review Meeting	Team	15%	2, 6
Project Demonstration	Team	2.5%	4
Final Team Report	Team	30%	2-3, 6
Team Video Presentation	Team	10%	6
Self-reflection	Individual	10%	5

Team assessment tasks reflected the philosophy of the subject being a ‘mini-capstone’ with students completing in sequence: a project plan, a project review meeting, a project demonstration, and a final technical report. Teams were not required to strictly follow their submitted project plan but needed to benchmark their progress against previous expectations. The project review meeting, in which student teams orally presented their progress and defended design decisions made up to that point, was intended to model such meetings as are typically held on industry projects. It was the most significant formative assessment task in the subject and an opportunity for instructors to give teams direct feedback on their verbal communication abilities and planned technical solutions.

A small percentage of the overall subject marks (2.5%) were allocated to a competitive project demonstration at the end of the semester. Team solutions were compared by their ability to meet announced performance requirements with the strongest team in each

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category awarded additional marks. The competition was intended to motivate students by providing a product-delivery element to the subject as well as a sense of achievement for the winners. It is important to note that instructors repeatedly emphasised the primary evaluations of the subject would assess the process taken in solving the project rather than performance in the end-of-semester competition.

The final team report was a 30-page document in which students were expected to provide rigorous evidence of the engineering analysis, design, and implementation methods employed to produce their solution. Students were not explicitly reassessed on theoretical knowledge from the prerequisite subjects; instead, assessment focused on their application of said theoretical knowledge to the project. This approach differs significantly in nature and scale to the problem set and workshop assessments found in prerequisite subjects. Specifically, students were expected to describe over-all system architecture, explain how subsystems were to interact, report multiple solution approaches considered for each subsystem, and justify design decisions made throughout the project. They were expected to make clear connections across their ‘silos of knowledge’.

Students completed three self and peer assessments (SPAs) through the semester associated with the project plan, project review, and final report, respectively. These assessments allowed students to provide each other with formative feedback on their performance, identified issues in team dynamics so that they could be addressed, and provided appropriate scaling of team marks based on individual contributions. The first SPA for the project plan was strictly formative with only the project review and final report SPAs impacting marks.

Finally, students completed a 1500-word individual self-reflection at the end of the semester in which they reflected on the experience of working as a member of a project team and the relevance of various professional attributes to the achievements made on the project. This self-reflection was intended to drive deeper student awareness of and appreciation for how their professional attributes had developed through the dual-impact activities of the subject. Additionally, the self-reflection provided valuable feedback to instructors for assessing the efficacy of subject design in meeting the stated high-level goals.

Implementation

Central to the implementation of any PBL subject is the selection and parameterisation of an appropriate project that enables students to achieve the defined learning outcomes. Based on the goals set for the clinics, this required selecting projects that were open-ended in nature, addressable by a diverse set of solutions, exercised concepts from all prerequisite subjects, and lent themselves to exploration of advanced domain topics through self-study.

For the clinic on autonomous systems, students were tasked with delivering

> *a working prototype of a robot that operates autonomously in a warehouse environment to repeatedly perform the task of collecting items from various locations in the warehouse and delivering those items safely to other parts of the warehouse.*

As the mechanical design was not a focus of the subject, a baseline differential-drive robot was given to each team composed of a chassis, wheels, motors, and a single-board computer. A variety of potentially useful sensors (distance, proximity, encoder, camera, IMU, colour) were made available to each team for integration into the baseline platform. The necessary code libraries were pre-installed and skeleton code was provided for retrieving the raw data from each sensor separately and for commanding the input voltage to each motor. Students were responsible for designing and implementing all additional features and algorithms that they determined to be necessary for achieving the task, including processing the raw sensor data, localisation, path planning, and motor control for path following.

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For the clinic on communication systems, students competed in a spectrum challenge in which they were tasked with

> *designing, implementing, and verifying a secondary communication link capable of opportunistically communicating using spectrum shared with an incumbent user without significantly degrading the incumbent's communications.*

Spectrum challenges (DySPAN 2017, ShaRC) are a common way to motivate the learning of digital communications and drive research in related areas such as software-defined radio (SDR) and cognitive radio (CR). Clinic students developed solutions on an SDR platform (GNU Radio and Nuand bladeRF), which presented a lower barrier to entry as compared to traditional hardware-based platforms and great freedom in the design of communication protocols. Workshops guided students through the development of a reference narrowband communication link useful as a baseline for their project. Students were responsible for designing and implementing the secondary link's spectrum access strategy and any improvements to the baseline link.

Enrolment consisted of 33 students and 12 students for the autonomous systems and communication systems clinics, respectively. Students completed the projects in teams of three and were allowed to choose their teammates. Team formation was completed by the fourth week, prior to which students were encouraged to work in a variety of constellations and discuss compatibility for discerning their teams.

As the focus of the clinics is on integrating existing theoretical knowledge and gaining new knowledge through self-directed study, the subjects utilised a non-traditional format of contact hours. The first four weeks of semester were an intensive period of instruction, having students attend three hour-long lectures and one three-hour guided workshop each week. The focus of instruction was introducing students to the design project, familiarising them with the software and hardware tools, motivating a range of viable solution paths for applying prerequisite knowledge, and scaffolding the independent teamwork that would form the remainder of the semester. A fallow period of reduced contact hours followed in which students worked independently on their design projects. Three-hour, optional workshop sessions were scheduled each week to allow students access to the hardware and to engage instructors for assistance with ad hoc questions. Project-related assessment tasks took place throughout this fallow period. See Figure 2 for the sequencing of contact hours and assessment tasks within the clinics.

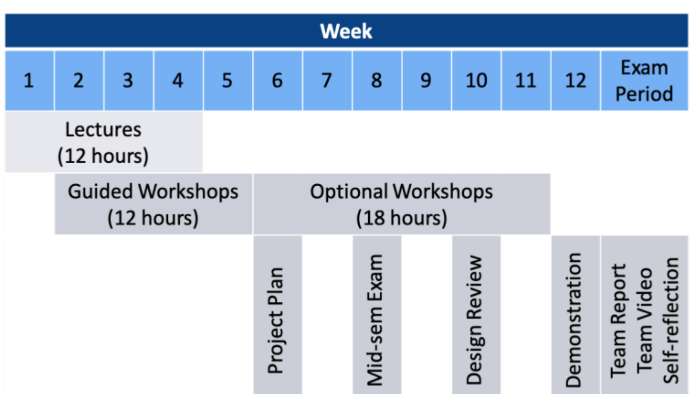

Figure 2: Engineering clinic contact hours and assessment structure

As a learning resource, students were provided with a set of video interviews conducted with instructors of prerequisite subjects and relevant industry experts. These videos were a way of framing the content studied in the prerequisites for the project at hand and gave helpful

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hints about potential advanced topics to explore. Additionally, discussion with industry experts demonstrated the real-world relevance of the projects and contextualised the importance of professional attributes to the success of an engineer.

Reflections

A quantitative and qualitative survey of students is underway to evaluate learning outcomes, with a focus on the perceived efficacy of dual-impact activities on professional skills development and students' experience of the project-based pedagogy. Results were unavailable at the time of writing; here we offer reflections based on the experience of creating and delivering these subjects and recurrent themes in student self-reflections.

Project scope, rigour, and ownership

A common theme raised in student reflections was that the size and scope of both projects was of sufficient scale to necessitate both efficient teamwork and a methodical design approach. Multiple students observed that these were the first projects they had completed not addressable in the given timeframe working individually. The inability for one individual to carry an entire team drove a greater appreciation among students for the importance of core skills around project work, such as the use of system-level thinking, documentation, distribution of workload, coordinating individual efforts, and managing team dynamics. These insights likely would not have been as strong if projects were of a smaller scope. The use of semester-long projects with a significant fallow period clearly has strong advantages in this regard and was made possible by focusing on the integration of existing theoretical knowledge.

Both instructors observed that the balance of student effort spent on the rigorous application of engineering design methods and the focus placed on implementation was heavily skewed towards the latter. Prerequisite subjects provided students with ample theoretical and analytical tools to apply but few teams fully utilised such tools, instead electing more ad hoc design approaches. Learning outcome 1 in Table 1 makes clear that applying engineering design methodologies was a key goal for the subjects. One approach to address this imbalance would be to give students a refined project platform to reduce time spent on implementation. A more promising alternative would be to include concrete examples of applying design methodologies within the guided workshops to prompt a more balanced approach. Care must be taken in any redesign of workshops that students do not simply see an example design approach as a prescriptive model directly applicable to the larger project without intelligent modification.

In line with the open-ended project philosophy of the subjects, a conscious choice was made to not give an example solution for the project task but instead be confident it was achievable starting from the skeleton hardware and software provided. In this way students were likely to have an experience more closely mirroring that of a professional engineer, i.e., needing to carefully consider the applicability of solutions from similar problems before adopting and combining. This differs from project experiences in other subjects, apart from capstone, and instructors observed a shift in student mentality during semester to a greater sense of project ownership. A number of students expressed in their self-reflection that this ownership over the project combined with the assessment emphasis on engineering process gave them confidence to pursue solutions despite uncertainty in the outcome and hence learn from the subsequent 'failure' of a given approach.

As this was the first time both clinics were taught, students naturally encountered multiple software and hardware issues throughout the semester. The need to independently identify and resolve such issues had a different impact on students of the two subjects. Within the clinic on autonomous systems, it was generally observed that students were highly motivated by the chance to engage with software and hardware tools to resolve such bugs. Within the clinic on communication systems, however, students seemed to be more discouraged by such issues, with some teams focusing on resolving a given issue rather than continuing to make progress in other areas. A key takeaway inferred is that students can gain valuable insight and motivation from addressing software and hardware issues that arise during PBL, but this must be carefully balanced to prevent students from becoming discouraged.

Team dynamics and influence on future project-work

Several students made thoughtful observations about different learning approaches taken by teammates and demonstrated an appreciation for the relative strengths and potential complementarity of such approaches. Particularly notable were observations reported in individual reflections that agreed within a team. Usually, students who made the keenest observations about their teammates were best able to identify the underlying emotional attitudes that drove their own behaviours and learning approaches and whether those had positive or negative aspects. Such self-knowledge and emotional intelligence are important professional attributes and fall under EA elements of competency *3.5 Orderly management of self, and professional conduct* and *3.6 Effective team membership and team leadership.* Again, it is believed the large scope of the team projects undertaken by students was a contributing factor to enabling these types of insights.

Many students made clear connections in their reflections between the nature of the project work in the subject and what their likely experience of industry work will be. This led students to express an appreciation for the chance to practice communication skills, develop greater expertise in computer programming, and apply engineering knowledge in a practical setting. Some students reported such opportunities were a strong contributor to an increase in self-confidence in their ability to function as professional engineers in the future. The required prerequisites for each clinic meant most students had either already commenced their final-year capstone project or would begin in the next semester; multiple students expressed an expectation that experiences in the clinic would boost the success of their capstone project.

Collaboration and workload

Despite the competitive end-of-semester demonstration, a collaborative atmosphere was encouraged between teams during the guided and optional workshop sessions, for example by guiding students with certain questions to ask others in the cohort who had encountered a similar question. Students highlighted in their self-reflection that the act of providing explanations to others and asking questions of others was mutually beneficial. Additionally, the optional workshops fostered a collaborative atmosphere through engagement with instructors, which enabled just-in-time and highly tailored learning opportunities. Even if such a discussion was with an individual student, the learning was observed to flow back to both their team and the cohort at large through the collaborative atmosphere.

Student self-reflections indicated a keen interest and preference for more experiential learning approaches to be incorporated into the program. This is in part attributable to continuing pandemic restrictions on in-person instruction creating a strong appreciation for the return to working in a practical lab setting and face-to-face interaction with peers. Six students concurrently enrolled in both clinics and commented on the challenge of managing the high workload entailed by project work, which was exacerbated by similar assessment due dates for the two clinics. A high workload is a well-known challenge of PBL as compared to traditional pedagogies but can also be viewed as a good opportunity for students to practice planning ahead and managing stress levels. A wider-scale adoption of PBL in the master's program would require careful coordination and execution to address this challenge.

Conclusion

According to the observations of instructors and the reflections of the students, the clinic subjects described in this paper, which employed PBL pedagogies, did indeed achieve the high-level goal of simultaneously improving students' technical and professional engineering

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competencies. For the technical skills, a major dissatisfaction among instructors was an imbalance between engineering rigour and implementation work, with the latter being the major focus of the students' efforts. For the professional skills, a clear theme in student reflections was that the dual-impact activities of the subjects raised student awareness of the importance of these skills to their future endeavours as professional engineers. In particular, teamwork was seen by the students as contributing positively to both the technical and professional skills development aspects. Pending survey results are expected to provide a better understanding of these aspects, including the students' perception of the balance between engineering rigor and implementation work.

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Development of and reflection on introducing a pass/fail course for first-year engineering students

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ABSTRACT

CONTEXT

The first-year courses for all College of Sciences programmes at Massey University were redesigned and a new set of courses were introduced in 2020. One of the new first year courses was 247.114 Science and Sustainability for Engineering and Technology. In this project-based learning course, groups of students take a component of a consumer product and examine its lifecycle. They then propose ways for the component to be more sustainable. It was decided that this course would be a pass/fail course rather than a graded course. This new course replaced a graded project-based learning course, and it is the only pass/fail course in the Bachelor of Engineering with Honours and Bachelor of Food Technology with Honours programmes.

PURPOSE OR GOAL

This paper provides an overview of the drivers for introducing a pass/fail course; how it was developed and implemented; reflection after the first offering of the course; and discussion on proposed strategies to improve the next offering.

APPROACH OR METHODOLOGY/METHODS

During the delivery of the course and at the end of the semester staff reflected on the overall course and the approach used for the assessments. Areas for improvement for the next offering were identified and discussed.

ACTUAL OR ANTICIPATED OUTCOMES

Key lessons learnt during the implementation of this pass/fail course are discussed along with areas for improvement and the approach which will be taken for the next offering of the course. It was found that this style of course aligns with competency-based learning very well and this helps guide the future direction for the course.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Pass/fail courses allow the focus to be on achieving a certain level of competency for each learning outcome rather than achieving 50% overall in a course. The assessments and marking rubrics need to be developed with this in mind and designed to minimise 'game playing'. This will be one of the key changes for the next offering.

The style of assessments including quizzes, team gate meetings and individual written assignments suited the pass/fail approach very well.

This course is moving towards a competency-based learning approach, however there are challenges which still need to be addressed. How to maintain motivation within the course when more effort is not rewarded by higher grades requires more consideration.

KEYWORDS

Competency-based learning; first-year; pass/fail

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Introduction

In 2019 the College of Sciences reviewed and redeveloped all the courses which were offered in first year. As a result of this process there were two new project-based learning courses developed for first year which were first offered in 2020. This paper focuses on the development and delivery of the first offering of the course 247.114 Science and Sustainability for Engineering and Technology. This course is compulsory for all students studying the Bachelor of Engineering with Honours and the Bachelor of Food Technology with Honours.

In order to develop professional skills including communication, teamwork, project management and problem solving, a project-based spine was established within the Bachelor of Engineering with Honours and the Bachelor of Food Technology with Honours at Massey University. This is a series of project-based learning courses with one course each semester taught in this way and is common to all students in Years 1 and 2. The students work in teams to solve problems. The context changes with each project and the projects progressively get more complex throughout the programmes. Different aspects of these project-based courses have been published in other studies (e.g. Goodyer & Anderson, 2011; Shekar, 2014; Gupta & Bailey, 2014; Brown, 2017; Tunnicliffe & Brown, 2017; Brown & Tunnicliffe, 2017; Konings & Legg, 2020; Brown, 2020; Brown 2021).

Science and Sustainability for Engineering and Technology is a pass/fail course. All other courses in the programmes use a graded system for their assessment (A+/A/A-/B+/B/B-/C+/C/C-/D/E). A student's overall GPA, to determine the level of honours that students graduate with, is calculated from year 2-4 grades so first year has no influence.

Pass/fail courses are not new and have been applied to many different fields including medicine (e.g. Gold et al., 1971; Bloodgood et al., 2009) and engineering (e.g. Stanton & Siller, 2011). There have however been varying degrees of success. Gold et al., (1971) found that students who had taken pass/fail courses had a lower GPA than those who took graded courses and there was an effect even if the student had taken only one pass/fail course. However, Bloodgood et al. (2009) reported that pass/fail did not result in any reduction in performance in courses, test scores or residency placements for medical students.

Our drivers for pass/fail

In traditional graded courses students can achieve a pass grade overall without passing all the elements of the course. One of the advantages of pass/fail is that it ensures all students pass all elements of a course. This can be particularly useful in first year as it makes sure that everyone has a baseline of knowledge which can then be built on in future courses.

Some of the topics in this particular course can be challenging for certain groups of students. An example is the content where we ensure students take cultural considerations into account when developing their solutions. As this project is based on an Aotearoa New Zealand context, that involves the students gaining an understanding of te ao Māori (Māori word view) and Mātauranga Māori (Māori knowledge). While domestic students typically find this straight forward due to their prior knowledge, it can be very challenging for international students who may have no prior knowledge. The course was set up to allow students to fail individual assessments but with further learning achieve these learning outcomes in later assessments. This helps to take the pressure off.

When the course was being developed the potential to lower staff workload was also seen as an advantage. This course is taught over two campuses and in all courses, we ensure that both offerings are equivalent. This involves checking that all assessments are marked to the same standards and some assessments are marked by both campuses to ensure this. At the end of the course both offerings are also compared to ensure the final grades are equivalent and the same grade point cuts are used. In a pass/fail course, equivalence is more straight

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forward as it is only the pass/fail point which needs to be calibrated. The end of semester is also much more simplified as determining pass and fail is straight forward and no grade cut points are needed.

One of the challenges of project-based learning courses which involve team-based assessment is that there is a reduced spread of grades and students tend to be clustered together. This means that these courses essentially already act as pass/fail because there is little separation between students. In cases where there is a spread of marks there tends to be teams which contain high performing individuals, and their ability helps to lift the performance of the weaker students. This means that a student's mark can be highly influenced by the team that they happen to be in, rather than the effort that the students put in.

It is often reported that pass/fail courses are implemented to reduce stress for students (e.g. Bloodgood et al., 2009; Stanton and Siller, 2011;). While this was not the primary reason for the pass/fail approach, a reduction in stress would be advantageous for our students.

Course design and assessment

This course was designed to provide an introduction to many important concepts which will be built on further in later courses. Many students associate sustainability with environmental sustainability, however, in this course the importance of social, cultural and economic aspects is introduced. In an Aotearoa New Zealand context, the importance of Tikanga Māori (including culture, ethics and knowledge systems) is discussed in relation to sustainability. The key skills developed include finding information, evaluating information, written communication to different audiences, working in teams, basic project planning and communication in a meeting setting.

The learning outcomes for the course are:

1. Critically appraise information.
2. Use scientific information to communicate issues of sustainability to a range of audiences.
3. Discuss the impact of mātauranga Māori for advancing sustainability.
4. Work collaboratively to explore society- through to individual-level solutions to sustainability challenges.
5. Reflect on the concept of sustainability.

The student projects

For this course students are placed in 3-5 member teams. In 2020 each major was given a different consumer product to focus on. Food Technology students looked at a block of milk chocolate, Chemical and Bioprocess Engineering students looked at a takeaway cup of coffee and Mechatronics, Electronics & Computer Engineering and Engineering & Innovation Management students focused on a toaster. Each group took one component of the product and looked at its lifecycle. For example, the takeaway cup of coffee was split into the cup, milk and coffee beans.

Students conducted research to understand the lifecycle of their component and produced a process flow diagram. They then mapped relevant UN Sustainable Development Goals (SDGs) to their process flow diagram. This information was used to narrow down the scope of their work to areas where they thought there was the highest potential to have an impact on the sustainability of the product with respect to chosen SDGs.

Once their problem/opportunity was identified the students used idea generation methods to develop a list of potential solutions. Screening tools were introduced to allow the students to narrow these down and justify their decisions. Each member of the team then developed one

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idea further and evaluated the potential solution in terms of its technical feasibility, environmental sustainability, social and cultural aspects, and its economic viability (at a basic level). Students give a recommendation for whether the potential solution should be developed further in a written report. Finally, the students write a reflective report on the skills they have learnt and the skills they feel they need to work on in future courses.

A Stage-Gate® process is used to monitor progress and there are three Gate meetings where progress within the team was assessed. Material was delivered through online pre-workshop books, followed up by a lecture and two workshop tutorials providing activities related to the pre-workshop books and supervisory meetings.

Assessments

The learning outcomes of the course are assessed in several ways. A description of the assessments is given in Table 1.

Table 1: Description of assessments

Assessment	Description	Links to Learning Outcomes
Online quizzes	The content of the course is split into 5 units. At the end of each unit there is an online quiz which is then used to open the content of the next unit.	1, 3, 5
Assignment 1 – Evaluating information	Students select one source of information that they have used and write a brief summary of the source and then evaluate the information source using the CRAAP framework (currency, relevance, accuracy, authority, purpose).	1, 2
Assignment 2 – Blog	Students select one company out of a list of five. They write a blog (350-500 words) which explains the sustainability initiatives the company is implementing. They also discuss the links between sustainability and Mātauranga Māori.	1, 2, 3, 5
Assignment 3 – Technical report	The final report covers the development of their solution and an analysis of its feasibility. They also write a reflective report on what they have learnt and what they feel they need to work on in future project courses.	1, 2, 3, 4, 5
Gate meetings	There are three gate meetings which monitor the progress of the teams. A list of tasks needs to be completed before they can move onto the next stage of the project.	1, 2, 4

The gate meetings are assessed as a group, but all other assessments are individual. A rubric was developed for each of the written assignments. The rubric described each of the learning outcomes covered by the assessment. To pass the course all quizzes and Gate meetings needed to be passed and each of the learning outcomes needed to be achieved in the written assessments. If a learning outcome was not achieved, then it could be picked up in a subsequent assessment.

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Reflection on the first offering

The process of introducing the first pass/fail course into these programmes has been a steep learning curve for all involved. It is quite a different approach to assessment previously used, and it took a while for staff to understand the implications of this.

One of the challenges was to try to anticipate how students would respond to this approach without having any experience of pass/fail grading. The students are strongly motivated by grades and staff did see this as a challenge when designing the course. Based on informal feedback students seem to fall into two groups:

- Those who treated the course the same as a graded course and tried to do their best in all assessments. Some of these students however became frustrated when their effort was not rewarded by a higher grade.
- Those who determined the minimum that needed to be done to pass and did no more than was required. These students were very strategic in the way they approached the course and the assessments.

Those who were strategic realised that many of the learning outcomes were assessed multiple times and that they only needed to pass those learning outcomes once to pass the course. Assessments did have unique learning outcomes, but they could ignore the ones they had already passed. This opened the course up for 'game playing' where students could ignore the areas of the assessments where they had already passed the associated learning outcomes. Students who were strategic missed some important aspects of the course and could instead spend less time on the course and put their effort into their other courses where their grades could be improved.

During the first offering of this course the pass/fail grading system was interpretated by some to mean that they needed to achieve what is equivalent to 50% in a graded course. This may have contributed to some students looking for the minimum they needed to complete in order to pass. Going forward it will be very important to explain that this course measures competency and explain to the students our expectations. This clarification will be very important at the start of the course.

Staff felt as if there was a lack of motivation within the class. Many engineering and food technology students are driven by their grades and there can be a healthy level of competition within the class which motivates everyone to do well. However, in this course more work did not change their grades. Some students were frustrated by this and therefore prioritised their other courses where they would be rewarded by higher grades. It is recognised that for engineers lifelong learning is very important (International Engineering Alliance, 2013) but to truly engage in self-regulated learning there needs to be intrinsic motivation to learn. It has been recognised in some medical schools that a pass/fail system can reinforce the need to have intrinsic motivation as the external motivation of higher grades does not exist (Spring et al., 2011). It has also been reported that students taking pass/fail courses have more freedom and can lower their priority of getting good grades which means that they can prioritise other things in their lives (Stanton & Siller, 2012). In our case there is only one course which is pass/fail so the students prioritised their other graded courses.

Changes for the next offering

There are two key changes which are being implemented for the next offering. The first is to ensure that the students understand that the course is about demonstrating competency for a range of tasks. It is hoped that this will lead them away from thinking it is equivalent to getting 50% in another course and get them focused on achieving a certain standard which may be equivalent to a higher 'pass' mark in other courses. It is important for students to perceive that the bar is high (Stromme, 2019).

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The second key change is to modify how the written assignments are assessed. In the next offering each learning outcome will be broken down into a series of achievement criteria. In order to pass the assignment each of the achievement criteria will need to be achieved and these will be unique for each assessment. If one or more achievement criteria is not met, then the students can resubmit that component. This will avoid ‘game playing’ and ensure that strategic students still complete all aspects of the course.

This course would suit a competency-based learning approach as discussed by Johnstone & Soares (2014). Competency-based learning sets strict standards for what is required in order to demonstrate mastery and can be applied to both theory and knowledge gained in practical settings (Hendri et al., 2017). Johnstone and Soares (2014) give five key principles which are needed for this approach. These are reviewed in the sections below with notes on where improvements could be made.

1 Robust and valid competencies

Being a professional programme there are key skills and knowledge needed to achieve the graduate outcomes which are defined according to the Washington and Sydney Accords (International Engineering Alliance, 2013). While staff are aware of the graduate attributes and the importance of the skills being developed the students probably aren’t aware of this. Additional information needs to be presented to explain where this course fits within their programme of study.

2 Students able to learn at their own pace and with support

The majority of the content is available online for students to access in their own time. There are however limits to how quickly students can progress through this course due to the group nature of the project. The role of staff is to make sure that students are progressing at a reasonable rate and that struggling students are offered support. The quizzes are a useful monitoring tool for this purpose.

3 Effective learning resources available at any time

Some of the learning resources were developed with the help of a Learning Designer and the rest of the content was designed with similar principles in mind. All online material is available for students to access at any time. The content is split into units and at the end of each unit there is an online quiz to ensure that they have understood key concepts. There are in-person sessions each week where activities are used to reinforce the online material and these activities are related to their group project. There will be ongoing review of the learning resources to continually improve them.

4 Mapping of competencies to courses, learning outcome and assessments is explicit

This is one of the key areas where the course needed improvement. One of the key changes will be making the connection between learning outcomes and the assessments stronger. As already discussed, each written assessment will have a unique set of achievement criteria which are linked to the learning outcomes. This should clarify expectations and avoid ‘game playing’.

5 Assessments are secure and reliable

The assessments consist of online quizzes, written assessments and group Gate meetings. The students receive immediate feedback for their online quizzes. Written assessments are submitted online and are automatically submitted to Turnitin to check the originality of their work. The gate meetings are typically conducted in person although some were conducted online due to Covid-19 restrictions and feedback is given in the meeting immediately.

The use of a competency-based learning approach may be particularly useful in first year where students come from a diverse set of backgrounds and may be starting at different levels of knowledge as discussed by Henri et al., (2017). The way that the students need to master one unit of material and complete an online quiz before continuing to the next unit is already following this model. The Stage-Gate® process used for evaluating the progress of the team also requires a set of tasks to be completed before they move on to the next stage of the project. The only parts of the course that did not follow a competency-based learning approach were the written assessments, which can be adapted to this approach. The final aspect currently missing is the students being able to progress at their own pace. The group nature of the project restricts the degree to which this can be done. It could certainly be adapted to some extent in the written assessments.

Another challenge is how to increase the motivation of the students within the course. It is possible that some of the proposed changes will help with this, but the course would still lack the reward of receiving higher grades present in their other courses.

Conclusions

One of the most important things which we have learnt during the implementation of a pass/fail course is the importance of explaining that the course is measuring competencies. Some had thought that passing the course was equivalent to gaining 50% in a graded course, which probably contributed to low levels of motivation in the class.

On reflection the course is progressing towards a competency-based learning style, which would be particularly appropriate for a first-year course where students have a wide range of backgrounds. More explicit links between learning outcomes, achievement criteria and assessments will help to strengthen this.

The style of assessments suited the pass/fail system well. The use of gate meetings as group assessments were very effective and having the written components as individual assessments ensured that all students focussed on developing their written communication skills.

There are other challenges needing to be addressed and more research is required. How to maintain motivation within the course when more effort is not rewarded by higher grades requires more consideration.

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A Customized and Automated Assignment Management and Marking System for Evaluating Student Performance in the STEM Disciplines

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CONTEXT

A strong increase in student numbers for CIV3204, an introduction to statistics unit taught at Monash University within an undergraduate engineering course, has been accompanied by decreased performance in the final exam. Anecdotal evidence suggests that this is caused by cheating in the in-semester assignments. Based on evidence in the literature that individualized assignments result in reduced cheating, and that automated marking allows for the completion of more assignments by the students (leading to more practice and feedback), a system to generate and automatically mark individualized assignments has been developed. A closed-form solution does not exist for most questions, so existing methods such as Moodle quizzes could not be used. This paper provides an overview of the system and the very positive results of the implementation.

PURPOSE OR GOAL

The objective of this study is to improve the students' performance in the final exam for CIV320 and their learning in the unit. The hypothesis is that automatically marked individualized assignments lead to reduced cheating and the completion of more assignments, and consequently an improved performance in the final exam. A user-friendly system working through Moodle has been developed for this purpose.

APPROACH OR METHODOLOGY/METHODS

An individualized assignment was generated for each of the 11 topics in the unit, which was automatically marked. Detailed feedback was provided to the students afterwards. This level of assessment would have been impossible to achieve with manual marking. The performance of the cohort in the final exam and the Student Evaluation of Teaching and Units (SETU) are used to evaluate the system.

ACTUAL OR ANTICIPATED OUTCOMES

The system has led to very positive results. 66% of the students appreciated that the assignments were the most effective aspects of the unit. The unit received its highest overall satisfaction in eight years. The failure rate in the final exam decreased from 22% in 2019 to 11% in 2020, even though the final exam was more difficult.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The greatest surprise from the study was that the students were very positive about the large number of assignments, and the automated marking. The students suggested to improve the python-based Graphical User Interface system, which we will replace with a website. The system improved the students' learning through more practice and feedback, evidenced by their achievement in the exam. Based on the positive outcome, we suggest that automated marking should be further developed and implemented in the STEM disciplines.

KEYWORDS

Automated marking, individualized assessment, statistics

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Introduction

Marking of assignments and exams is a very labour-intensive and thus, costly, task (Vista et al., 2015) spurring decades of effort to develop automated marking systems, initially focusing on computer code. Fleming et al. (1988) compared the results of automated versus manual marking of Fortran-77 codes, concluding human markers placed undue emphasis on cosmetic (versus functional) aspects and Jackson (1996) showed that automation led to faster and more comprehensive marking. However, Cheang et al. (2003), who developed a system to automatically mark student C++ codes for a class of more than 700 students, argued that there were not only positive outcomes of accuracy and more focused assessment, but also complexity limitations and inadequate feedback.

More recently, generic code markers, like that of Blumenstein et al. (2008), and spreadsheet and database management evaluation systems of J. Kovacic and Green (2012) have been developed. Both Naude et al. (2010) and Vujosevic-Janicic et al. (2013) demonstrated high correlation between manual and automated marking using graph similarity. Partial marking of Structured Query Language codes was enabled by Chandra et al. (2015), while Kiraly et al. (2017) describe a system to automatically mark JAVA codes for Massive Open Online Courses (MOOCs). Further advances have been seen from Conejo et al. (2019), who developed an approach based on well-founded assessment theories (Classical Test Theory and Item Response Theory) and Janicic and Maric (2020) used regression verification. Ma et al. (2020) developed a machine-learning-based peer tutor recommender system, concluding that student learning improved with the automated system; mainly because students could complete more assignments in the available time. In their study of automated computer code marking, Aldriye et al. (2019) concluded that two issues persisted: the systems tend not to work on all operation systems and feedback quality was poor.

Automation of essay marking has also received significant attention. Reilly et al. (2014) compared two automatic systems to human markers for approximately 15,000 student submissions, concluding further improvements were still needed. Systems, such as that developed by Vista et al. (2015) can analyse an essay based on predefined rubrics and reduce workload by highlighting important content to the expert marker. Meanwhile, a comparison of automated and manual marking of open-ended writing assignments by Reilly et al. (2016) showed that the automated system disadvantaged non-native English speakers; evidencing human markers' tolerance for imperfect language and willingness to focus on content. Later, Zupanc and Bosnic (2017) developed improvements to such systems by incorporating additional semantic coherence and consistency attributes, demonstrating increased accuracy compared to nine existing systems.

Several attempts have made to automate the marking of assignments in the exact sciences. Stockburger (1999) developed a web-based system to automatically generate and mark homework for statistics units. A machine-learning based method to automatically mark open-ended questions in creative problem-solving was developed by Wang et al. (2008) and demonstrated high correlation with manual marks. Donnelly et al. (2015) developed a system to automatically provide tailored feedback to middle school students of thermodynamics, depending on the quality of the original essay and concluded that the guidance was more effective for students with lower prior subject knowledge. A system to automatically score students' graph construction learning was developed by Vitale et al. (2015). Barana and Marchisio (2016) strongly advocated to automate formative assessment in mathematics and science. For applications in chemistry, a web-based automated marking system is described in Munoz De La Pena et al. (2013) and a spreadsheet-based method was introduced by Carberry et al. (2019). Lee et al. (2019) developed a more advanced method of automating marking of open-ended questions and concluded that the system caused significant improvements to uncertainty-infused scientific argumentation from pre-test to post-test. A different approach was used by Zhu et al. (2020), who examined the effect of automated feedback on students' revision of scientific arguments. While all studies mentioned above

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focused on assignments in English, Cinar et al. (2020) developed a machine learning algorithm for grading open-ended physics questions in Turkish. Machine learning has also been used to automatically mark assignments in a number of different fields, including medicine (Gierl et al., 2014), computer programming (Blikstein et al., 2014), and physics (Zhang et al., 2020). Zhai et al. (2020) provide an overview of the application of machine learning in the assessment of scientific assignments, concluding that it can significantly improved the automaticity of examining and scoring complex constructs such as explanation, argumentation, scientific inquiry and problem-solving, and thus is promising for next generation science assessments.

At Monash University, the delivery of CIV3204 (Engineering Investigation), an introduction to statistics unit in an undergraduate engineering course, has faced a number of problems over the last few years. Along with nearly 3-fold growth in enrolments, we have witnessed an increased rate of academic infringements (cheating) in continuous assessment; logically leading to inferior understanding and subsequent poor summative results which is evidenced by the increase in failure rate seen during this period from approximately 10% to as high as 27%. This situation has forced the Unit Coordinator to drastically restructure the approach to continuous assessment to one which discourages cheating and ensures students invest time in the formative assessment tasks.

This paper focuses on the development and operation of an automated generation and marking system of individualized assignments for this unit and the lessons that have been learned in its first application. An overview of the results of the implementation of the system, including an evaluation by the students and an analysis of the impact on their final examination performance, is also provided.

Purpose or Goal

The objective of this study is to improve the students' performance in the final exam for CIV304 and their learning in the unit. The hypothesis is that individualisation of assessments will discourage cheating, while automatic marking will enable more immediate feedback on a greater number of assignments completed by students; consequentially, increased student engagement (practice) should improve final exam performance and knowledge acquisition. A user-friendly system working within the Moodle Learning Management System (LMS) has been developed for this purpose.

Approach or Methodology/Methods

The Workflow

The system was developed based on a number of prerequisites. These are:

1. Each student must work with individualized data.
2. The system must allow a range of question types, including questions of stochastic nature, which inherently include uncertainty in the answers.
3. The students must be able to submit their answers in a user-friendly manner.
4. The system must work through the e-learning system, more specifically Moodle.
5. The system must lead to challenging questions, and not provide direct information on how to solve the problems.
6. The system must work on all operating systems (more specifically Windows, Mac, and Linux).
7. The students must receive constructive feedback on their submissions.

The system has been coded in python, ensuring it can work on all platforms. The overall principle is that all information exchange from assessment generator to student and to marker is passed through Moodle. To begin, questions, random numbers, and input files are

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generated for each student. The input files contain the random numbers that make up the question being asked and any further data that students need to answer the question in the form of input files. If a question, for example one on probability, can be constructed using different random numbers contained in the pdf, students do not need a separate input file. On the other hand, students may be asked to calculate a sampling distribution of a specific data set; in which case they will need the input file.

It is important to note that the random number generator is a pseudo-random number generator, using a seed that is based on the student ID number. This has the advantage of the same random number set being obtained for each student every time questions are regenerated.

The system creates a directory (folder) for each student following the conventions of MOODLE. These directories can later be zipped into one file which can be uploaded on MOODLE. The uploaded files include, for each student, the pdf with the assignment questions, a Graphical User Interface, and the input file for each question (if this is necessary).

The students can then download their assignment files and enter the answers in the Graphical User Interface, which generates Excel files following a naming convention which includes the student ID number, for later traceability. Students then submit their spreadsheet files via Moodle, and markers download all student submissions at once. The marking script then marks all submissions and writes all feedback to a single file per student. Feedback files are then batch uploaded to Moodle for review by individual students.

Generating Questions

In order to generate a unique question, two Python subroutines must be modified. The first, “input maker” creates random numbers and data. These could be, for example when doing hypothesis testing, the sample sizes, the means and standard deviations of the samples, and the confidence level. The upper and lower limits for these random numbers need to be specified, as well as the distributions from which they are drawn. The second subroutine that needs to be modified is “tex maker”, which uses these random numbers to generate the question to be solved by the students (“tex” referring to LaTeX, the standard markup language used in scientific writing). The system then uses these subroutines to typeset a pdf of questions for the students.

The Graphical User Interface

The next step is setting up the Graphical User Interface (GUI) for the students. Two short python codes need to be modified for this purpose. The first is structureMaker.py, which generates a YAML file with the structure of the GUI. Essentially, this program can be set up by copying from example programs, and lists, for each row in the GUI, which variable needs to be entered, and how it should be entered (from a drop-down menu or by manually entering the number). The second is the program for the GUI itself. This program specifies the assignment and question number, the order in which the variables entered by the students must be saved, and can be developed by copying from example programs. Figure 1 shows an example of the resulting GUI for a question on hypothesis testing.

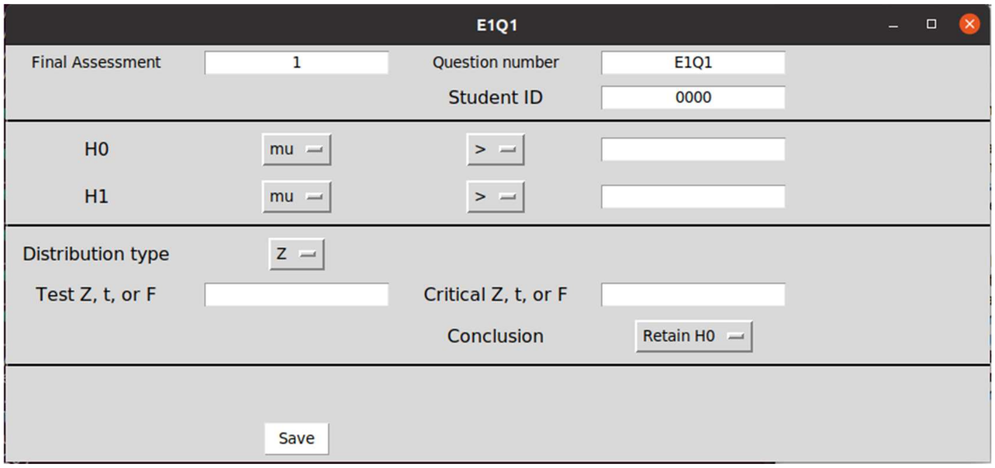

Figure 1 Example of a Graphical User Interface (GUI) for a question on hypothesis testing. This was used on the final examination, hence the question number E1Q1.

Marking Questions

This is the part of the system in which the user has the most freedom. Three subroutines must be modified here.

1. input loader: Here the inputs written in the csv file (for example, the random numbers described in Section II-B) are read in and stored in a vector (or matrix) "inputs".
2. result loader: Here the results from the students are read in, and entered in the vector or matrix "results".
3. marker: This subroutine uses the vectors or matrices "inputs" and "results", and generates a LaTeX string "feedbacks" and a number "mark". As the name suggests, "feedbacks" contains the feedback that is written to the feedback file for the student. "mark" contains the student's mark for this specific question. In this subroutine, the user needs to calculate the correct answers to the
4. question: compare the student's answers to the correct answers, and calculate the mark for the question and generate the feedback.

It should be noted that the system makes consequentially marking questions very easy. If an intermediate error when solving the question is made, the system can calculate the pseudo-correct answer, compare the student's response to this number, and assign a lower mark.

Types of Questions Enabled by the System

The most straightforward questions are those that require simple calculations. The marking software can compute the correct answer, compare the correct answer to the student's response, and mark the answer as correct or incorrect using a specified tolerance. These type of questions include hypothesis testing, analysis of variances (ANOVA), regressions, etc. Other straightforward questions are multiple choice questions, which can be developed using the dropdown menu option. A further benefit of the system is that it can also work with questions that are stochastic in nature and, thus, must support uncertainty in the answers. One such question is the calculation of a sampling distribution. In one instance, students were provided an individualized data set from which they had to calculate the sampling distribution of the mean, using a sample size of three, and 10,000 repetitions. They were then provided six different sampling distributions, of which one was correct.

Actual or Anticipated Outcomes

By operationalizing the system for the unit in the second semester of 2020, a number of

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lessons could be learned.

A first lesson was that the marking system needed to be made more robust with respect to the numbers entered by the students. Even though it was made very clear to the students to only enter numbers in the GUI cells, and no letters or special characters, in the beginning of the semester this request was consistently ignored. The marker crashed if a string was being read in while a number was expected. A short subroutine was then written that checked, for each cell where a number was expected, if a number was entered.

A second lesson what that students Students would often submit files which did not comply with set guidelines, leading the marking software no to recognize submissions, and consequently return a mark of zero. A short code was then written to list the missing files for each student. The zip files were then manually unzipped, and the file names with errors manually corrected.

Student Evaluation of the System

Table 1. The Student Evaluation of Teaching and Units (SETU)

Question	Responses (2019 / 2020)	Median (2019 / 2020)	% Strongly Agree or Agree (2019 / 2020)
University Wide Items (Summary)			
The Learning Outcomes for this unit were clear to me	112 / 67	3.72 / 4.01	59.82 / 79.10
The instructions for the assessment tasks were clear to me	111 / 67	3.51 / 4.03	50.45 / 76.12
The Feedback helped me achieve the Learning Outcomes for the unit	111 / 67	3.75 / 3.90	60.36 / 70.15
The Resources helped me achieve the Learning Outcomes for the unit	112 / 67	3.32 / 4.01	45.54 / 79.10
I attempted to engage in this unit to the best of my ability	111 / 67	3.74 / 4.22	61.26 / 86.57
Overall, I was satisfied with this unit	112 / 67	3.51 / 3.95	50.45 / 74.63
Faculty Wide Items (Summary)			
The assessment tasks helped me to develop the knowledge and skills required for this unit	112 / 67	3.76 / 4.10	59.82 / 82.81
I understood the grading criteria used in assessing my work	112 /67	3.73 / 3.89	59.82 / 68.66
This unit contained a good mix of theory and practical	112 / 67	3.68 / 3.89	58.04 / 68.66
The Moodle site was engaging and enhanced the learning experience	112 / 67	3.65 / 3.97	56.25 / 74.63
The lectures were valuable for my learning	112 / 67	3.53 / 4.02	50.89 / 74.63

Individualized assignments were generated for each of the 11 topics in the unit; they were automatically marked and detailed feedback was provided for each. This level of assessment would have been impossible to achieve with manual marking. The performance of the cohort in the final exam and the Student Evaluation of Teaching and Units (SETU) were used to evaluate the success of system.

The implementation of the system has led to very positive results for the unit. Table 1 shows an overview of the Student Evaluation of Teaching and Units (SETU) for the Clayton campus. Of the 350 students enrolled, 67 participated in the evaluation. The result for the overall satisfaction question is the highest for the eight years in which the responsible academic taught the unit. Important as well are the results of the qualitative analysis. The first question is “Which aspect(s) of this unit did you find most effective?” 42 Students answered this question, and 28 students stated they appreciated the nine relatively short assignments, and four students stated clearly that they appreciated that this forced them to keep on track with the unit.

The second question is: “Would you suggest any changes to enhance this unit in the future?”, which 44 students answered. Seven students replied that the setup of the GUI’s could be improved. These have now been replaced with html-based GUI’s, which are much more user-friendly.

Another advantage is that student complaints regarding unprepared tutors have disappeared. A week earlier than for the students, an individualized assignment was also generated for the tutors, which they also had to generate the answers for, and for which they also were marked. This forced the tutors to prepare themselves for the tutorials.

A final advantage of the system was that it led to a strongly improved performance of the students in the final exam, even though this was more difficult than in the previous years. For the students enrolled in CIV3204 in 2019, 107 out of the 475 did not pass the unit. In 2020, after the implementation of the system, 40 out of the 350 students enrolled in CIV3204 failed the unit. The failure rate thus decreased from 22% to 11%. One explanation, which is suggested by the answers to the SETU questions, is that the individualization of the assignments has forced the students to do them, and consequentially they were better prepared for the exam.

In response to the students' comments, an improvement to the GUI's has been made. These are now written in html, and the students can activate them by double-clicking, upon which the GUI's appear in the browser of their choice. This eliminates the need to install python and type in the command line interface.

Conclusions/Recommendations/Summary

The greatest surprise from the study was that the students were very positive about the large number of assignments and the automated marking. The students suggested to improve the python-based Graphical User Interface system, which we have now solved using html-based GUI's. The system improved the students' learning through more practice and feedback, evidenced by their achievement in the exam. Based on the positive outcome, we suggest that automated marking should be further developed and implemented in the STEM disciplines.

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‘Optimised Blackboard’; How first year students created their own pseudo-LMS

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ABSTRACT

CONTEXT

Learning Management Systems (LMS) provide a mechanism for academic teaching staff to interact with students and upload learning content. In 2020, a group of first-year undergraduate engineering students at an Australian regional university constructed ‘Optimised Blackboard’ – a student-managed psuedo-LMS hosted on the popular gaming chat app Discord. ‘Optimised Blackboard’ provided a forum for student discussion, as well as a refined and consistent library of essential course content. At its peak, Optimised Blackboard had nearly 500 first-year students enrolled.

PURPOSE OR GOAL

In this paper, we investigate and discuss the motivations of the developers of ‘Optimised Blackboard’ and reasons for the relative success of this tool. We were particularly interested in; how and why the site came to exist, how it was managed, concerns about academic integrity/assignment posting/copyright and why it was ultimately discontinued, what lessons from this could be learned to improve the ‘officially sanctioned’ LMS, if any, and the lasting legacy of this tool and subsequent uptake of Discord for teaching in first year courses at this University.

APPROACH OR METHODOLOGY/METHODS

In this work we will refer to qualitative interview and survey data from the developers and users of the site to address our research questions.

ACTUAL OR ANTICIPATED OUTCOMES

Meeting students ‘where they are’ and enabling autonomy over their own learning are important factors in engagement with a content-delivery platform. These, as well as the ease-of-use of the Discord-based solution compared to the ‘official’ LMS deployed by the institution, were motivators for the developers for Optimised Blackboard.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

‘Optimised Blackboard’ was discontinued due to perceived potential liability of the developers to its users posting copyright-infringing or plagiarised work. Given the relative success of this tool in engaging hundreds of voluntarily-enrolled students, there is substantial motivation to gain insight from these issues with the potential to support future student-run platforms and/or supplement the officially-sanctioned LMS.

REFERENCES (OPTIONAL)

KEYWORDS

LMS; Learning Management System; Student Autonomy

Introduction

This paper discusses the emergence and development of a student-led initiative to improve teacher-to-student and student-to-student communication within a first year engineering course (ENGG1500) at the University of Newcastle (UON) in 2020. This course was part of a suite of courses running vertically through the engineering degree programs, these courses were framed as based around the premise of ‘professional practice’ and were implemented as new courses in 2017. ENGG1500 is positioned as an introduction to professional engineering as well as to their undergraduate program.

As a direct result of the spread of Covid-19, UON directed all courses to migrate to online delivery to allow all students to complete their studies without attending the campus. For ENGG1500, this took effect in Week 4 of the semester, resulting in an immediate and controlled migration from face-to-face delivery to 100% online. This course had a large cohort (700+ students) which placed pressure on any potential online software options to ensure sufficient capacity and the ability for rapid implementation. The expected transition time for the course to migrate to 100% online was 2 weeks, in reality the transition occurred over 4 days, from Thursday to Monday.

The Course Coordinator (CC) had previously identified the need to improve channels of communication among students. It was their understanding that the existing UON LMS, Blackboard, had limited functionality with respect to interactive communication, leading them to consider options that sat outside of the official channels provided by the LMS. To involve and engage the students, the CC offered the students of the course the opportunity to propose ideas and concepts on how to improve the online communication methods within their own course.

Tutors of the course, proposed a prototype using Discord as a potential core platform. Discord is a proprietary, instant- messaging application frequently used by the online gaming community. The working prototype, developed by the students and tutors, established itself as the dominant communication channel for the remainder of the course. This raised prospects of intentionally supporting aspects of ‘connectivism’ as a learning framework within the course. As we expand below, the self-directing actions of the students suggested characteristics associated with synergogy and established themselves as the primary learning framework within the course.

The integration of this prototype offers a range of insights to the learning expectations of the students and the possibility of utilising similar platforms as effective pedagogical devices for engineering education

Responding to a changing learning environment

Significant pressure was placed on this course by UON as it was framed as the ‘flagship’ course within the professional practice stream. It represents the first course in the students first year of their engineering programs, so facilitating communication among the students was crucial. All students were new to the UON system and needed to be ‘on-boarded’ into the institution as well as this course.

The CC offered the tutors and students of the course the opportunity to propose ideas and concepts on how to respond to the shifting learning environment. Student feedback on existing UON online courses were experiencing a rising level of digital fatigue, where students expressed their concerns that their learning environment was drifting towards a ‘degree by Zoom’. This reinforced the need for ENGG1500 to now reach for higher levels of real-time interactivity and connection between students, lecturers and tutors.

The existing LMS used a ‘live’ platform called Collaborate, however the CC wanted to maintain their face-to-face teaching style into the online environment and their experiences

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with Collaborate lead them to seek alternatives. In particular, the CC was seeking technologies that were less prescriptive and encouraged the students to take the lead.

Course tutors proposed reviewing Discord as a potential (partial) solution. It was an established platform with more than 250 million registered users worldwide in 2020 and was capable of high speed messaging between large numbers of simultaneous users. It was also demonstrably running on a broad range of platforms including; Windows, macOS, Android, iOS and Linux. The task presented to the CC was to review the applicability of Discord and to determine if it would be suitable as a method of supporting the existing learning platforms.

ENGG1500 was a problem-based learning (PBL) course that used a high degree of flipped methods for learning. This new platform would need to support both PBL activities and the capacity for the students to manage their own learning.

Development of a working prototype

Microsoft Teams, Zoom and Slack offered a broad suite of functionality to promote inter-student communication. However, in the understanding of the authors, a Discord prototype was more strongly aligned with the demands of this course based on the openness of the architecture and the multiple levels of administrative controls.

Preference would be given to platforms with low latency issues, with respect to audio and video feeds from students. Discord at the time was running at 10 millisecond or less in delay times, which was ideal for voice/video. The course co-ordinator knew from previous experience that when latency exceeded 100 milliseconds student interactions became staggered and cumbersome.

Table 1 below is a summary of major performance differences between the standard UON platforms and the tutor's first working prototype.

Table 1: Function comparisons for 'working prototype'.

Functionality	Existing UON softwares	Working 'prototype'
Multi-modal communications (text, video, voice & graphics)	No	Yes
Student customisable communication 'channels'	No	Yes
Lecturer/tutor control over global chat volumes (for directing attention, updating information etc)	No	Yes
Posting student-generated & Internet sourced video	No	Yes
Sharing of individual student screen, camera	Yes	Yes
Perpetual student 'breakout' groups	No	Yes
Student ownership / modification of platform	No	Yes
Students-led movement between breakout groups	No	Yes
Live chat between breakout groups	No	Yes
Keeps percentage engagement / contribution of all students for Lecturer to review	No	Yes

Compounding the demands on the prototype were the needs for enabling multiple levels of users interacting within the course. These system users included; course coordinators, lecturers, tutors, workshop staff, markers, technical support staff, faculty administrators,

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student teams and the individual students. The testing phase of the Discord prototype, confirmed its capacity enable a broad range of administrative hierarchies and controls for organising communications across the course.

The working prototype was outlined by a team of three tutors over less than one working day. The 2020 version of Discord was more manually driven than subsequent releases which added to the time taken to develop the prototype. More recent releases include higher automation of repetitive administrative tasks, such as building 'templates' and swapping between different user views.

Discord uses the concept of 'servers' to manage its digital communities. These 'servers' are entirely digital and act as platforms for collating and organising interactions between users and can be set up as 'public' or by 'invitation only', depending on need. Within each server is the concept of 'channels', which act as administered platforms for sharing visual, verbal, video and text-based content. There were two types of Discord channels in 2020; text-channels which facilitated posting messages, uploading files and sharing images, and voice-channels which facilitated voice or video in real time, including screen sharing from any user.

To support the 'student-led' aspects of the prototype, the CC promoted the undergraduate engineering students to propose the initial setup of 'servers' and 'channels' used for the course. The intent of this new prototype was to retain the social networks of a face-to-face classroom as much as possible, including the capacity for inter-student and inter-group chat.

On a smaller course, this may not have taken on such importance, however ENGG1500 has particular demands due to its relative size and complexity. The course utilises 150 student teams from 13 different engineering disciplines. These groups are aligned to 10 different assessment projects running simultaneously. Each student project requires the development of physical prototype solutions by accessing 5 different workshops within the engineering precinct alone.

The initial student experience: 'on-boarding' to the new platform

Once the working prototype had been 'bench tested' for its functionality, the CC made the decision to go 'live' and the platform was made available to the students of ENGG1500 in Week 4 of the semester. The process of 'on-boarding' students into the digital community proved simple and stable. New and late-enrolling students were sent an electronic link to join the online community via their student email account. By selecting this one hyperlink they were effectively connected directly to the course community.

To assist with the on-boarding process an instructional 4 minute video, generated by the CC, was imbedded into the process. This video included explanations of the various channels, some of which were mandatory for engagement with the lecturers and course content. Other channels, relating to preferences for extra-curricular chat lines, were on a voluntary 'opt-in' basis.

The electronic invitation presented each student with a list of the relevant engineering disciplines and they were directed to select their own discipline from the list. This automatically connected them into the general communication channels for the course as well as the discipline-specific channels. At this point, students could also then nominate their preferred tutorial/assessment groups from the filtered lists presented to them. Once connected into the various course communities, students were able to further customise their account profiles using visual avatars and connection to any of the auxiliary channels of their choice.

Students with limited or no engagement with the prototype did not express any perceptions of being isolated, excluded or anticipated impacts on their learning outcomes. Formal broadcasts and course content were still conveyed on the official LMS and student focus

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groups and forums did not reveal any issues relating to negative impacts on the student experiences.

The staff experience: expanding levels of interaction

As the number of student participants expanded, a number of Discords functionalities revealed their importance to the course. The application facilitated lecturers and tutors to 'hover' over the top of all student groups or to 'drop in and out' of the different groups as required. Student allocation into tutorial discussion breakout groups were perpetual (MS Teams and Zoom are temporary) and the method of subsequently calling all groups back the central session was powerful and intuitive. Discord included the capacity for individuals or groups of students to electronically 'raise their hand' or click on the audio to speak directly to the lecturer / tutor. This capacity is not unique to Discord, however the speed and ease of use (essentially a 'single action') distinguished this application from available alternatives within the UON system.

For those students generating their own code, they were now able to post their 'code' in its correct format, enabling tutors to help them source errors and then for all students to watch the results being applied and tested in real-time.

Implementing the prototype brought with it the opportunity to reposition large portions of the course pedagogy. Discord lent itself to exploring the potential benefits of 'connectivism' across the first year engineering students. Connectivism is a relatively recent learning framework and is reliant on the levels of technology access and usage available in the digital age. Online forums are fundamental to supporting connectivism, as they introduced a range of technologies specifically aligned to compliment and reinforce inter-student learning. Students were encouraged to form their own knowledge and opinions based on their experiences with the course content, the online forums and constantly evolving discussions.

Because this course is a 'first university experience' for the majority of the cohort, the CC was not considering the potential influences of cybergogy in the learning framework. While cybergogy also has its foundations in digital and online communities, it reaches for higher levels of learner-centred autonomy than those that were appropriate for ENGG1500. So while the student engagement with technology was directly impacting their learning outcomes, the students would not have the complete control of their learning processes necessary for an authentic cybergogic approach.

Students personalising their course interfaces

Students feeling overwhelmed by the information volume were empowered to self-regulate their exposure by adjusting the channels feeding into their accounts. This was done by selecting/authorising essential feeds and de-selecting channels of information that were distracting or non-essential. Those students who were seeking higher levels of engagement and information exposure were able to set up 'advanced channels' to distinguish and participate in the auxiliary discussions.

It was the understanding of the CC, lecturers and tutors that the capacity for the students to self-regulate; their identity, their connectivity and their levels of exposure within this courses digital community, may provide a critical component to supporting future student experience. While some discussion forums were allowed to self-organise and expand, those course activities that required more curricular control were built around smaller, more closed forums to give the lecturers and tutors greater influence over the content and to guide the focus points across specific topics.

Discord includes the potential for individual users to purchase a 'boost' to increase their benefits within the software. These 'boosts', which were approximately $4.00 USD each, may take the form of higher capacity for uploads/downloads or increased upload/download speeds. These 'boosts' were applied at the 'server' level, regardless of which student had paid for them, so the increased benefits from the boost were shared by all students using that server. Students voluntarily paid to boost servers because they wanted to see the prototype succeed in their course. The percentage of course students who paid for boosts represented less than 2% of the cohort and offered the boosts as the user demands steadily increased

Prototype outcomes; the anticipated aspects

For many of the first-year students the actions of their online 'personality' is different to their actions in face-to-face forums. Students are often reluctant to put up their hand or interact in front of 25 other students in face to face environments, however they will happily do so in the live online discussions. This proved of particular relevance to international students and those who may be reluctant to interrupt the flow of lectures/ tutorials by asking questions as they arise. By facilitating the capacity for these students to ask questions without drawing attention to themselves or interrupting the lecture, the Discord platform effectively removed the often time-consuming process of attempting to address these questions after lectures / tutorials had finished.

The Discord-based prototype reduced the email traffic by an order of magnitude (previously more than 50 emails/day). Email was still the preferred exchange for official issues and information not related to teaching content. Discord was perceived by the students as being less 'official', more accessible and more strongly aligned with the intuitive and interactive forms of communication they were experiencing with social media platforms. Part of this perception may also have its foundation in the expectations of the dominant demographic of students in this course (in excess of 95% of the students were less than 26 years old).

Emails between lecturers and students historically exhibited peak traffic periods just prior to the due dates for student submissions. The Discord platform proved to be effective at mitigating these peaks by offering students the capacity to quickly get reassurance or guidance from course staff without needing to structure formal enquiries via email. Students were also supported in developing their capacity to identify solutions to their own questions by monitoring the outcomes of similar topic discussions occurring online.

Prototype outcomes; the emergent qualities

While the administrative time-sinks historically associated with this course were reduced, the number of student interactions increased dramatically. Students were now using the discussion platforms to replace the previous (and more ungainly) processes around using emails. Communication and course participation was now occurring within the same program and generated hundreds of questions from the students.

The online forums were remarkably self-policing as students collaborated to build a set of expected communal values and behaviours when participating in course discussions. As the prototype began to attract higher levels of engagement within the student body, it became evident to the CC that many of these etiquettes were being intuitively translated from social media platforms.

Discord included the ability to use emojiis as a form of communication. Less verbally communicative students were now empowered to use emojiis to acknowledge receipt of course information and to provide immediate feedback to the staff regarding the clarity and relevance of information. Simple 'thumbs up / down', 'like' and 'OK' symbols became empowering devices to promote inclusion and engagement. These emojiis quickly developed into a sophisticated and semiotically broad medium of bi-directional communication that allowed the course staff to quickly determine student uptake, response and engagement.

It was also observed by the course staff that students responding to each other's questions were respecting the course content, rather than containing student speculation. These often

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included ‘links’ to the relevant sections of course content to enable the individual asking the question to locate and comprehend the answer for themselves.

The ‘lifecycle’ of the working prototype

Just as this working prototype had its beginning in Week 4 (of 12) in the semester, it also had an end point – the end of the course. The original prototype was developed and maintained by the students until the completion of the course content. The initial concept had matured considerably across 8 weeks and acted as the launching pad for a series of sequel prototypes that were developed for use across multiple first year engineering courses in subsequent semesters.

Initial concerns were raised by students and staff relating to the potential for issues around liability for the developers, rises in plagiarism due to student sharing of draft submissions and of copyright infringement. To manage these concerns UON Student Academic Conduct Officers (SACO’s) were invited to review the role out of the prototype and to monitor for potential issues relating to student plagiarism. Course material that contained intellectual property for UON was distributed to students via the (password protected) LMS and students quickly acclimatised to using the prototype platform for sharing ‘safe’ content. The continued presence of course staff in online discussions acted to support the emerging environment of students using the platform for open discussion and collaboration, rather than confidential or official content.

5 of the 8 first year engineering courses at UON now use Discord platforms to support the student experience. The version that succeeded this first prototype was facetiously called ‘Optimised Blackboard (OB) by the students – in reference to the incumbent UON LMS. OB was a direct beneficiary of the student’s experiences with the ENGG1500 prototype and shifted away from the Zoom-based classroom replacement of their first prototype and towards ‘helpdesk’ oriented forums.

OB was owned by the students who acted as its administrators and moderators. The students were now confident in being responsible for providing structure for their own learning environment and were exploring using the same ‘tool’ (Discord), in a similar manner yet towards different goals. The students perceived so much value in the platform, they took on its development and maintenance themselves. OB now includes more than 500 channels responding to multiple levels of interest, intent and accessibility. It spans 30 subjects within UON involving in excess of 1200 students.

Data Collection

Anecdotally, student uptake on the prototype appeared to be broad and consistent, based on the frequency and number of interactions. Informal methods of collating data such as lecturer and tutor feedback supported the observation of high percentage student utilisation.

Empirical data relating to student engagement levels is problematic to gather in online courses. Within the UON Engineering programs, students were encouraged to contribute to the voluntary Student Feedback on Course (SFC) surveys held at the completion of each course. Results from SFC responses use a combination of quantitative and qualitative data to gauge the reception and engagement of students. The quantitative SFC data is filtered to determine overall course satisfaction, quality of learning experience and individual ratings. Individual ratings are for; assessments, learning criteria, student expectations, knowledge gained, resources available, course structure and student workload.

The qualitative responses (free comments) for this course were reviewed to gather any thematic data relating to the communication and support perceived by the students. This dataset is not exhaustive as it is a voluntary system and tends to be utilised by those students compelled to pass comment (either supportive or critical). While data-mining student posts may only evaluate behavioural engagement (ie interacting with the platform),

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cognitive engagement was assessed by the quality of student submissions and the nature of the questions being posted.

In Figure 1 below, the Quality of Learning Experience (QLE) for 2020 reveals a significant increase over the 2019 results. The CC attributes this directly to the use of Discord within the course. SFC comments contained no negatives from students relating to course satisfaction and supportive comments about the online prototype outnumbered neutral or negative by more than 5 to 1.

Figure 1: Student feedback demonstrating the impact of Discord from 2019 onwards

(Note; this graph is best viewed in colour for results comparison)

The majority of the evaluation of student uptake was informed by the daily/weekly live forums and discussion posts. More than 17,000 posts within Discord from students across the 8 weeks of the course strongly indicated positive student engagement with the platform. During the course, monitoring of student posts were predominantly used as a flag for identifying and addressing student issues, rather than qualitative reporting. It also provided supportive evidence when analysing student participation in group assessments, and an auxiliary method for determining and supporting student grades.

Observations and Directions

The authors recognise the use of Discord within higher education is not novel. However, they are not aware of its use within an engineering course designed for heavily flipped PBL in a face-to-face delivery mode. While many UON staff chose to go back to staff-driven broadcast of course content as a result of Covid-19 isolation, ENGG1500 used Discord to run a flipped course 100% online. Its relative successes are directly attributed to the students leading and developing their own communication platforms. Rather than pulling back to theoretical PBL projects, students were able to continue collaborating to build physical solutions by using the digital platform for sharing real-time testing and reflecting.

The learning framework around this working prototype was engineered to shift the students' knowledge-gain away from the individual expert passing on facts and experience, towards students building their own collectives to facilitate emergent learning. Lecturers and tutors could then highlight any patterns or relationships that arose, and their connections to existing engineering perspectives. Students were no longer recipients of pre-formed messages and were encouraged to become active participants in acquiring knowledge.

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Blackboard was still used for Assessment submissions from students as it had an established level of security for student submissions and acted as an archive that was within the UON IT system. However, the Discord platform also supported the student's preferences for sharing links to active documents, rather than sharing static copies of files. The student's perception of the course contributions as being as active and evolving, was reflected in their approaches to interactive problem solving and 'live' collaborations.

The CC (who had also administered this course in the preceding 3 years) estimated the administration workload saving (across all course staff) to be in excess of 80%. This was mainly attributed to the prototypes capacity for course staff to 'catch' the student issues at the moment of deviation, rather than after students had committed extended periods of time and effort. The prototype enabled the CC to step-in and make a 'one button' video/verbal call to the student/s or immediately generate FAQ style announcements for all students as a result of any issues that arose.

Conclusions

As a direct result of Covid-19 isolations, a functional communication prototype, based around Discord, was successfully integrated into a 'first year – first course' engineering program in the UON. The working prototype was initiated by the tutors and then developed and maintained by the students of the course. This platform facilitated this large cohort, PBL course to migrate quickly from face-to-face to 100% online while preserving its focus on flipped content delivery.

The high-speed, open architecture of Discord enabled the educators to maintain direct, real-time connection with more than 700 students as they collaborated to generate physical solutions to complex problems. The emergent digital community also acted to support the students learning of how to use these constantly expanding online communities for their own development.

This prototype was not framed as a replacement to the existing UON LMS, rather as an auxiliary platform for the students to explore higher levels of self-direction in their learning. While the platform was not embraced by all students, it established itself as the dominant LMS for the duration of the semester. Based on its relative successes with the initial prototype, the Discord-based platforms were expanded and revised to be used in most of the current first-year engineering courses.

Although this prototype generated an 80% drop in administrative workload, it also activated a massive number of lecturer to student interactions, which the course staff are still developing the protocols to manage. The real-time, immersive nature of the digital community generates a 'wall of interaction' between lectures, tutors and students. Expectations of both students and staff will need to be structured to allow deeper connectivity without unnecessary information fatigue and increased workloads.

The levels of self-organisation exhibited by the students, although lightly constrained by the architecture of the existing software application, revealed potential applications for connectivism as a pedagogical framework within this style of course. The exploration of a web-based, open platform for inter-student communication highlighted the need to further consider how engineering education may benefit from community-based, e-learning platforms.

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Exploring the effectiveness of a framework using e-Portfolio-type learning activities to develop teamwork skills in student engineers

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ABSTRACT

CONTEXT

Graduate engineers are expected to possess strong teamwork, communication and interpersonal skills in addition to their capabilities in the technical domain. e-Portfolios are integrated online learning, development and content delivery platforms that are becoming increasingly relevant for developing professional skills in engineering education. e-Portfolio activities, such as goal setting, peer feedback and reflection, have the capacity to facilitate continuous and ongoing development of such skills.

PURPOSE OR GOAL

This research aims to study how a framework using *e-Portfolio-type developmental activities* can help student engineers improve and understand the value of teamwork skills. The three main objectives of the study are: to understand how e-Portfolio type activities can help student engineers understand the value of developing teamwork skills; to investigate the effectiveness of these activities and to understand the implementation challenges.

APPROACH OR METHODOLOGY/METHODS

Based on an ethnographic framework, an exploratory mixed methods data collection was used, with 239 first-year engineering students forming the participant group of the study. They participated in a range of e-Portfolio-type teamwork development activities. The data, consisting of artefacts, peer evaluation reports and observations, was analysed using a framework methodology and thematic approach.

OUTCOMES

Initially the students stated the importance of teamwork skills in attaining good grades, but by the end of semester they placed a greater emphasis on using these skills for improving team relationships and personal growth. Most students stated that they improved their teamwork skills over the semester, a claim supported by the results of their Peer Feedback. However, students were not fully engaged in the class discussions relating to their teamwork skills development over the semester.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This study found that peer feedback exchange and reflective activities helped students to understand how they behaved in teams and the impact of their behaviour on their teammates and project outcome. Though e-Portfolio type activities improved students' teamwork skills, the teaching support staff required more guidance in teaching and assisting students through these activities and team development.

KEYWORDS

Teamwork skills, reflective practice, peer feedback exchange, e-portfolio

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1. Introduction

The disciplinary accreditation bodies and the industries that recruit our graduates expect engineering courses to produce high-calibre graduate engineers who are industry ready. Specifically, graduates are expected to possess strong teamwork, communication and interpersonal skills in addition to their capabilities in the technical domain; yet these skills are often reported as poorly developed among the graduates (Leydens, 2012). These skills cannot be assessed using traditional means, such as exams, and are difficult to implement within discrete, semester-long units, as they require continuous development throughout a degree (Heinrich et al., 2010). Over the past 20 years, e-Portfolios have emerged in engineering education due to intersecting developments in technology, pedagogical approaches and changing workplace requirements (Alam et al., 2015). As a digital platform that can be used to deliver assessments, store resources, showcase achievements, and to develop skills required for lifelong learning, e-Portfolios can successfully be used to integrate both personal development and content-specific requirements (Alam et al., 2015).

Studying how e-Portfolio *developmental activities* can be used to develop skills for teamwork effectiveness is, therefore, an emergent area of engineering education research that combines technology with theory. For the purposes of this paper, only e-Portfolio-*type* activities are studied in a framework which mimics the experience of using e-Portfolio for developmental purposes. The use of e-Portfolio software is outside the project scope.

2. Research Objectives

This paper examines the use of e-Portfolio-type activities in the development of students' teamwork skills through peer feedback, goal setting, and reflective practices in a first-year engineering unit. The problem statement is:

How can a framework using e-Portfolio-type developmental activities help first-year student engineers understand the value of, and improve their teamwork skills?

The research question identifies three gaps in the current research. Studies into e-Portfolio platforms tend to address administrative challenges of implementation, focusing on personal development holistically, rather than teamwork skills development specifically. Secondly, where e-Portfolios are implemented in a teamwork setting, the objectives are to test their technical suitability to deliver collaborative engineering assessments. Finally, though there is a significant body of engineering education research about methods to improve teamwork effectiveness, there is a lack of studies of frameworks using e-Portfolio developmental tools.

This research project had three main objectives:

1.To understand how e-Portfolio-type activities can help first-year student engineers understand the value of developing teamwork skills;

2.To investigate the effectiveness of e-Portfolio-type activities in developing student engineers' teamwork skills;

3.To identify and understand the challenges in implementing e-Portfolio-type activities to develop teamwork skills.

3. Literature Review

According to the Australian Council of Engineering Deans (ACED) Engineering Futures 2035 report, priorities for future engineering education programs include: an increased focus on non-technical attributes such as "EQ, resilience, creativity and interaction and engagement skills" (Burnett et al., 2019). Therefore, the Australian tertiary sector is aware of the need to integrate development of personal skills into the student curriculum (Heinrich et al., 2010).

3.1 Current e-Portfolio Implementation and Utilisation for Personal Development

The 'Australian e-Portfolio Project' (2008), commissioned by the Australian Learning and Teaching Council (ALTC), is the most comprehensive investigation into e-Portfolio integration in Australian universities to date. Results suggest that e-Portfolios are a valuable tool to aid students in developing their personal and professional identities over time; the main finding is, however, that while the tertiary sector is highly interested in e-Portfolios, integration of the platform in curriculum is shallow, inconsistent and lacks implementation on a faculty- and institution-wide basis (Hallam & Creagh, 2015). The main challenges related to e-Portfolio implementation have been identified to be of technological, administrative and educational nature (Fielder & Pick, 2014; Alam et al., 2015), suggesting that additional guidance is needed to assist students with their reflective practice, goal setting and finding value in completing these required tasks (Heinrich et al., 2010). Findings from literature indicate that e-Portfolios are not being effectively implemented as a development tool, and research examining its effectiveness is limited (Oakley et al., 2013; Roberts et al., 2016). Studies by Yang et al. (2015) and Ayala and Popescu (2018) suggest that students are unlikely to participate in activities that are ungraded, even if they provide a valuable learning experience. In contrast, although the pilot e-Portfolio study at Virginia Tech was ungraded and voluntary, most students felt that e-Portfolios assisted their learning and self-evaluation, and consequently exhibited interest in using the platform after the pilot had ended (Knott et al., 2004). However, the participant pool was biased towards students who were inclined to engage in e-Portfolio activities.

3.2 e-Portfolio Implementation in Teamwork Settings

A review of the literature indicates that research into effective use of e-Portfolios within an engineering team context is scarce, so further research opportunities are feasible. Abidin & Saleh (2011) conducted a study into testing the effectiveness of an e-Portfolio platform to deliver team assessments at a Malaysian University, examining the technical aspects of using an e-Portfolio platform and the ability of the platform to facilitate teamwork. The study, however, did not focus on whether e-Portfolio tools can develop teamwork skills per se, but whether students can work collaboratively on the platform. Only simple teamwork activities were assessed by Abidin & Saleh (2011), such as "recalling names of new members", and "participating in team discussions". Similarly, Willey & Gardner (2010) use the e-Portfolio platform 'SPARK' to deliver a group assessment in their study at Sydney University to examine how self- and peer- assessment activities within the assignment can promote student learning. The findings suggest that feedback activities added value to teamwork experience (Wiley & Gardner, 2010), however the results of the peer assessments were used to moderate project marks. Consequently, Willey & Gardner (2010) state that students perceived the feedback tasks as a way to 'deter free-riders', rather than as an opportunity to receive constructive feedback to aid in self-development. This may have diminished the effectiveness of such tasks to develop teamwork skills.

3.3 Teamwork in Engineering Education Research

Engineering education research into teamwork skills development focuses on understanding the skills required for effective teamwork, and not necessarily on developing the requisite skills in students, consequently there is a research gap regarding how e-Portfolio developmental activities can be used as a framework to effectively develop teamwork skills.

Vasquez et al. (2020), Michalaka & Golub (2016) and Boudreau & Anis (2020) have conducted studies into the importance of team formation. Vasquez et al. (2020) experiments with three different formation approaches – instructor-defined, self-selected and a mix of the two – with results suggesting that a combined approach improves team effectiveness. Boudreau & Anis (2020) argue that a structured approach to team formation is required because merely assigning group work is insufficient for developing collaborative skills. An issue which arises with optimising team dynamics to increase performance is that it decreases opportunities for students to learn how to be effective team members, nor does it actively train students to manage team-related challenges when they occur.

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Project-based learning (PBL) is accepted as an effective method of instilling teamwork skills in engineering students (Du et al., 2020; Gomez Puente et al., 2020; Mostafapour & Hurst, 2020). According to Gomez Puente et al. (2020), the following characteristics of PBL are conducive to developing teamwork skills: they require significant interaction between members, they are open-ended and ill-defined and require multidisciplinary and diverse technical skill sets. Students, however, commonly responded by dividing the workload and completing elements of the project individually, rather than engage in collaborative processes (Hurst et al., 2016; Lindard & Barkataki, 2011). Additionally, Hurst et al. (2016) contends PBL approaches are less effective if students have not been taught the necessary interpersonal skills – such as open communication and conflict resolution – required to navigate dysfunctional team dynamics. Consequently, models to teach and facilitate teamwork in students are required in engineering education. Zou & Ko (2012) implemented a three-year study in engineering students at a Hong Kong institution with the aim of developing teamwork skills by giving explicit instructions, formative feedback and practice opportunities. The study found that students learned to effectively address team conflicts via open and constructive communication and changed their initial understanding of teamwork as a division of labour (Zou & Ko, 2012).

4. Methodology and Framework

Based on an ethnographic design, this study seeks to explore the perceptions and understandings of a group of undergraduate students in relation to their teamwork skills development. The project involved multiple exploratory methods of data collection and a framework analysis approach to student responses to developmental tasks, in addition to the researcher's own observations (Parkinson et al., 2015). The research was conducted during the first semester of 2021 in a first-year undergraduate engineering course at an Australian university. The first-year common unit 'Engineering Design: cleaner, safer, smarter'' was selected because one of the unit's outcomes is to "work collaboratively and articulate practices that lead to successful teamwork in a multicultural context". The assessment schedule included the delivery of two major chemical and electrical engineering team projects using the PBL method.

A framework using e-Portfolio-type developmental tasks was implemented in the unit. The framework involved formative peer feedback exchange in weeks 4, 8 and 11 using the ITP Metrics Peer Feedback Tool (itpmetrics.com), where students rated each other from 1-5 for the following teamwork competencies: commitment, capabilities, knowledge, focus and standards; guided goal setting in the form of an Individual Action Plan (IAP); weekly reflective discussions in weeks 7-10 class tutorials; and a graded summative 400-word 'Teamwork Skills Development' Reflective Essay. The framework (Figure 1) was designed to complement the assignment submission dates and allows for students to continuously practice and develop their teamwork skills via a feedback loop (Figure 2).

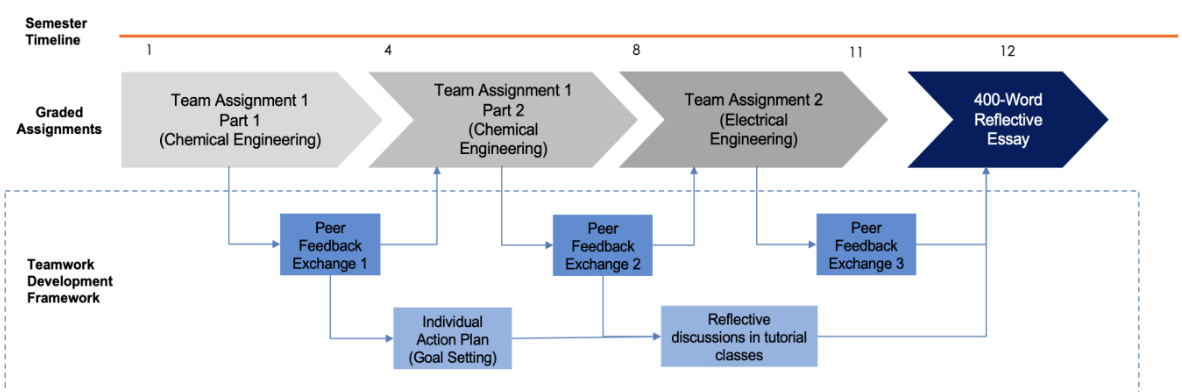

Figure 1: Diagrammatic representation of framework in relation to assignments

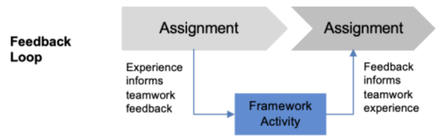

Figure 2: Framework feedback loop

The study was approved by the university's Human Research Ethics Committee under Project ID 28198, and students were required to give consent for their data to be used in this paper. All unit students (n = 641) were invited to participate in this study, with 239 consenting students forming the participant group. Student responses to the teamwork activities formed the data sources for the project. Responses to the ITP Metrics were accessed online. Students uploaded their IAP to a Google Drive after selecting a semester-long teamwork goal based on their week 4 ITP Metrics results. The main researcher attended class reflective discussions to observe tutorial dynamics and recorded the sessions for transcription. The Reflective Essays were submitted to the university's 'Moodle' portal. To analyse the data, a framework and thematic approach was used due to the volume of available qualitative data. Framework analysis (Parkinson et al., 2015) offers a rigorous and flexible approach to understanding a large volume of qualitative data and is suitable for analysing evaluative investigations. The thematic evaluation of the reflective essays for this paper was separate to the graded evaluation that contributed to students' final grades. The Reflective Essays were graded by teaching assistants and assessed students' reflection on their teamwork skills development and the challenges associated with goal setting and achievement. They were not used to assess the proposed e-Portfolio type activities or the unit coordinator role. In addition, the main researcher was not involved in either the design of the teamwork skills development framework implemented in the unit, or the delivery of such activities or marking.

5. Findings

5.1 Individual Action Plan (IAP) Findings

Seven themes emerged from a keyword analysis of the IAP responses, summarised in Table 1 and 2. 'Outcomes' and 'Teamwork Processes' were the most frequent themes used by students in discussing why their selected teamwork goal was important for their personal development and for their engineering career.

Table 1: Summary of keyword themes found in IAP responses

Themes – Theme Definition	**Keywords**
Outcomes – consequences of teamwork	Outcomes, grades, marks, standard, quality, performance, completing work, complete tasks, goals, achievement
Teamwork Processes – actions and processes involved in conducting teamwork	Communication, teamwork, collaboration, consensus, contribution, group projects, delegation, fairness, workload distribution, cooperation, leadership, dedication, sharing ideas, engagement
Time Management – actions and consequences related to timely task organisation	Procrastination, efficiency, organisation, deadlines, up to date, rushing, on track, get things done, time management, timely, delay, last minute, productiveness
Relationships – interpersonal aspects of teamwork and interactions between team members	Relationships, understanding, helping others, conflict management, encouragement, feedback, learning from another, trust, influence, support, care, valuing others, respect, openness, different backgrounds, social skills, morale, getting to know each other
Career – consequences, relevance and application of teamwork in professional setting	Career, employability, being a better employee, workplace, clients, money, cost, stakeholders, professionalism, workforce
Personal Growth – development of individual habits, mindset, and attitudes	Personal growth, improvement, learning, strengths and weaknesses, motivation, confidence, capability, effort, ITP metrics, pride, progress, striving, habits, accountability, progression, attitude

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Wellbeing – impact of teamwork experience on personal health and enjoyment	Stress, mental health, balance, leisure, extracurricular activities, hobbies

Table 2: Frequency of keyword themes and illustrative examples in IAP

Themes	Occurrence	Examples
Outcomes	145	*My whole life depends on grades, and it is the only way to prove myself* – Student E18.1
Teamwork Processes	123	*Team members should understand each other's capabilities, so they can divide the work up to work more efficiently* – Student Z14.3
Time Management	106	*Focus is required to reduce procrastination, ensure deadlines are met and that work is completed in an efficient manner* – Student C25.3
Relationships	94	*Forming good relationships with team member is important…with little focus, the team can quickly become dysfunctional* – Student C25.3
Career	83	*If I wish to work at the places which I deem desirable, obtaining and improving my personal and technical skills will make me the best engineer I can be* – Student D2.3
Personal Growth	82	*Student engineers should identify their strengths and weaknesses so that engineers can enhance and work on them* – Student Z14.3
Wellbeing	33	*I feel a lot of stress if work is done at the last minute* – Student A3.1

5.2 Teaching assistant (TA) Engagement

All TAs were instructed to provide feedback for the IAPs. However, only 4 out of 18 TAs provided feedback to their students, with only 61 out of 239 students receiving feedback for their IAPs. TAs were also tasked with leading reflective discussions in tutorial classes to facilitate student discussions about their teamwork skills development. Although TAs were provided with guidelines for a 30-minute session, discussion topics and lengths were inconsistent across discussions, impacting student engagement. Findings pertaining to the twelve observed tutorial sessions are summarised in Table 3.

Table 3: Engagement levels in teamwork skills development tutorial discussions

Engagement Level	Low	Medium	High
Class Discussion Length	2 – 5 minutes	6-9 minutes	10 + minutes
TA Behaviour	TA calls on students in quick succession without providing feedback.	TA engages with students by asking simple follow-up questions	TA asks multiple-follow up questions and gives targeted guidance
Student Behaviour	Students are unprepared for discussion and unwilling to volunteer. Students use generic examples.	Students are prepared for discussion and use specific and personal examples. Students do not engage in reflection.	Students actively volunteer, evidence of reflection, self-awareness, engages with feedback
No. Classes	6	3	3

5.3 Peer Feedback (ITP Metrics) Findings

The collective average of the participant group's ITP scores did not vary across weeks 4, 8 and 11 ITP Metrics results. The peer-rated ITP scores remained within a range of $\pm$ 0.04 for all competences: Communication: 4.44-4.47; Capabilities: 4.48-4.50; Commitment: 4.51-4.54; Standards: 4.43-4.45; Focus: 4.34-4.38. Students rated their teamwork competencies more accurately as the semester progressed, reducing the difference between their peer- and self-rated scores (Figure 3). 37% of students in week 11 gave themselves a rating that was equal to that given by their teammates, compared to 4% in week 4.

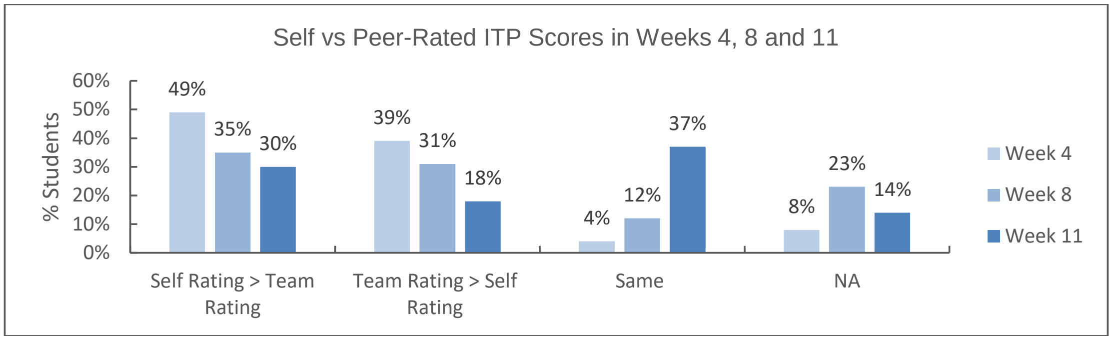

Figure 3: Comparison of self- and peer- ratings for weeks 4, 8 and 11, n = 239

Overall, students improved their goal competency score more than their overall teamwork score. Figure 4 shows the proportion of students whose overall ITP and individual goal competency scores increased, decreased, or stayed the same between weeks 4 and 11. Students who fell into the 'NA' category did not complete their survey, or specified a goal that was not one of the five competencies. A smaller proportion of students received a lower week 11 goal score (21%) compared to the proportion of students who received a lower overall score (41%).

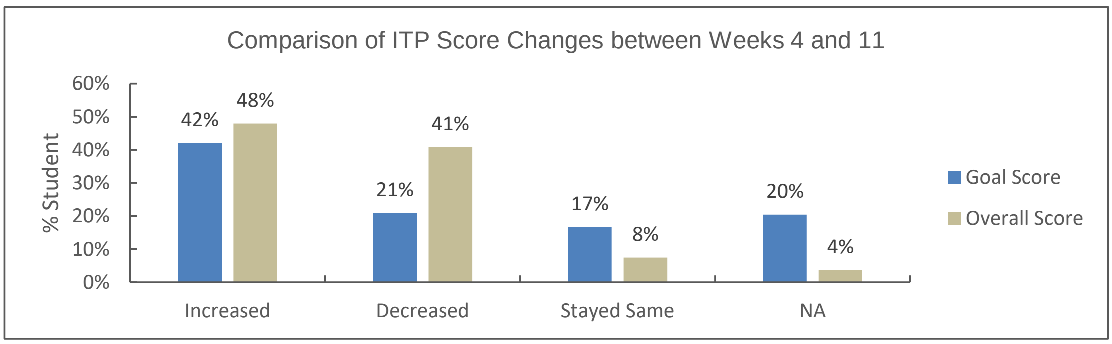

Figure 4: Goal and overall ITP score changes between weeks 4 and 11, n = 239

5.4 Reflective Assignment Findings

Similar to the IAP responses, keyword analysis of the Week 12 Reflective Essays yielded seven themes related to teamwork and skills development, summarised in Table 4.

Table 4: Frequency of keyword themes and illustrative examples in Reflective Essays

Themes	Occurrence	Examples
Personal Growth	345	*[The project] has allowed me to grow my teamwork skills and motivate myself without the need of external pressures* – Student A1.3
Relationships	280	*One of my goals was to establish and maintain a respective relationship between the team, being able to seek help from each other. I felt like I managed to achieve that…it felt like we were fostering our friendship* – Student Z14.3
Teamwork	180	*If I had actively engaged with group members and had clearer communication with them to express my commitment, I believe that may have improved the group dynamic* – Student B13.2
Time Management	150	*I perceive time management to be an invaluable skill not only for work at university but also in engineering and other workplaces as there will always be deadlines and time pressure* – Student B13.3
Outcomes	120	*I made it a goal to get try my best for my team as by only working towards my goal in a unit where teamwork is key was selfish- Student D12.1*

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Health and Wellbeing	95	*I was able to learn the importance of delegating work and trusting my teammates such that none of us was working towards stress burns outs* – Student Z8.2
Career	50	We *would get caught in the inequivalent distribution of the work required. By week 11, rather than being irked by the uneven workload, I started to embrace it – taking it as an experience to prepare myself for the rest of my engineering career* – Student Z8.2

A second level of framework analysis was undertaken, with a focus on understanding how students used the e-Portfolio-type developmental activities (ITP Metrics and IAP) to improve their teamwork skills over the semester, results are summarised in Table 5.

Table 5: Use of development tools and examples from Reflective Essays

Tool	Use	Examples
ITP Metrics	Bench-marking tool	*The feedback I received over the 3 ITP Metrics helped me to understand my strengths and the areas that I need to improve* – Student D4.2
	Feedback tool	*I paid attention to the written feedback in each review. My teammates were kind and helped to highlight my strengths. This helps me realise there are people who notice the things I do to help* – Student C21.2
	Catalyst for change	*Although I had set my goal, in the period from week 4 to week 8 I had not actively taken any action to work towards fulfilling it. This is evident from my week 8 ITP metrics report…however, this plateau acted as a much-needed reminder of my Individual Action Plan* – Student E3.2
	Teamwork attribute framework	*ITP Metrics highlighted areas in which I needed to improve team skills and provided a platform for in depth analysis and improvement of beneficial team skills and attributes*
	Catalyst for reflection	*It should also be noted that much of my self-ratings had been highly biased as I had given myself perfect ratings even when not deserved. Therefore, I intend to continually improve on peer feedback throughout the coming units and beyond* – Student B26.1
IAP	Goal Identification	*Setting goals enabled me to better my focus in not just this unit, but across all of my studies, which will moreover aid in the development of my career* - Student E21.1
	Future Actions	*It was insufficient to only set goals, the tracking of progress and the making of appropriate alteration was more important to achieve impactful effects. Goal setting presented the first step of self-awareness in my professional development as an engineer* – Student Z15.1

6. Discussion

6.1 Developing student understanding of the value of teamwork skills

Initially, students struggled to articulate why teamwork skills are important to their personal growth and their engineering career. Keyword analysis of IAP responses suggests that students value teamwork skills because it can improve grades. For example, Student E18.1 emphasises grades as the most important factor for success – "*my whole life depends on it, and it is the only way to prove myself*". In total, 'outcome'-related keywords appeared 145 times, which was more frequently than for any other keyword theme. Only a small proportion of student IAP responses explained why teamwork skills are important for building and managing relationships, personal growth, and career development. These responses framed the student's teamwork competency goal as an attribute they wished to improve because of its intrinsic value, and not only because it can improve their grades. For example, Student Z05.1 states that "*I hope to improve myself so I can do more, communicate with my peers better and assist them in areas they are confused about*". It is likely that students initially struggled with explaining why and how teamwork skills were important for their personal development as the participant pool consists of engineering students in the first semester of their degree, and, therefore, lack experience working in an engineering-related team. Students cannot speak to what they do not know. Indeed, Engineers Australia's attainment indicators for the teamwork competency are for students who have *completed* their degree (Engineers Australia, n.d.). At this starting point in their engineering education, the students are not expected to have developed a full awareness of the value of teamwork skills.

Thematic analysis of students' Reflective Essay responses – submitted *after* the students have gained experience working in engineering teams – indicate a shift away from an outcome-based understanding of teamwork and towards an experience-based understanding, with an emphasis on personal development and interpersonal experiences. In contrast to the IAP, the most prevalent keyword themes in the Reflective Essays are 'Personal Growth' and 'Relationships'. Students measured teamwork success based on whether they developed a good relationship with their team members and whether they enjoyed their experience, rather than with their project outcomes. This is evidenced by Student Z17.2, who states that "*the first step in effective communication is to see the other party as an individual rather than a pawn to further grades. I'm proud to say I consider my teammates my friends*". In addition, where students did discuss 'outcomes' in their reflective responses, the emphasis shifted away from personal success (i.e., "*my* grades") and towards the team's collective goal. An illustrative example is Student D12.1's reflection that "*only working towards my goal in a unit where teamwork is key was selfish*". A large proportion of students explicitly attribute their greater appreciation for the value of teamwork skills to the e-Portfolio-type developmental tasks (unprompted), which complimented their lived experience of working in teams. Based on the Reflective Essays, the ITP Metrics tool was instrumental in improving student understanding in three ways – as a framework to understand how specific teamwork competencies contribute towards teamwork, as a feedback tool to understand how behaviour impacted teammates, and as a catalyst for reflection (particularly when students' peer ratings differed significantly from expectations). In essence, the peer-feedback exchange helped students develop greater empathy. This is evidenced by Student C21.2, who stated that positive feedback from teammates "*helped me realise that there are people who notice the things I do to help the team…the feedback motivates me to keep up my good habits*". Conversely, Student Z14.3 realised that activities could negatively impact their teammates, stating that "*after our week 4 ITP feedback came, my team and I organised a meeting to discuss our grades. Through the meeting I discovered the problem lies within my very awkward work schedule.*"

6.2 Assessing the effectiveness of a framework using e-Portfolio-type tasks

In their Reflective Essays, most students evaluated their teamwork skills to have improved. Indeed, students were more successful in developing their goal teamwork skills compared to their overall teamwork skills. Students explicitly attributed their teamwork skills development to both the ITP Metrics tool and the IAP. Peer feedback exchange helped students improve their skills in two ways – as a benchmark for their progress over the course of the semester, and as a catalyst for improvement (particularly when students received poor feedback from their teammates). For example, Student D5.2 stated that their peer feedback results "*came as an initial shock, but the drop in score acted as a wake-up call to myself*". Similarly, Student E3.2 stated that "*although I had set my goal…I had not actively taken any action towards fulfilling it. This is evident from my week 8 ITP metrics report…However this plateau acted as a much-needed reminder of my Individual Action Plan*". For many students, the IAP worked in tandem with peer feedback exchange – the ITP Metrics was used to monitor and motivate progress, while the IAP aided with the practical development of teamwork skills. Students found goal setting to be an important 'first hurdle', with Student E21.1 stating that "*setting goals enabled me to better my focus in not just this unit, but across all of my studies*". This suggests that a framework using e-Portfolio-type developmental activities is effective in improving teamwork skills in student engineers.

In addition, students became more accurate at assessing the level of their teamwork competencies. Accurate self-assessment is an important step in the developmental process – it is likely that students who perceive their skills to be more advanced would be less motivated

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to develop them to a higher standard. This is evidenced by Student B26.1, who stated that "*my self-ratings had been highly biased as I had given myself perfect ratings even when not deserved. Therefore, I intend to continually improve on peer feedback throughout the coming units and beyond*". This suggests that ITP metrics (or other peer-feedback tools) can be effective in helping students to assess their strengths and weaknesses and illuminate personal 'blind spots'. This contrasts with Willey & Gardner's study (2010), where peer assessment is determined to be less effective for learning and developmental purposes, as most students predominantly used them to 'deter free-riders'. Significantly, the weeks 4 and 8 ITP results in this study were not used as a moderating tool, therefore shifting the focus of its use away from 'punishing' poor teammates to informing personal development. In addition, while the week 11 ITP results were used to moderate assignment grades, there was no evidence that students assessed their peers, or themselves, any differently. Indeed, many students who had received low peer-ratings in their week 11 ITP results commented in their Reflective Essays that it was a fair assessment based on their performance.

6.3 Challenges in implementing e-Portfolio-type developmental tasks

There were two challenges in implementing e-Portfolio-type tasks to develop teamwork skills. The first is the low rate and varying quality of TA engagement, specifically in providing feedback to students and directing tutorial discussions. The second challenge is the lack of ongoing student engagement with some of the developmental tasks.

Only four TAs out of eighteen left comments on their students' IAPs, resulting in 61 students (out of 239) receiving feedback. TAs who did not provide feedback may have not done so for a variety of reasons. They may have had a high marking workload (other unit assignments), may have been uncertain as to how best to provide feedback for these 'non-traditional' assessments, or saw little value in the tasks themselves. This is consistent with the findings of Mostafapour & Hurst (2020), whose interviews with instructors suggest that while they valued teamwork and project management skills, many were not confident in 'teaching' such skills. Varying levels of engagement are also reflected in the length of the guided reflective tutorial discussions – none of the twelve tutorial discussions reached the 20 minutes allocated for teamwork development, with four sessions lasting under five minutes. Although each class contained approximately twenty students, only two to three students in these tutorials had an opportunity to share. Furthermore, these four short discussions lacked a conversational back-and-forth, with TAs directing the conversation by merely moving from one group to the next ("ok, next team?") without providing any guidance. Additionally, the level of student engagement in tutorial discussions positively correlated with the TA's engagement, and discussions that showed genuine reflection occurred when TAs asked multiple follow-up questions and gave targeted guidance. This is consistent with the observation by Hurst et al. (2016) that students look to their lecturers and TAs as important sources of knowledge for their engineering development – therefore, TA attitude towards such activities is important.

Overall, the completion rate for the e-Portfolio-type developmental tasks was high (i.e., 87% of the cohort wrote an IAP, and nearly all completed their 3 ITP Metrics surveys). This compares favourably to studies by Roberts et al. (2016) – where completion rate was 20% – and Yang et al (2015). In previous studies, participation in e-Portfolio developmental activities was voluntary (e.g., in Roberts et al. (2016)) or graded and therefore mandatory (Ayala & Popescu (2018)). In this study, developmental tasks were delivered in a 'hybrid' manner, where student learnings from unassessed activities such as ITPs, IAPs and class discussions contributed to the summative graded 300-word reflective essay. Additionally, the graded reflective essay was only worth 4% – not a significant proportion of the student's overall unit mark. It is likely that a high number of students completed the tasks because they were integrated with the unit's two PBL-teamwork assessments and reinforced regularly in tutorial discussions. The high participation rate suggests that this project's 'hybrid' approach balances the need to develop teamwork skills in students and enforce participation by allocating marks for their effort, with the need to develop their intrinsic motivation so that students can then independently improve these skills. Active and ongoing student engagement, however, was an issue in this study, evidenced by the lack of responsiveness to TA feedback and in-class discussions. It was observed that students were also largely unprepared for reflective discussions. This is consistent with findings by Du et al. (2020) and Hirsch & McKenna (2008), which states that engineering students are generally unfamiliar with and unaccustomed to reflective practice.

7. Recommendations and Limitations

There are two practical recommendations that can be introduced to improve the effectiveness of teamwork developmental tasks for future cohorts. Firstly, TAs require greater professional development training to standardise the amount and type of feedback they are providing their students in the developmental tasks. Increasing TA engagement is not necessarily effective, however, if students themselves do not reciprocate or respond to suggestions and comments. As a result, it is recommended that students be instructed to treat their IAPs as a living document, so they can update it to reflect their progress over the semester. An additional reminder to guide students through the reflective process would enable students to feel prepared for class discussions and engage more constructively with their TA.

While this study drew upon a range of data to assess the effectiveness of e-Portfolio tasks in developing and understanding teamwork skills among engineering students, the study is limited as it lacks a first-person perspective about the experience of undertaking the tasks. Such data would give insight into participants' feelings and beliefs about teamwork skills, as well as an understanding of what they found effective and challenging about completing the developmental tasks. Currently, the study has inferred these insights from the results of the tasks themselves. It is recommended that future exploratory studies include semi-structured interviews or open-ended surveys to allow participants to share their experience and thoughts about the activities. Other limitations include – lack of a comparison group (i.e., a cohort of students who did not participate in e-Portfolio-type developmental tasks) to assess the extent to which e-Portfolio-type tasks aided in teamwork skills development, and an inherent bias in the analysis of the qualitative data (as the framework was largely constructed by a limited number of researchers).

8. Conclusion

This study examined the potential for e-Portfolio learning activities to be used in a framework to develop teamwork skills in student engineers. It found that peer feedback exchange and reflective activities helped students to understand how they behaved in teams and analyse the impacts on their teammates. As a result, students developed a greater appreciation for the importance of teamwork skills in fostering healthy working relationships and personal growth, compared to the initial perceptions that teamwork was important to achieve good grades. This study also found that while e-Portfolio type activities – such as peer feedback exchange, goal setting and reflective practice – improved the teamwork capabilities of students, TAs require more guidance to teach and develop teamwork skills in students in order to increase the effectiveness of e-Portfolio learning activities. The project's findings can be used to enhance content delivery for future cohorts and more broadly, be used to inform an integrated e-Portfolio framework to develop teamwork skills in engineering students over the length of their degree.

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A Framework for Game-based Learning on Sustainability for Construction and Engineering Students

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ABSTRACT

CONTEXT

The United Nations Agenda 2030 indicated that higher education institutions need to be at the front line of achieving sustainable development goals through knowledge transformation and innovative learning and teaching of next generation professionals. The increasing global push for sustainable construction means that decision-makers need to be more agile in responding to this demand. Unfortunately, students have been passive knowledge receptors in a traditionally deductive instructor-centred learning approach. Serious gaming can be an engaging tool to support effective sustainable construction education to enable active experimentation, exploration, competition, cooperation and realistic experience.

PURPOSE OR GOAL

This study aims to develop a preliminary framework for serious gaming on sustainable construction. The objectives of this paper are: (i) to develop a conceptual model highlighting the complexity of sustainable construction system; (ii) to identify the underpinning pedagogy principles of the game and discuss how the game can improve students' understanding of sustainable construction; (iii) to describe the key design components, including gameplay, game mechanisms, and students' performance evaluation system.

APPROACH OR METHODOLOGY/METHODS

The literature review was conducted to retrieve key decision and performance variables related to sustainable construction. A system thinking approach was employed to develop the conceptual model based on the identified variables. The literature review also extended to the serious game framework development to identify and compare pedagogy principles and game design elements suitable for sustainable construction problems.

ACTUAL OR ANTICIPATED OUTCOMES

The overall findings indicated that: (i) sustainable construction is a complex system where decision-making activities involve conflicting objectives between different actors in the supply chain; (ii) a card game concept will be utilised where players can take different roles and objectives; (iii) cyclical design will be used in the game where participants make choices, take actions, get the results, reflect on the results and proceed to take another action; and (iv) students' understanding will be measured through in-game quizzes.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Using the systems thinking approach, this study provided a holistic insight into the serious game framework for sustainable construction education by revealing the system's complexity, pedagogy principles, game design elements and the students' evaluation system. The framework is a precursor for the game development process to plan and design a serious game that effectively conveys the learning objectives.

KEYWORDS

Serious games, Sustainable construction, Experiential learning, Game-based learning, system thinking

Introduction

The United Nations (UN) Agenda 2030 indicated that higher education institutions need to be at the front line of achieving sustainable development goals (SDGs) through knowledge transformation and innovative learning and teaching of next generation decision-makers (United Nations, 2015). The increasing global push for implementing sustainable construction such as energy and water efficiency, responsible material uses and management throughout the building life-cycle means that decision-makers need to be more agile in responding to this demand. From a higher education perspective, students have frequently been passive knowledge receptors in a traditionally deductive instructor-centred learning approach (El-adaway et al., 2015). An engaging educational tool should be incorporated into the higher education curriculum to engage students in an experiential learning environment; thus, increasing their collaboration and decision-making skills.

Serious games have been popularly used in an education setting to increase student interaction, collaboration, and engagement (Vogel et al., 2006). They support experiential learning by providing students with a virtual replica of an existing system and enabling active experimentation, exploration, competition, cooperation and concrete experience (Sadowski et al., 2013; Whalen et al., 2018), which is usually not addressed in a traditional teaching approach. A serious game in higher education challenges students with a complex problem that allows multiple solutions and requires intelligent reasoning, problem-solving strategies, and interaction with fellow learners. According to Westera et al. (2008), higher education students should be confronted with problems that require multiple solutions and the application of certain methods, tools and collaboration. Despite the rapid development of gaming industries in the last few decades, the use of games for education remains limited.

Several serious games have been built for sustainable construction problems. Dib and Adamo-Villani (2014) created a serious game that allows students to take a role as designers, constructors and building owners to improve their buildings' environmental and economic performance such as water and energy efficiency, waste reduction and low emission transportation. Juan and Chao (2015) developed a board game that allows students to implement various strategic actions to develop an ecologically sound city. However, these games lack consideration into systems thinking given that sustainable construction systems consist of conflicting objectives between stakeholders and feedback mechanisms. Another gap that needs to be addressed in the serious game literature is the need to establish indicators or a system to measure students' learning performance.

Integrating systems thinking into game design framework development is imperative to capture system complexity and dynamics into the pedagogy (Madani et al., 2017). In this paper, a preliminary design framework for a sustainable construction serious game was proposed by integrating systems thinking approach. A literature review was conducted first to retrieve variables related to project management practices in sustainable construction. The variables were used in a causal loop diagram (CLD) to describe the complexity and dynamics of the system. Then, the proposed serious game's pedagogical principles and design elements were identified and discussed based on the framework by Annetta (2010).

Methodology

Firstly, a conceptual model needs to be developed to gain a systemic understanding of sustainable construction. This will help to inform the game development process, especially in creating game mechanisms and learning objectives. Secondly, the game design framework was built to describe the pedagogy principles and design elements that will be utilised during the game development process.

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Model conceptualisation

This research capitalised on the systems thinking approach to create a causal loop diagram (CLD) for describing the structure and dynamics of the sustainable construction system. Systems thinking helps to create dynamics hypotheses to understand better the multi-faceted consequences of a decision and the trade-offs between different strategies (Sahin et al., 2020). This approach is well-suited for this system since sustainable construction is underpinned by conflicting objectives and decisions between different actors in the supply chain (Solaimani & Sedighi, 2020). There were two steps to create the conceptual model: 1) problem scoping and 2) causal loop diagram development.

Problem scoping

The problem scoping stage aims to clarify the purpose of the model by selecting the boundary of a problem (Sterman, 2000). The preliminary problem scoping was conducted through the literature review. Firstly, this study reviewed and summarised the key drivers and barriers to sustainable construction. Secondly, the authors discussed and selected the variables which suit to be integrated into the system model following the *Sustainable Construction (1605ENG)* course profile at Griffith University. Model boundary and selected variables will still need to be confirmed and validated with experts to ensure they are relevant and up to date.

Causal loop diagram development

After model boundary and key system variables had been established, a preliminary CLD was developed. CLD is the most common systems thinking tool to map and visualise a collection of relationships forming a complex system (Sahin et al., 2020; Sterman, 2000; Suprun et al., 2018). The advantage of employing a CLD is its ability to challenge entrenched mental models and test assumptions which enable a counterintuitive understanding of system structure and behaviour (Hovmand, 2014).

A CLD consists of causal relationships between different variables and the underpinning feedback loops. A pair of variables is connected using an arrow with an assigned positive (+) or negative (–) polarity. The positive relationship indicates that the cause-and-effect variable is moving in the same direction (i.e. when the cause variable increases, the effect variable will increase too), whereas the negative relationship indicates otherwise (i.e. when the cause variable increases, the effect variable will decrease). The double lines across the arrow indicate information delay. Feedback loops also exist within a CLD, which can be reinforcing (R) or balancing (B). A reinforcing loop accelerates growth in the system, whereas a balancing loop counteracts change to produce stabilising system behaviour.

Creating the game design framework

Fotiadis and Sigala (2015) suggested that pedagogy principles, design elements, information provision and students' evaluation system are the critical aspects in developing a serious game that can effectively convey the learning objectives. To identify these aspects, this research followed the framework for serious game design by Annetta (2010). The study suggested six elements to be considered in serious game development in order of magnitude: identity, immersion, interactivity, increasing complexity, informed teaching, and instructional (Figure 1).

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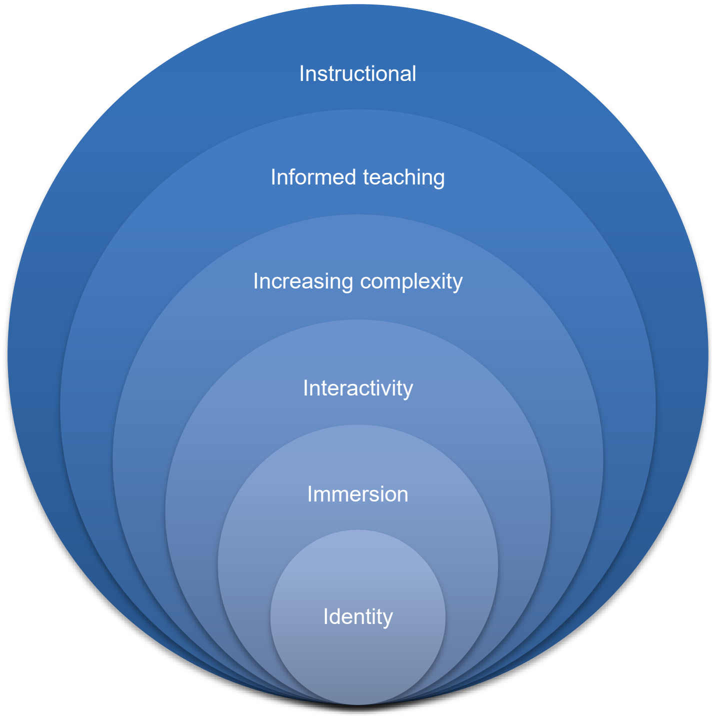

Figure 1: Elements in serious game design (Annetta, 2010)

Identity refers to representing a player in the game such as an avatar to convey their identity, presence, location and activities to other players. The provision of identity in a serious game will induce immersive gameplay. An immersive game means that players feel their presence in the game and are engaged in the content; consequently, motivated intrinsically to succeed in the challenge presented. A well developed serious game must also increase its complexity such as increasing difficulty level as the player progresses. Informed teaching means that player data related to decisions and results should be obtained to capture students' experience and understanding of the subject. Instructional refers to the provision of information or recommendation systems that will guide players through the game. Considering the elements mentioned above, this research reviewed different game elements and designs and selected the suitable elements to be applied in a sustainable construction context.

A Systemic View on Sustainable Construction

To design a serious game with effective pedagogy elements, a systemic view needs to be considered as the underpinning game decision support system design (Madani et al., 2017). When examining a problem, feedback mechanisms and the interrelationship between different subsystems need to be drawn. Systems thinking is one of the important professional skills in addressing sustainable development issues; therefore, students can improve their ability to deal with complex systems through serious games (Miguel et al., 2020). Integrating systems thinking into the game decision support system will enable students to learn this skill implicitly through the reflective process during the game session.

Figure 2 visualised the sustainable construction system complexity through a CLD. The sustainable construction concept attempts to integrate environmental, social and economic aspects into construction business practices and management. It adheres to the principles of sustainable development from the extraction of raw materials, through the planning, design and construction of buildings and infrastructure, until their final deconstruction and waste management (El-adaway et al., 2015).

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The economic dimension involves the initial cost of construction and building life-cycle costs. The initial cost is affected by transportation use, material consumption, construction time and the use of renewable energy. To achieve a low building life-cycle cost, the constructed building must minimise its energy and water consumption (Sev, 2009). This can be achieved by promoting a better indoor environmental quality, using renewable energy, and using eco-friendly fixtures (e.g. water efficient water tap, low flow toilets, recycled water system, rainwater tanks, and automatic sensors for lightings).

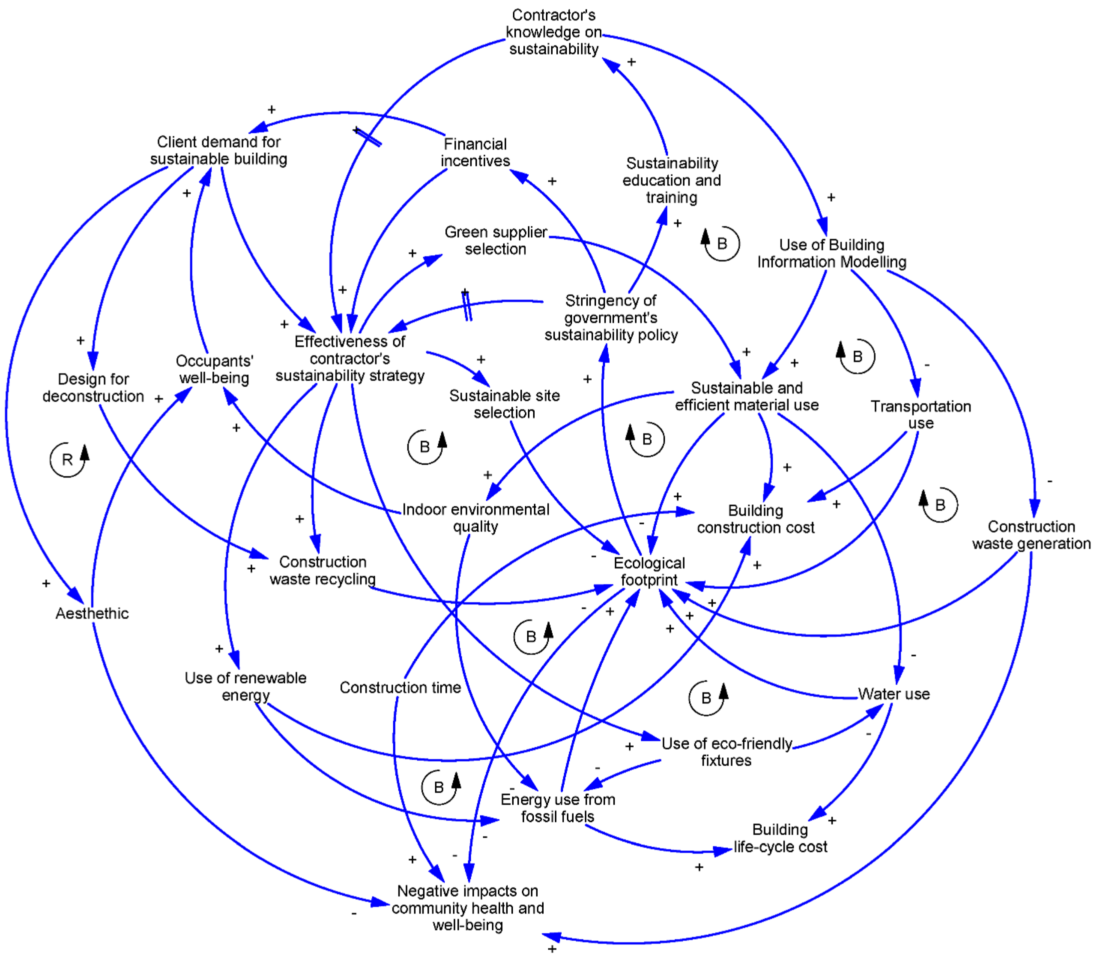

Figure 2: Preliminary causal loop diagram for sustainable construction system

The environmental dimension involves the ecological footprint derived from energy and water use, material use, land use, waste generation, and transportation. Construction managers must work together with other stakeholders to minimise consumption and on-going maintenance of the building. It was suggested that reducing the ecological footprints of a building will have economic benefits from initial cost reduction and on-going maintenance costs (Ries et al., 2006). An example is using materials that can promote better indoor environmental quality, thus reducing energy use from fossil fuels.

The social aspects cover community health and well-being and occupants' well-being. The literature has strongly suggested that indoor environmental quality strongly links occupants' well-being (Al horr et al., 2016). Studies highlight sick building syndrome, thermal comfort, acoustic comfort and visual comfort as the most critical issues surrounding the building's indoor environment. Furthermore, construction should minimise its adverse impacts on community health and well-being by minimising construction waste generation, construction time and delivering an excellent aesthetic (van Kamp et al., 2003).

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Several interventions representing actions from different stakeholders were also outlined in the CLD based on the variables identified from the literature review. For example, the government can action different incentives such as green bonds, standardisation and sustainability policy for buildings (Häkkinen & Belloni, 2011; MacAskill et al., 2020). Construction industries can employ Building Information Modelling (BIM), sustainability education and training, and green supplier selection to support their sustainability strategy (Mills & Glass, 2009). Architects can improve the aesthetic and indoor environmental quality and create a building designed for deconstruction to avoid large waste generation during decommissioning phase (Murtagh et al., 2016). Surveyors can work closely with construction professionals to perform life-cycle assessment and sustainable site selection to minimise the ecological impacts (Sfakianaki, 2019).

Design Framework for the Serious Game

Pedagogy principles

Construction managers are required to handle critical problems such as material planning and calculation, determine construction methods, communicate with other parties (e.g. architects, clients and suppliers) and oversee the construction process to deliver sustainable construction projects effectively (Mills & Glass, 2009). The educational implication of this game is to expose construction and engineering students to the project management decision options throughout the construction life-cycle available to different actors in the sustainable construction supply chain and how the decisions will impact construction sustainability. Furthermore, by integrating the systems thinking approach, students will learn about the feedback mechanisms (i.e. how their decisions will affect other variables and the decisions of other actors in the value chain) in the system. The combination of Kolb's experiential learning theory and collaborative learning theory will form an engaging and immersive education tool that improves students' understanding through active experimentation, collaboration and negotiation.

The sustainable construction serious game will be based on the cyclical design, where players can make choices, take action, retrieve the results, reflect on their action, and based on their outcomes proceed to take further actions (Fotiadis & Sigala, 2015). A cyclical design follows experiential learning (Kolb, 1984), where it bridges students' understanding from active experimentation to abstract conceptualisation. The game will be designed to allow students to learn and reflect on the positive and negative outcomes resulting from their decision experimentation (Ypsilanti et al., 2014). It is based on a continual improvement principle where students will pick different decisions each round, review the sustainability condition and make another decision in the subsequent round.

Collaborative learning theory involves a group of learners working together to solve a problem or complete a task (Laal & Ghodsi, 2012). In this game, students will take different roles with different goals and balance the sustainability indicators within the construction system. Students will bring and improve their negotiation skills and implement effective solutions to achieve their goals through discussions with their peers. This design also allows students to better understand their roles and tasks within the sustainable construction system.

Design elements

Game interface and mechanism

Before playing the game, players will have to input their username and select a role they intend to take (e.g. construction managers, architects, civil engineers or surveyors). When the game starts, players in the same lobby will be presented with a sustainable construction challenge. A clear goal should exist in the game for an immersive experience and effective knowledge acquisition of players (Poplin, 2012). The challenge will be randomised representing different building types, designs and sustainability requirements.

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Each player can pick different decisions representing the roles and project management options applicable to different stakeholders in the supply chains. Players can negotiate with each other to select their decisions throughout the game session. Each decision will have different impacts on the completion time of the building and its sustainability performance and each player must understand the trade-off between building performance, economic, environment and social objectives. The building must be completed within the given timeframe; otherwise, all players in the group will be penalised. A time compelling game is important in a sustainable construction problem as timely delivery is one of the main factors determining client satisfaction (Yang & Peng, 2008).

Game information system

An information system (i.e. recommendation system, tutorial and e-learning materials) will be in place to guide players in understanding the problems and goals and making decisions. Firstly, the game will have a recommendation system to guide students in making the right decisions. Player data will be collected in real-time in order to derive a recommendation for the players. For example, if there is a large gap between the sustainability goal and the current game status, the game will recommend specific players to pick certain decisions to improve their future performance (Annetta, 2010).

Secondly, students will be able to access e-learning materials related to sustainable construction and the underpinning systems model used in the game (Fotiadis & Sigala, 2015). These materials will be in the form of books, articles and videos. This will provide students with in-depth knowledge on how systems thinking works and how it applies to sustainable construction problems. Thirdly, a tutorial on how to play the game will also be provided within the game.

Students' performance evaluation system

To evaluate the effectiveness of the game, a mixed method approach by Mayer et al. (2014) will be employed such as interviews, focus group, and surveys during the game test session. This game test session will be held with sustainable construction students at Griffith University after the game's first release. This approach allows direct interactions with students to capture user experience and gain their feedback and inputs of how effective the game mechanics are in conveying the learning objectives and curriculum and improving their learning outcomes (Harteveld, 2012).

Randomised quizzes will be placed at the start and end of the game to measure changes in students' understanding of the roles and tasks performed by their respective roles in the game. It is the most common approach in learning and teaching system in measuring higher education students' performance (Cook & Babon, 2017). According to Cook and Babon (2017), online quizzes were proven to incentivise student completion and time efficiency. A quiz is also a good instrument to determine if the serious game effectively conveys students' knowledge acquisition and problem-solving ability (Riemer & Schrader, 2015). The quizzes will focus on evaluating students' understanding and knowledge of each stakeholder's actions and reflecting on the long-term implications of their decisions.

Conclusions and Future Directions

This paper is the first step of developing a serious game for sustainable construction to develop its design framework. Firstly, a causal loop diagram focusing on the interlinkages between sustainability aspects (i.e. environment, economic and social aspects) of construction and different interventions was developed using the systems thinking approach. In addition, key variables were identified through the literature review. Secondly, the game will integrate experiential and collaborative learning to facilitate active experimentation and collaborative actions to solve a specific sustainable construction problem. Thirdly, design elements such as interface, information system and students' performance evaluation system have been

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established following the framework by Annetta (2010) to enable an immersive, interactive game, possess good complexity, informative and instructional.

The limitation of this study is the use of literature review as a primary means to create the conceptual model and design framework. Future research should utilise an expert consultation approach to validate the systems model and confirm the pedagogical principles and design elements suitable for the sustainable construction course. A preliminary concept of integrating the systems model, pedagogical principles, and user interface should also be developed to better understand how the game is developed and convey the key learning objectives.

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Robot Simulation for Teaching Engineering Concepts

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ABSTRACT

CONTEXT

Teaching Robotics to Engineering students is at the same time exciting as well as a challenge. Students come from different areas of Engineering (Mechanical, Electrical or Software) and have therefore different previous knowledge. Also, visual geometric understanding and making the link between a line of software and the movement of a robotic vehicle are key elements.

While we are using real mobile robots for the student labs, the lab time is quite limited, so students can only prepare "in theory" at home. Also, real robots have real problems, such as battery problems, connection problems, sensor and actuator problems, and so on. These will reduce the available lab time and therefore diminish the actual learning outcome.

PURPOSE OR GOAL

We designed and implemented the EyeSim simulator for our EyeBot mobile robots. This simulation system is source code compatible, so robot programs on the simulator will run on the real robots without having to change a single line of code. The simulation system is free and allows students to implement the complete lab solution at home – without having to cope with any of the potential problems mentioned above.

APPROACH OR METHODOLOGY/METHODS

We conducted anonymous online surveys of students using the simulation system for the UWA units in Embedded Systems and in Robotics.

ACTUAL OR ANTICIPATED OUTCOMES

The vast majority of students reported that the simulation system was easy to use and that it benefited their understanding of robotics principles. They highly rated the ability to prepare, test and debug their software solutions on the simulator before they run it on the real robots.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The use of simulation systems is seen as very beneficial for teaching robotics concepts. Students can practically prepare algorithms for labs and do not have to rely on theoretical approaches. Since the simulated robots do not suffer from battery, sensor or other failures, more time can be dedicated to robotics concepts and a higher level of complexity can be achieved.

KEYWORDS

Robot simulation, engineering concepts

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Problem and motivation

Robotics is, at its core, a sub-discipline of Engineering that focuses on combining software and hardware to affect physical change in the world around us. With a diverse range of applications and new opportunities to explore, this burgeoning field is attractive to students who wish to learn and shape the technology of the future.

Vitko et al. (2010) argue that due to the complexity of the subject and its dependency on a variety of existing technologies it is difficult to teach robotics concepts through theory alone. Students must engage with robot systems that can actively sense and interact with their world in order to progress towards a more complete understanding of the field. In the UWA Robotics course, this engagement is primarily driven through weekly lab assessments.

Over-reliance on physical robots as teaching aids

As the primary goal of learning robotics is to be able to apply the knowledge to real-life applications, the use of physical robots as teaching tools is advantageous. However, there are several drawbacks to relying on real robots. Robotics hardware can be expensive, often requires regular maintenance and must be upgraded as the field of robotics itself evolves. There is also the risk that there may be too many students for the equipment available, or conversely that the purchased equipment is underutilized.

Due to logistical challenges, risk of physical harm and/or prohibitive cost, students may also have limited access to larger scale robotics systems such as industrial manipulators, autonomous vehicles and submersibles. Additionally, the increasing need for remote working arrangements (often at short notice) means that access to smaller scale robots may also be limited without warning during a teaching semester.

When using physical robots, a multitude of factors such as battery health, sensor degradation and manufacturing defects can create unwanted variance in behaviour, as found by Kumar (2004). This inconsistency can influence how the same student's code solution performs across different robots, potentially leading to unfair assessment.

Some students may also wish to design their own robots, but with typically limited time and resources this undertaking may not be feasible in a physical capacity.

Robotics lab assessments

Prior to 2017, lab assessments leveraged a fleet of custom-made teaching robots called EyeBots. The EyeBot is a small differential-drive robot equipped with simple sensors, running the RoBIOS operating system (Bräunl, 2003).

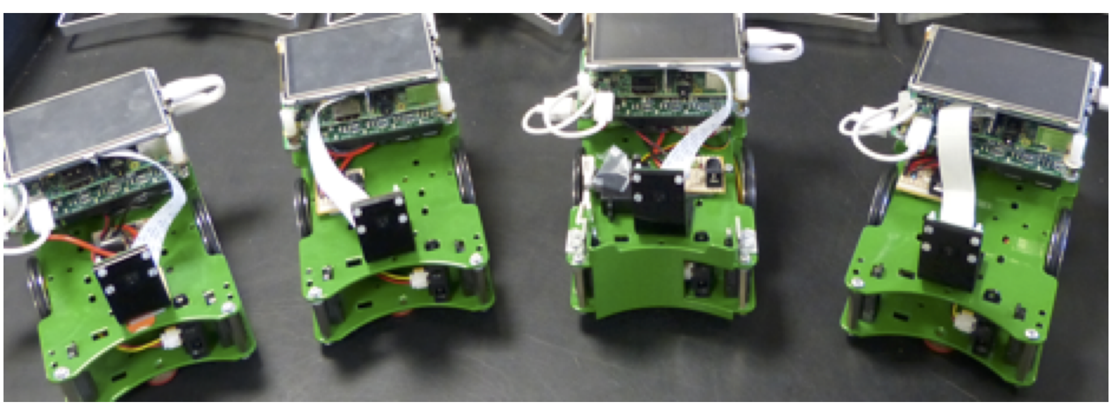

Figure 1: Four EyeBot 7 robots (the latest model)

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Typical problems that students would be tasked with include driving a simple lawnmower pattern (Bräunl, 2021a), to using the built-in EyeBot camera to seek and transport objects (Bräunl, 2021b).

Since the EyeBots could not be made available outside of the prescribed time due to resource limitations, the majority of the work would have to be done in theory at home, with the limited lab assessment time used to actually run and debug the code. Additionally, as these EyeBots are used and maintained by students, they are susceptible to defects that can severely impact valuable lab time.

The EyeSim robot simulator

To address these issues, it was determined that a robot simulation tool could be leveraged. A basic multi-robot simulator, the original EyeSim, already existed and had been in use at UWA as a research tool, but its rudimentary graphics and lack of a realistic physics engine meant that a significant divide remained between the simulated and real-life robots. More popular solutions such as Gazebo (Koenig & Howard, 2004) and V-REP (Rohmer, Singh & Freese, 2013) had rich feature sets and realistic physical simulation, but were deemed unsuitable due to the relatively steep learning curve and lack of interoperability with RoBIOS.

Instead, the new EyeSim simulator (Bräunl, 2020) was developed. EyeSim is a free robot simulation platform that students can use at any time to rapidly deploy their code solutions at scale and with significantly more deterministic results than on physical robots.

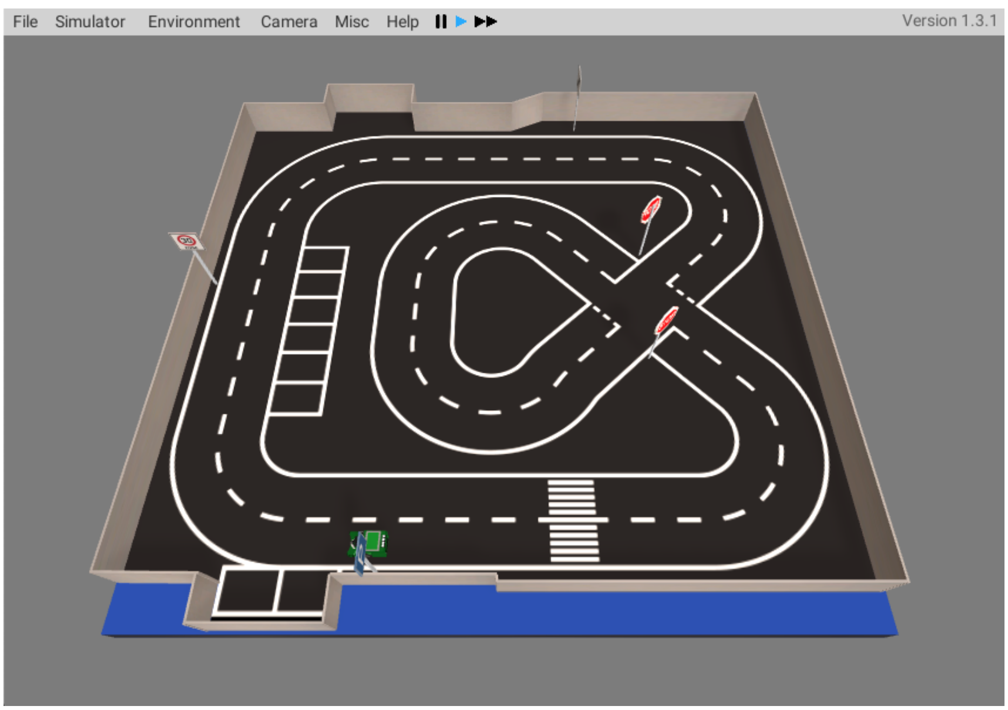

Figure 2: An example EyeSim scene

A 'scene' containing robots, objects and terrain (as shown in Figure 2) can be set up by hand, or via a specialised SIM file defining how a scene should be initialised that can be opened and processed within seconds. The ability to set up a scene this way, as opposed to manually resetting a physical environment, allows robot software development to be done faster and more iteratively.

The SIM file in Figure 3 creates the scene shown in Figure 2. The 'world' command selects the driving environment and defines its size, walls and any textures. The 'object' command introduces passive objects, such as the stop signs, which can then be included multiple times

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into the scene by using their respective keywords. Finally the keyword ‘S4’ adds a certain type of active mobile robot to the scene and specifies its starting position (x, y), its starting angle (phi) and its control program.

```
# Environment
world world/Carolo-lab.wld

# Settings
settings TRACE

# Objects
object ../../objects/StopSign/stopsign.esObj
StopSign 2300 1900 -45
StopSign 2280 1250 135

object ../../objects/ParkingSign/ParkingSign.esObj
ParkingSign 1050 230 180

object ../../objects/SpeedLimitSign/speedlimitsign.esObj
SpeedLimitSign 50 1700 90

object
../../objects/SpeedLimitSign/cancelspeedlimitsign.esObj
CancelSpeedLimitSign 2000 2900 0

# robotname x y phi
S4 1000 340 180 carolo.x
```

Figure 3: An example SIM file

An important feature of EyeSim is that the robot source code, written in C/C++ or Python, uses a standardised control API from the RoBIOS library (Bräunl, 2020). This means that a program can be written for a simulated robot, then run on a physical RoBIOS-based robot and vice-versa without requiring any code changes. This gives students the ability to develop code quickly and safely in simulation before deploying it on a physical robot, a feature that is especially powerful in terms of robots requiring lengthy initialisation/tear-down procedures, or those that are shared by many students at once.

This interoperability also means that students can be far more confident in the veracity of their assessment results, as the performance of their code will not be subject to varying physical factors. The high confidence in reproducibility also dispels the “it worked on my machine” excuse commonly used by students.

Using specialised ROBI robot definition files, students are also able to modify existing robots or create new ones from scratch within minutes. This provides the ability to easily prototype vehicles and manipulators before committing resources to a physical build.

Currently, the majority of lab assessments use EyeSim, while some assessments still focus on using EyeBots to provide students with a modicum of hands-on experience. The time requirement for assessments still exists, but in both EyeSim and EyeBot labs students now have the ability to debug their code from home using the simulator, shifting much of the workload away from lab time.

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Survey of EyeSim users

Students that had used EyeSim in their units were surveyed once in Semester 2, 2017 and again in Semester 1, 2021 for a total of 25 respondents. The survey focused on determining the perceived impact of EyeSim on their experience of studying robotics.

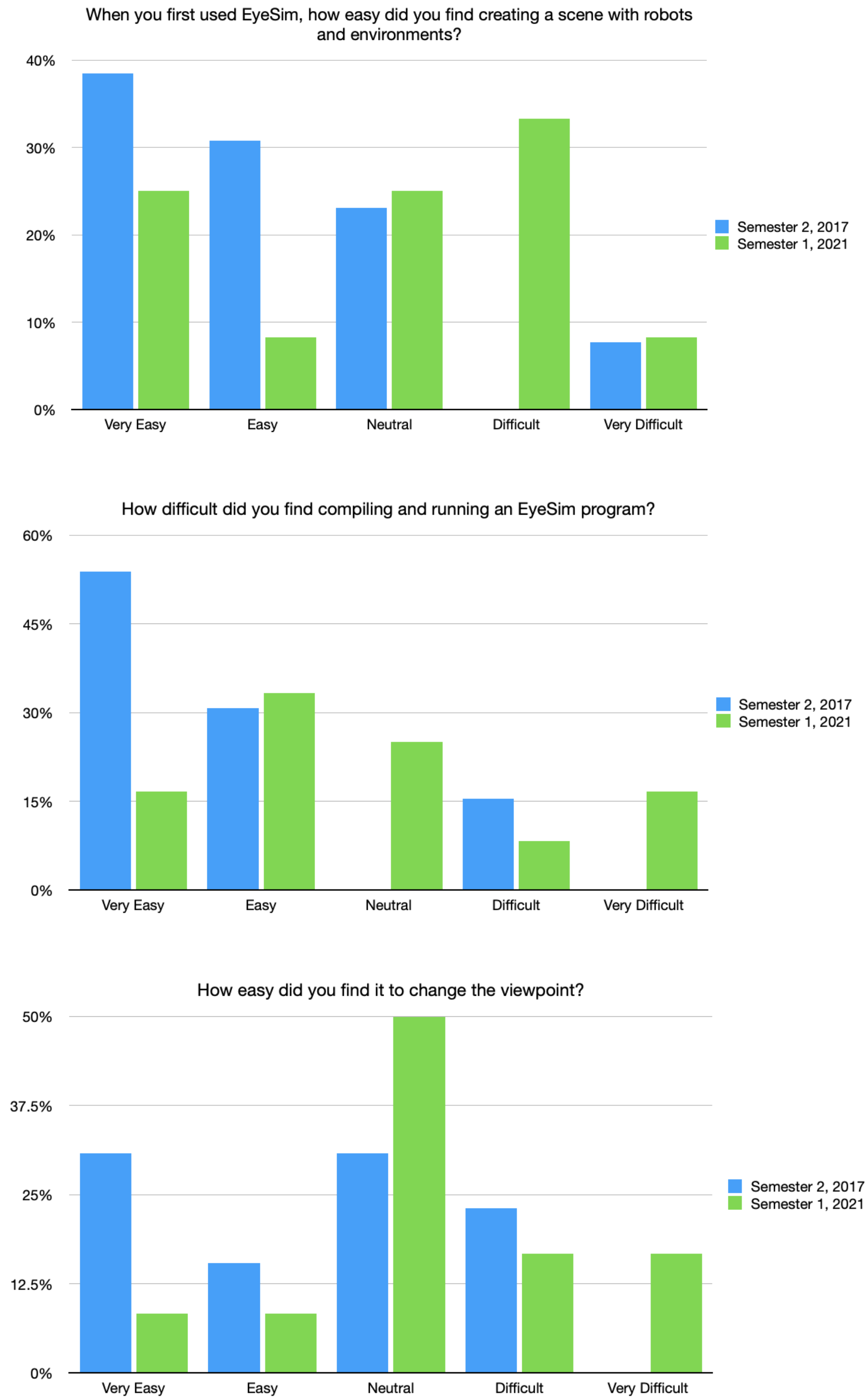

Figure 4: Survey questions relating to ease of use

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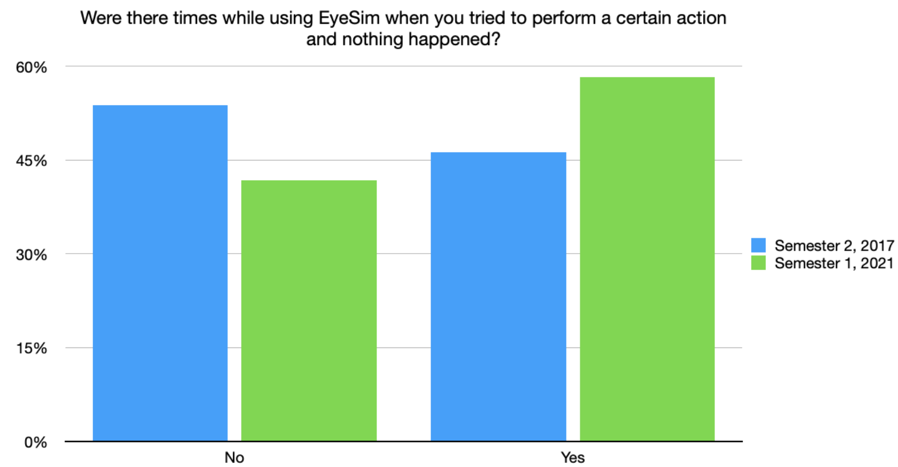

Figure 5: "Were there times while using EyeSim when you tried to perform a certain action and nothing happened?"

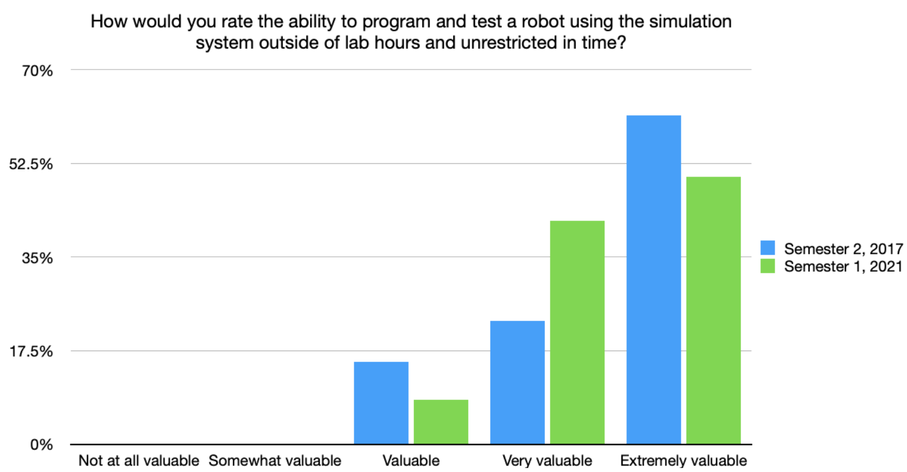

Figure 6: "How would you rate the ability to program and test a robot using the simulation system outside of lab hours and unrestricted in time?"

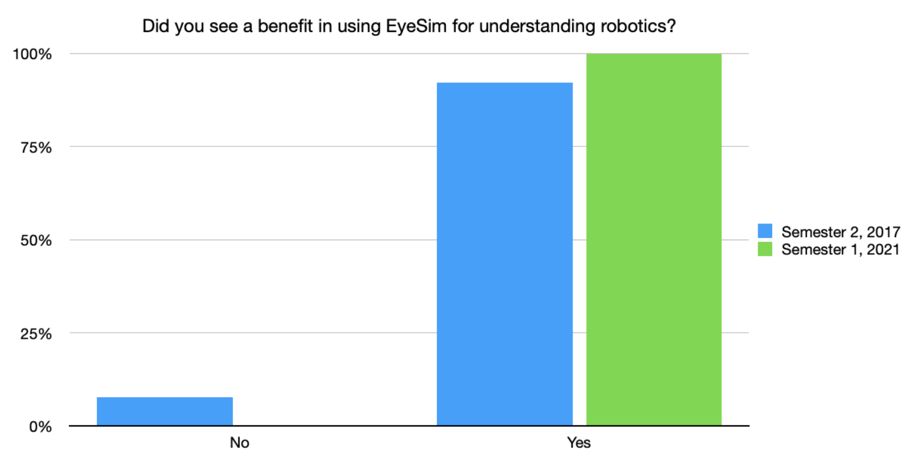

Figure 7: "Do you see a benefit in using EyeSim for understanding robotics?"

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Discussion of results

The survey questions relating to ease of use (Figure 4) depict a generally positive response. Across each question in this set, it can be observed that responses from the 2017 survey round trend more clearly towards a positive response, whereas responses from the 2021 round trend towards a more mixed response. This shift correlates with several significant changes made to the EyeSim system between the two survey periods. The first question addresses scene creation, which was initially simple on the release of EyeSim, but became more complex as new features such as terrain, water and submersible robots were added as options. Similarly, the second question pertains to the difficulty of running control programs in EyeSim, which was initially constrained to C programs but had been expanded to also allow C++ and Python programs by the 2021 survey round. As EyeSim assessments begin within the first few weeks of the semester, students have limited time to familiarise themselves with the system, and it is suggested that increasing the feature complexity of EyeSim had a proportionally deleterious effect on ease of use. Since EyeSim is a research tool, new features will continue to be added, and so instead of reducing the feature set this issue could be addressed through more comprehensive documentation and training.

Figure 5 shows responses to the question “Were there times while using EyeSim when you tried to perform a certain action and nothing happened?”, and a roughly 50/50 split can be observed for both survey rounds, with a slight trend towards ‘Yes’ in the later round. This question was designed to assess the proportion of students that encountered defects, and many of these defects were enumerated in the long-form accessory section of this question. With about half of all students encountering defects, this defect rate is significant. Moreover, it is suggested that the higher defect rate in 2021 implied by the trend towards ‘Yes’ answers is consistent with the increased feature complexity; a greater number of interconnected features lends itself to a higher defect probability. As EyeSim is developed and maintained in the course of student projects, it may not be possible to reduce this defect rate in the future without acquiring funding for professional software development resources.

Figure 6 shows responses to the question “How would you rate the ability to program and test a robot using the simulation system outside of lab hours and unrestricted in time?”, with both survey rounds indicating a significantly positive response. As respondents had indicated that each lab assessment required on average 4-6 hours of preparation time prior to the lab session, it is unsurprising that they found EyeSim to be a useful tool in this capacity. Additionally, a majority of survey respondents had previously participated in lab assessments using the physical EyeBot robots and would therefore appreciate being able to run code outside of a lab session from this perspective.

The final question, “Do you see a benefit in using EyeSim for understanding robotics?”, directly asked respondents whether they felt EyeSim was a valuable teaching tool. An overwhelmingly positive response in both survey rounds can be observed, indicating that EyeSim had a positive effect on the perceived learning outcomes of the vast majority of students.

It is acknowledged that there is a time difference of four years between the 2017 and 2021 survey populations, however the structure of the UWA Robotics unit did not change significantly during this period. It is also important to note that the 2021 survey was performed during the COVID-19 pandemic, at which time UWA mandated mask wearing on campus, but student contact hours were unaffected.

It is also acknowledged that the questions in Figure 4 regarding ease of use are phrased in a leading manner that may have influenced a disproportionately positive response. This will be remedied in future surveys.

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Summary

Overall, reasonably consistent results were observed across both survey rounds. The inconsistency in the ease of use section can be explained by the feature set expansion that took place between 2017 and 2021, and identifies a need to improve documentation and training processes for future cohorts. Additionally, the high proportion of students encountering defects is evidence that more resources need to be dedicated to quality control processes as new features are added.

The sample size of the survey was limited by the number of students in the unit, and although a larger number would have been desirable, the results seem to confirm our hypothesis that the use of a mobile robot simulator like EyeSim improves motivation and learning outcomes. We conclude that the ability to put theoretical robotics concepts into practice at any time, without the limitations and risks that accompany physical robots, is highly advantageous for robotics students. We expect that EyeSim will continue to mature and provide value to students in the years to come.

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Exclusion from constructive alignment unmasked by emergency remote teaching

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ABSTRACT

CONTEXT

The research study was conducted at a contact-based, research-intensive university in South Africa, where the faculty of engineering has adopted a feedback-feedforward approach to improving engineering pedagogy through theoretically-supported, interdisciplinary and community-of-practice approaches. The outcomes-based curricula are designed to explicitly align teaching/learning activities, the intended learning outcomes and assessment tasks. The Covid-19 emergency remote teaching (ERT) phase has raised the question of the disjuncture between student perceptions and assessment performance during independent, remote learning.

PURPOSE OR GOAL

A faculty-wide research initiative to determine how undergraduate engineering students were experiencing ERT revealed significant systemic challenges and heightened academic stress. Of particular concern in 2021 is the 2nd year cohort, whose entire 1st year was under ERT conditions. Poor first term assessment performance suggested the need to investigate not only how students were studying, but their perceptions of their practices and efforts in relation to their perceptions of course requirements, and consequently their performance.

APPROACH OR METHODOLOGY/METHODS

A mixed-method survey-based approach was used to assess second year students' perceptions of a design-based module. The surveys were sent out when it became clear that performance was going to be substantially poorer than expected for their first in-person and closed-book assessment after ERT. The samples were taken after the assessment, after the model answers lecture, after the marks were published, and again after an intervention. The 2020 marks were compared with the last in-person assessments from 2019. Out of the 280 students, 142 responded to the survey.

ACTUAL OR ANTICIPATED OUTCOMES

Students overestimated their marks after writing, even after seeing the model answers. Two thirds reported the paper as difficult, which reduced to 58% after the model answers, and 74% after releasing the marks. Two thirds said online lectures prepared them sufficiently, but after the marks only 45% did. After a reflection-in-action intervention, 81% considered them sufficient and the error in estimated marks for the next assessment reduced by 41%. Despite 97% engagement with the lectures and 96% claiming to have done the tutorials and practicals on their own, only 38% used the Q&A forums, and not a single student made an appointment with the lecturer.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

While constructive alignment is a common pedagogical approach, it does not explicitly include alignment to student abilities or perceptions. In contact-based, socio-culturally mediated contexts, educators may tacitly be responsive to (mis)conceptions to enhance alignment between student abilities, expectations and intended course outcomes. We suggest, in this paper, that a constructive alignment model needs to include methods to overcome self-efficacy gaps, given that we need to produce critically-thinking, confident, and capable graduates.

KEYWORDS

Evaluative judgement; Constructive alignment; Engineering education; Emergency remote teaching.

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Introduction

The International Engineering Alliance Graduate Attributes (2013) for a professional engineering graduate (Washington Accord) stipulate outcomes designed to enable the holistic development of graduates who are capable of solving 'complex problems'. These outcomes extend across the knowledge, skills and 'dispositions' continuum, and are intended to ensure that graduates engage in engineering activity which is "carried out responsibly and ethically" in "meeting the needs of people, economic development and the provision of services to society" (IEA, 2013, p. 1). The changing nature of the engineering profession has seen two decades of global engineering curriculum reform, with greater attention to the explicit integration of appropriate 'knowledge, skills and attributes' (DHET, 2013). Competencies in these areas are specified in engineering standards, which are supported by the global engineering accords and the IEA Competency Profiles (2013). Increasingly, pedagogical strategies such as project- and/or problem-based learning are intended to enable the holistic development of engineering knowledge, skills and attributes in the context of real-world problems. Recent research on how 21st century engineering knowledge, skills and attributes are holistically developed demonstrates the importance of explicitly teaching the different ways of thinking and doing in relation to the different engineering disciplines (Wolff and Booysen, 2019). Students need to be taught how to recognise conceptual and contextual 'codes' which require simple to complex approaches (Pott and Wolff, 2019). Learning to code shift using appropriate strategies could be termed 'critical thinking' (Douglas, 2012; McPeck, 2016), which is based on the interpretation, analysis and evaluation of a problem situation. Critical thinking is the basis of engineering judgement, an under-researched competency (Tai et al., 2018).

Our Higher Education (HE) system is replete with examples of the continuous exercise of 'judgement': from the selection of materials judged to be necessary in the curriculum to the eventual judgement of student performance by way of assessment. In other words, the educational space offers an ideal space for the modelling of judgement practices as well as their development. Research on undergraduate student perceptions of their performance, however, reveals a significant disjuncture between student and educator judgements. By way of example, two studies on students' perceptions of their computer skills versus their actual abilities reveal a notable discrepancy (Grant, 2009; Peng, 2009), with students consistently believing they are more able than they actually demonstrate in practice. This misconception is further evident in the "disconnect between students and faculty in expectation, perception, and reasoning behind academic evaluation" (Tippin et al., 2012). Another common misconception (or perception) is that the exam paper differs significantly from exam practice papers (Young et al., 2019), and students often demonstrate "a low degree of success in predicting their success on a given problem" (Gulacar and Bowen, 2014).

Confidence is a key element in effective judgement, impacting on decision-making (Christopher and Herbert, 2021). Bandura (1977) links confidence in effectively executing action (or taking decisions) to what he terms 'self-efficacy'. Additional judgement-related factors which impact on decision-making are *fear, avoidant behaviour,* and *motivation*. Motivation is linked to '*goal-setting*' (Schunk and Gunn, 1985), a key cognitive process which can be modelled through pedagogical strategies and enhance self-efficacy. While acknowledging the complexity around what we are terming 'evaluative judgement', the ability to confidently and independently interpret practices and criteria (in order to make effective decisions) is not only a central engineering graduate attribute, but one that is necessary throughout life (Boud and Soler, 2016). But given that 'evaluative judgement' is so poorly researched and there is little empirical work on how to develop students' evaluative judgement (Tai et al., 2018), the question for this paper is *what do we know about engineering student judgement in a particular context and how can we foster its development?*

The starting point for many educators in designing curriculum and pedagogy to facilitate the development of equipped, problem-solving critical thinkers, is the Constructive Alignment (CA)

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framework. CA is the alignment between a constructivist understanding of learning and the design for teaching (Biggs, 1996). The CA framework is intended to enable educators to explicitly link intended learning outcomes to the associated learning activities and the eventual assessment instruments. If our intention as educators is to design and engage in learning that enables the development of holistic engineering graduate outcomes, and our design instrument is that of CA, we argue that 'evaluative judgement' is a hidden outcome (Fitzpatrick, 2009), dependent on student and staff perceptions and expectations being made more explicit.

The experience of emergency remote teaching (ERT) (Hodges et al., 2020) at a residential university in South Africa highlighted a significant disjuncture between student perceptions of their performance and that of lecturer expectations. Drawing on Vygotsky's sociocultural theory of learning (Kozulin, 2002), the paper uses a particular case study in an electrical engineering department to examine student perceptions of their performance during ERT and an intervention strategy to improve evaluative judgment going forward. Drawing on this study, we illuminate student performance perception patterns and suggest an more contextually nuanced review of the Constructive Alignment framework that better enables potential graduates to develop 'evaluative judgement'.

Theory

Learning happens in socio-culturally mediated settings (Kozulin, 2002), where 'social' refers to the relevant stakeholders (such as, but not limited to, students and teachers) in a particular 'community of practice' (Lave and Wenger, 1991). This community, then, refers to the 'cultural' aspect, where the culture of the community is that which constitutes the 'rules of the game' in a specific field. Sociocultural learning (to survive in the world) happens from the beginning of life, where human beings learn the rules of the game through modelling and repetition. Formal learning is facilitated when human beings engage in activities (whether perceptibly active or passive) that draw on mediating tools and resources, such as texts, knowledgeable others, artefacts and events. An iterative, scaffolded learning process can enable 'cumulative learning' (Maton, 2013), the connection of concepts to contexts through forms of application. Kolb (1984) describes this cycle as concrete experience, reflective observation, abstract conceptualisation, and active experimentation. The concept of reflection in this learning cycle is taken further by Schon (1983), who usefully differentiates between reflection-in-action (during) and reflection-on-action (after). It is this concept of reflection that is vital to the development of 'evaluative judgement' (Tai et al., 2018).

In order to enable learning to happen, educators use artefacts to design their curriculum and pedagogical strategies. At each of these stages, a process of recontextualisation (Bernstein, 2000) takes place, where *what* is selected and *how* it is to be taught is dependent on a range of stakeholders and contextual factors. A common instrument in aligning the *what* and *how* is Bigg's (1996) Constructive Alignment (CA) model in which the focus is on the relationship between objectives, 'appropriate' teaching activities and assessment. The question of 'what is appropriate' is highly contextual and suggests it is necessary to consider Vygotsky's 'Zone of Proximal Development' (Kozulin, 2002). Although used to describe the distance between *actual* and *potential* development in childhood learning, Vygotsky's aim in formulating the ZPD was the development of theoretically-based pedagogical interventions, responsive to the individual needs of learners (Shabani et al., 2010). Global massification in the HE system, and particularly in resource-constrained contexts (such as this study), makes individually-focused tuition unlikely. The alignment of objectives to outcomes, teaching activities and assessment, thus, does not explicitly reflect the learner position in a particular context and his/her ZPD.

One way to address the lack of attention to the individual student's position, perspective or needs in large class contexts is to draw on students themselves as 'mediation resources'. Furthermore, the educational activities in and of themselves represent mediating 'artefacts', potentially enabling Kolb's experiential cycle (1984). A key mediating artefact is the

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assessment event. Given the examples from the literature on observations of disjunctures between student perception and lecturer expectations, which manifest in assessment performance, assessments present a significant opportunity to 1) determine individual students' ZPD, 2) enable reflective, experiential practice and 3) teach students 'what counts'. Engaging with student perceptions of and reflections on assessment processes can enable educators not only to enrich their own pedagogical and curriculum design, but also construct a more holistically aligned framework.

Drawing on socio-culturally mediated learning concepts, this paper proposes that we cannot get the student to achieve the 'outcome' if we do not know where the student is at. Secondly, the student cannot truly develop if he/she also doesn't know where he/she is at. If a key objective in engineering education is to produce critical thinking problem-solvers, how do we explicitly enable the development of evaluative judgement?

Context

The research study was conducted at a residential, research-intensive university in South Africa, where the faculty of engineering has adopted a feedback-feedforward approach to improving engineering pedagogy through theoretically-supported, interdisciplinary and community-of-practice approaches. The outcomes-based curricula are designed to explicitly align teaching/learning activities, the intended learning outcomes and assessment tasks. In March of 2020, with the looming onset of the Covid-19 pandemic, South Africa entered one of the most severe lockdowns for any country, due to fears of an overburdened health system in a developing country. The lockdown commenced in the middle of the first semester, with all teaching moving online in an emergency remote teaching (ERT) (Hodges et al., 2020) phase. Although the transition was managed as well as reasonably possible, this modality inevitably severed important feedback loops between students, teaching staff and content. Moreover, the lockdown, which enforced teaching & learning-distancing, commenced before the first-semester exams started, and also encapsulated the second semester exams. This had the unfortunate consequence that the first-year cohort from 2020 wrote online-only exams. In 2021 ERT was augmented with limited in-person practicals and tutorials, and examinations. The 2020 ERT phase had raised the question of the disjuncture between student perceptions and actual assessment performance during independent, remote learning, which appeared particularly prevalent among the first-year cohort of 2020.

This study focusses on a second-year Computer Systems (CS) course presented by Electrical and Electronic Engineering (E&E). The course is compulsory for a nominal 280 students every year, and builds on the work covered in a first-year Computer Programming course, in which many students encounter software development for the first time. CS is also the first course in which the students are expected to transcend the boundaries of theoretical knowledge and design logic circuits. The main focus of the CS course is to teach students about binary and hexadecimal number systems, digital circuits, Boolean logic, combinational circuits, sequential logic, state machines, and assembly language. The course is heavily scaffolded by practicals which contribute to a continuous assessment grade. However, the lion's share of the students' marks are made up by a written Assessment 1 (A1) and written Assessment 2 (A2), contributing 30% and 50% respectively. The focus of this paper is the two-hour, written A1 exam, the first in-person assessment the students wrote after a year of pandemic-inflicted online assessments.

Methods

A mixed-method, online, survey-based approach was used to assess second year students' perceptions of the design-based module. The survey consisted of seven Likert-scale questions to assess the students' perception of the assessment, their personal preparedness, and resource use. Four separate surveys were taken to assess students' initial and subsequent

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perceptions. The first survey was taken within two days after the assessment. Students were asked to guess their mark, to state whether they believed the CS online teaching prepared them sufficiently for the assessment, and whether they thought the paper was difficult. The second survey was taken after an online video was posted in which the lecturer worked through the A1 model answers (called a "memo") in detail using a tablet and electronic pencil and recording the screen. The same three questions were posed in the second survey. The mark estimates from these two surveys were compared with the results from the 2019 CS class (predating any Covid-19 impacts) and also with the achieved A1 marks for the research study cohort. A third survey was conducted after the marks were released, and students were asked again if they thought online teaching prepared them sufficiently for the assessment and also whether they thought the paper was difficult.

After the A1 model answers were shared and the results released, an intervention was designed to engage with the course content "in full view of" the students using an online 'flipped classroom' approach. Students were encouraged to share their own screen with their own problems from the practical assignments. In full view of all the other participants, the lecturer would then guide the courageous student in real-time as if they were in an in-person practical, or answer questions they may have. A fourth and final survey was conducted after the final major individual assessment (A2) was written six weeks later.

The 2020 marks were compared with the last in-person assessments from 2019, which were unaffected by online learning. Out of the 280 students, 142 responded to the survey. All data were anonymised and collaboratively analysed using Microsoft Excel.

Discussion of Findings

Student performance perception

Figure 1 shows the responses to the four surveys on the level to which the online lectures prepared the students and the difficulty of the paper. The initial responses just after writing A1 indicated that 68% of the students believed the online lectures prepared them sufficiently, which matches closely with the 69% of them stating the same after watching the memo lecture. However, after receiving their below-par marks, this number reduced to a mere 45% of students believing that the lectures prepared them sufficiently. This shift is interesting since it happened after the students watched the memo lecture. This supports the common disjuncture between student self-efficacy perception and the evaluative judgement of the educator. What is of further interest is the shift back to a high 81% after the students wrote A2, which included the course content for A1. However, A2 was preceded by the Q&A lectures with high levels of problem-solving engagement.

Figure 1 also shows the perception of A1's difficulty. After writing, two thirds believed the paper was difficult. This number reduced to 58% after they had the opportunity to observe the lecturer working through the question paper. A similar (but inverted) trend is seen after the marks were released, with 74% of students claiming A1 was difficult. Again, this finding is supported in the literature on student perceptions on the difference between actual exams and their expectations (Young et al., 2019).

Figure 2 shows the comparison of marks students thought they would receive and what they actually received at the different assessment stages. As stated, the expected performance was poor - the 2019 median mark for A1 was 56%, which is in line with expectations from previous years. However, the median actual mark for 2021 was only 33% and mean 34.5%. The respective 75th and 25th percentiles were 43% and 24%, compared to 64% and 44% in 2019. It is worth noting that several independent moderators -- both as part of moderation before A1 was written and after the poor performance was reported to the home department as part of a post-mortem investigation -- confirmed that there was no significant difference between the

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course content and types of assessment questions in the previous years and 2021 examinations.

Immediately after A1 was written, the median guessed mark was 50% and the mean 48.8%. The 75th and 25th percentile guesses were 60% and 40% respectively. After watching the lecture detailing the memorandum, but before the marks were released, the median guessed mark decreased to 40% (reduction of 10 percentage points), with the mean of the guesses reducing to 42.8% (a reduction of 6.0 percentage points). The distribution of guesses was narrower and more accurate after watching the memo lecture, with 75th and 25th percentiles of 50% and 35%.

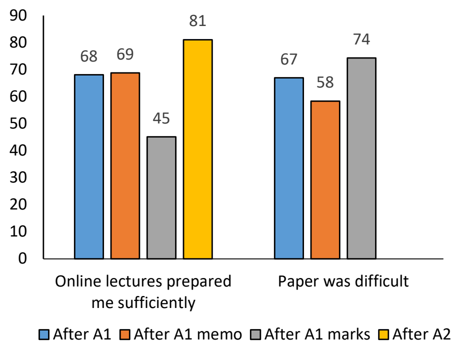

Figure 1: Students' assessment of sufficiency of online lectures and paper difficulty.

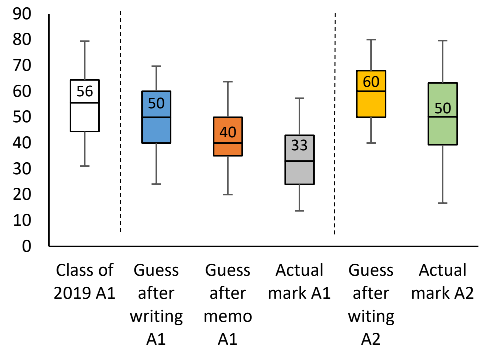

Figure 2: Marks achieved for 2019, marks guessed and achieved for A1 and A2 at different times.

Despite the more accurate guesses after seeing the model answers, these guesses were still overly optimistic - The actual marks were still substantially lower than the estimates. The difference between the initial guesses and the achieved marks for A1 were: 17 percentage points for the median (14.3 percentage points for the mean). After watching the memo lecture, the difference between the guesses and the median achieved marks reduced to 7 percentage points (8.2% for the mean). We reassess the accuracy of their guesses for A2, following the intervention described next.

Evaluative judgement intervention

An analysis of claimed student engagement with the online lecture material, practice resources and forums revealed that while around 97% engaged with the resources, only 38% used the Q&A forums. No student made use of the option to consult the lecturer. In other words, the majority of students did not engage in active, socially-mediated learning opportunities. Given these observations, as well as the poor performance and perception disjunctures during the A1 assessment rounds, a set of Q&A lectures was introduced using a flipped-classroom approach.

The Q&A lectures were set up to ensure engagement with the content in a way that would mimic in-person and individual lecturer engagement while also emulating a question being asked during a lecture. The lectures were scheduled ad-hoc, anything from an hour to a day in advance and after hours (e.g. 9pm on a Friday). Students were invited generally to ask questions, but specifically to share problems they struggled with in the tutorials (theoretical problems such as a Boolean algebra derivation), or problems encountered during the simulated practice sessions. Students were encouraged to all turn on their cameras to make the encounter more human, especially after a year of on-and-off lockdowns. When a student asked a question, the lecturer did not help on their own device, but rather asked the student to share their desktop or webcam with the problem (written on paper or simulated on the application) with the whole class. The lecturer would then start asking probing questions to the

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student to lead them to realisation. This method is similar to what would happen to in-person engagement, with the added advantage that the engagement scales to the rest of the students who joined in real-time (34%) or watched the recording (88%). In this approach, the rest of the class could also observe and engage with (1) the particular problem step with which a student was struggling, (2) the recognition of peer misconceptions, (3) the advice from the lecturer, (4) the modelling of required approaches and solutions. Although they may not have been struggling with the same steps, peer observation facilitates both cognitive conceptual alignment and confidence building (Houghton et al., 2013). In other words, this encouraged other students to come forward with their problems, thereby cascading to the most common problems students faced collectively.

The class' performance was substantially better for A2 than for A1: the median mark was 50% with 75th and 25th percentiles of 63% and 39%. Encouragingly, the difference between the initial guesses after writing and the achieved marks for A2 were less: 10 percentage points for the median and 9.6 percentage points for mean. This indicates that the students fared better at adjudicating their performance. In the fourth and final survey, students were also asked "After A1 and memo, the project, and the Q&A lectures, I had a better idea of what was expected of me" in a final question. The resounding response was affirmative from 84% of the respondents.

Developing evaluative judgement

Using the A1 assessment as a mediation device, students were effectively encouraged to 'reflect-on-action' (Schon, 1983) by considering how they had prepared for the assessment and how they thought they had performed. The disjuncture between their perceived and actual self-efficacy was addressed through a reflection-in-action strategy, where examples of course material were actively interrogated by students themselves in the online, flipped-classroom Q&A lecture sessions. The first obvious benefit of this approach is the opportunity for practical, active, peer learning using mediating examples (student screen-shares). The less obvious benefit of the approach is the opportunity to overcome the broken feedback mechanism, by which the lecturer (reflecting in action) becomes aware of the range of student ZPDs during the live Q&A sessions. While this form of online engagement may appear self-explanatory, it is important to note that in large class, resource-constrained education environments (predominant in the global South), there are seldom opportunities for student-centred, individual diagnostic teaching approaches. Determining a student's ZPD is crucial for effective teaching, and more easily facilitated in in-person teaching environments where students can ask questions. The ERT era has highlighted a significant constraint to educators' being able to identify and respond to the range of student learning needs. Reports on poor self-regulation and low digital fluency during ERT are highly concerning, given that self-regulated learning and technology self-efficacy are predictors of academic success (Wang et al., 2013).

The survey iterations in this case study offered students the opportunity to engage in Kolb's (1984) experiential learning cycle, where students could reflect on the experience of A1 (as well as their own perceptions of how they performed) and then actively engage in the preparation for A2. The shift in performance perception following A2 suggests a better alignment between perception and expectations. This, we argue, suggests the development of evaluative judgement through *practical experience*, which Bandura (1977) links to self-efficacy as a result of students experiencing the consequences of their own behaviour. In other words, being asked how they thought they would perform before and after receiving actual marks encouraged the kind of reflective practice necessary for the development of evaluative judgement.

For the educator, the reflection-on-action cycle (A1 survey iterations) and the desire to intervene productively led to the observation that the current CA model – which focuses on the relationship between intended learning outcomes, appropriate learning activities and aligned

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assessment - does not explicitly acknowledge the student position, nor the disjuncture between student perceptions and lecturer expectations. If *appropriate* learning activities are designed to enable students to achieve course outcomes (which are evaluated through assessment activities), then what is appropriate for whom? Observations of student performance and expectations during the ERT period (including cases beyond this study) suggest a need to develop a contextually nuanced CA framework which includes the curriculum and stakeholders. The disjunctures between different stakeholder interpretations of criteria and expectations calls for (1) a recognition of the context and (2) the need to make expectations explicit, since these impact on student interpretation of intended learning outcomes. Context implies both the available resources as well as the students themselves. In order to design appropriate teaching activities, it is essential that educators consider their students from a socio-cultural context, what they bring with them into the learning space, including their perceptions and expectations. It is only through explicit iterative practice that better alignment can be achieved between activities and intended outcomes, leading to improved evaluative judgement. This holds for both educator and student.

Conclusion

The Covid-19 emergency remote teaching (ERT) phase has raised the question of the disjuncture between engineering student perceptions, assessment performance and interpretation of course expectations. Given the importance of developing evaluative judgement as a future professional engineer, the observations of a 2nd-year electrical engineering cohort at a South African institution offered the opportunity to intervene. An iterative sequence of surveys enabled students to reflect on perceptions of their practices in relation to course requirements and the mid-semester assessment. The initial gaps in perceived versus actual performance led to a reflection-in-action intervention whereby students shared and discussed their particular challenges in three online, recorded, Q&A sessions. The initial survey experience and intervention appeared to enable greater alignment between student perceptions and actual performance, as was evident in the final semester assessment.

The constructive alignment framework, which provides the basis for much of outcomes-based education, does not explicitly include alignment to student abilities or perceptions. The student context is possibly implied in the descriptor ‘appropriate’ in relation to ‘learning activities’. We propose further work on developing a CA model which includes the educator's role and expectations in relation to being able to determine ‘appropriate’ teaching activities based on a better understanding of the student context. Furthermore, this alignment in conjunction with the recognition that assessments themselves are invaluable mediating artefacts, can enable the bridging of evaluative-judgement gaps, given that we need to produce critically-thinking, confident, and capable graduates.

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Systematic Literature Review of Students' perception of Employability Skills

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ABSTRACT

CONTEXT

Over the years, research investigating how engineering education contributes to the employability skills of students has led to the adoption of scenario-, problem- or project-based learning being implemented as effective methods for developing skills. Measuring student perception has emerged as an effective tool to gain insights into how changes to engineering curricula can contribute to various skills and attributes of engineering graduates. The COVID-19 pandemic has, however, disrupted teaching methods, making student engagement challenging. The effectiveness of teaching methods is dependent on the students' engagement level, which in turn translates into developing their employability skills.

PURPOSE OR GOAL

In order to pave the way for the post-pandemic approach towards improving the employability skills of engineers, it is important to gain a comprehensive understanding of the existing literature in this area of study. Thus, the aim of this study is to conduct a systematic literature review of undergraduate engineering students' perceptions of employability skills.

APPROACH OR METHODOLOGY/METHODS

Utilising the PRISMA protocol, a systematic review of the existing literature will be performed, looking at student perception of employability skills. The review will look at peer-reviewed research reporting on post-secondary engineering education in the last 20 years. Highly relevant papers will be chosen based on the protocol and reviewed.

ACTUAL OUTCOMES

Throughout the literature on this topic, a recurring theme is that employability skills are not well-defined, and a range of reference frameworks are used, such as accreditation requirements, 21st century skills and global engineer skills. The review found that the employers perceive that graduating engineers' non-technical skills are inadequate. In response, universities are constantly evolving their curricula and teaching methods to address this gap. Mismatches are identified in terms of the student perceptions of important employability skills and the perceptions of universities and industry employers. Internships, job placements, and problem- and project-based learning have found their place in helping undergraduate students to develop their skills. Suggestions for future work include a comparison with other professional degrees and how engineering education has deviated from these other degrees.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The effect of COVID-19 on engineering student's employability and how long it will persist is currently unknown. This study contributes to the understanding of student perceptions about employability skills before the pandemic to understand the state of play when the COVID-19 disruption to teaching and learning occurred. It adds to the growing body of knowledge on engineering education focussed on employability skills and will help develop this field progress as we emerge from the pandemic.

KEYWORDS

Systematic review, student perception, employability skills, teaching methods, engineering

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Introduction

Historically, engineering education was dependent on a master-apprentice relationship where the master played the role of not only training the apprentice in technical knowledge but also providing guidance with non-technical skills to be a valuable member of society. This had been the practice for hundreds of years, and when technical advancements and knowledge creation began to explode after the industrial revolution, the role of training engineers for society eventually became the responsibility of universities (Bagherzadeh et al., 2017). Over time, this has brought the engineering education field to the present situation where the responsibility rests with tertiary educators to impart both technical and non-technical skills to engineering graduates, with employers demanding job-ready engineers for the workforce.

The employability of engineering graduates has drawn much attention in the past three decades, necessitating changes in the targeted graduate attributes of students and the accreditation requirements of university courses (AlMunifi & Aleryani, 2019; Cruz et al., 2021; Franklin et al., 2012; Martin et al., 2005). The 1990s signalled a transition in accreditation requirements from basing them on time spent on teaching the requisite subjects to a focus on the qualities and attributes with which engineers should graduate (Martin et al., 2005).

The general view among employers within the industry is that among the engineering graduates, there is a shortage of non-technical skills, making them less work-ready for the demands of the engineering profession (Itani & Srour, 2016; Lee & Chin, 2017; Rizwan et al., 2021; Simmons et al., 2021; Thirunavukarasu et al., 2020). In response to this notion of skill gap, universities have made changes to their pedagogy and adopted approaches such as project-based learning (Bozic et al., 2014; Jaeger & Adair, 2018; Williams & Ringbauer, 2014), flipped or hybrid classes (Cano & Garcia, 2020; Rodrigo-Peiris et al., 2018), included internship subjects (Mohd Salleh & Yusof, 2017), and organised skill-specific out-of-semester camps (Gerhart et al., 2015). However, other professional degrees, especially in the medical field, have integrated job placements and other forms of employment training into the curriculum (Sharghi et al., 2015) to good effect.

Employability skills are referred to in the literature variously as ‘professional skills’, ‘soft skills’, ‘non-technical skills’ and ‘core skills’, amongst others, and do not have a universal definition (Itani & Srour, 2016; Jesiek et al., 2010). However, some of these commonly accepted skills that feature in the literature are communication, teamwork, problem-solving and interpersonal skills, with skills such as engineering ethics and lifelong learning also prominently entering the discussion.

We see that employers are expecting well-rounded graduates, universities are constantly innovating course structures, and students are upskilling themselves to be employable. Amidst this engineering ecosystem, the COVID-19 pandemic has significantly disrupted the higher education system. Admittedly, the coronavirus pandemic has distorted every walk of life, but this paper will specifically be contextualised around how this pandemic has affected engineering education.

COVID-19 has forced universities to adopt an online teaching medium due to the lockdowns and restricted physical movements, which is still in place in several parts of the world, including Australia. This forced adoption has disrupted the approaches designed to make university students more employable, such as internships and work-integrated learning (WIL). Students and employers are understandably concerned that skill development may be affected. It is important to understand how employers and students perceive how skill development has been impacted by the pandemic, specifically in terms of employability skills. This understanding, in conjunction with the literature of the past, will help educators develop the engineering pedagogy for an effective ‘new normal’ and ensure that employers have confidence in the skills of our graduates.

As a first step in investigating the effect of the COVID-19 disruption on the development of employability skills in university students, this paper reports on a systematic literature review

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of the undergraduate engineering students' perceptions of their employability skills. This review will form the basis of a future student perception survey investigating how the pandemic has affected the undergraduate engineering students' perceptions of their employability for those who have been learning in the COVID-19 disruption.

Methodology

In order to select literature in an objective and unbiased manner, this review followed the principles of the PRISMA protocol, used extensively in systematic literature reviews in medical journals (Moher et al., 2015). Journal papers were searched on three databases using the Boolean search as described in Table 1.

The inclusion criteria for review the papers were:

1. Papers published in the Past 20 years.
2. Papers published before 2019 should have been cited at least three times.
3. Papers should measure student perception.
4. Perception should be of employability skills/professional skills/generic skills/soft skills, and so on.
5. Students should be studying undergraduate engineering degrees.

Table 1. Prisma flow diagram of the systematic review process

Identification	The search Boolean used was: (TITLE-ABS-KEY(("student* perception*" OR "undergraduate* perception*" OR "graduate* perception*") AND ("employab* skill*" OR "professional skill*" OR "soft skill*" OR "generic skill*" OR "graduate* attribute*" OR "competenc*")) AND KEY(engineering))	
	Database	**Number of papers**
	Scopus	208
	ProQuest	179
	Web of Science	69
	Total number of search results = 456	
Screening	Duplicates removed, n = 145	
	Abstract and/or Title screening, n = 311	
	Excluded as not published within last 20 years, n = 1	
	Excluded as not related to engineering and/or undergraduates, n = 29	
	Excluded due to less citations, n = 21	
	Excluded as student perception and/or employability skills not studied, n = 190	
	Excluded, full text not available or in a language other than English, n = 4	
	Inclusive list, n = 66	

After screening, 66 papers were selected for the systematic literature review. These papers were further refined by reviewing the abstracts. The output was a star-rating system for the papers, with 5 stars being the most relevant to the topic and 1 star being the least. The criteria for the star ratings are explained in Table 2.

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Table 2. Criteria for assigning star-rating to the papers based on relevance to focus areas

5-stars	Undergraduate students' perception is measured exclusively	✓
	The main focus of the paper is employability/professional skills	✓
	Compared with industry standards/employer expectations/accreditation requirements	✓
4-stars	Undergraduate students' perception is measured predominantly	✓
	The main focus of the paper is employability/professional skills	✓
3-stars	Student perception is just one of the factors measured	✓
	Employability skills measured indirectly through course/subject outcomes	✓
	Undergraduate engineering students not focussed exclusively	✓
2-stars	All the focus areas are loosely studied	✓
	Indirectly covers the topic area	✓
1-star	The focus area may or may not have been studied. It can only be verified in full text.	✓

Using the star rating resulted in 38 papers with ratings of 3-stars or less and 28 papers of 4- and 5-star ratings. Of the 28 papers, five papers were excluded after reviewing the full-text as the conditions of our selection criteria fully emerged while reading the full-text. Thus, after going through the whole systematic process, there was a final paper count of 23 papers, which have been reviewed, synthesised and reported on here.

Results

Ross et al. (2011) surveyed undergraduate engineering students studying in a large Midwestern University in the United States of America (USA) with a focus on the students' inclination towards lifelong learning and how they use their information skills to achieve this. They found that the students considered themselves competent at simpler information skills such as defining a problem, citing references and performing self-reflection, whereas the authors found that the students' confidence levels were low with more complex tasks such as critical evaluation, devising alternative solutions and planning courses of actions. The study showed that students lacked the know-how to source accurate and relevant information using various resources such as library databases, indicating a significant barrier to pursuing lifelong learning. They surmise that students who are particularly good at information skills are better at evaluating themselves (Ross et al., 2011). This relates to the limitation where students tend to inflate their competencies during perception surveys, a typical characteristic recognised in most of the papers using such a methodology. This limitation was also noticed by Cruz et al. (2021) where they noticed over-estimation of their skills by students of both undergraduate and postgraduate levels.

In order to determine the skills that undergraduate civil engineers view as crucial for their future engineering practice, Polmear et al. (2020) conducted detailed interviews with thirteen students as an exploratory study and compared the results with a framework derived from professional body guidelines and the expectations of industry practitioners. The authors investigated, out of the 19 competencies identified, how many competencies the students relate to their future success in their engineering careers. Unsurprisingly, there were

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widespread acceptance of the well-known competencies, with at least one student deeming 15 of the 19 competencies as important. Four competencies related to engineering, namely, economic fluctuations, engineering ethics, safety requirements, and legal issues, were not identified by even one student out of those interviewed. On the other hand, being passionate about one's job was considered important by the students but did not get featured in the employers' framework (Polmear et al., 2020). Additionally, an understanding of economic trends and business fluctuations by the engineers gained attention in many studies that, in turn, found that engineering graduates generally lack the necessary comprehension in this aspect (Chan & Fong, 2018; Goold, 2015; Martin et al., 2005).

In continuation of the Polmear et al. (2020) study, Simmons et al. (2021) surveyed undergraduate engineering students of eight universities in the USA, with a focus on the students' alignment towards their leadership identity. The students surveyed were from various majors and at various stages of their undergraduate degrees. Based on the theory of Leadership Identity Development (LID), which describes a six-stage leadership transition starting from seeing leadership in others to finally seeing it in oneself, the authors have reinforced the view that leadership qualities are not inherent and rather cultivable. This stresses the importance for educators to identify the students who are in the early stages of this transition and nudge them towards completion by utilising course designs (Simmons et al., 2021).

The impact of the problem- and project-based learning on student perceptions were studied by Mohd Salleh and Yusof (2017) and Estévez et al. (2018), respectively. Although similar, problem-based learning is open-ended with groups of students working together to find a solution, whereas project-based learning has students working to achieve a set target (Chan & Sher, 2014). Yu et al. (2020) specifically studied the impact of project-based learning on students' ability towards collaborative teamwork. Even though working on industrial problems as part of problem-based learning has benefitted students in the form of academic successes and overall employability, some of the students identify a lack of cohesion between the academic supervisors and the industrial supervisors. Additionally, students have varying views about the independence and autonomy accorded to them by their supervisors (Mohd Salleh & Yusof, 2017). Having the students working on time-constrained project-based learning seems to have improved the project management skills of students with notable improvements in creativity, time management, and customer-focussed project deliveries (Estévez et al., 2018). Notable by its absence in these studies was a comparison of the perception before and after the problem- or project-based learning course.

'21st-century skills' was another recurring frame of reference in the literature to study engineering students' perceptions of employability skills (AlMunifi & Aleryani, 2019; Itani & Srour, 2016; Mekala et al., 2020; Tomić et al., 2019). Established by the Partnership for 21st Century skills in 2009, the P21 framework is aimed at making engineering students more suitable for the 21st-century workplace. In a study focussing on the impact of gender and medium of instruction on the Learning and Innovation skills and Life and Career skills defined in the framework, Mekala et al. (2020) found no relationship between the two factors and the two skillsets studied. The authors, however, did find a universal shortage of language proficiency across all the students surveyed, irrespective of the medium of instruction, prompting universities to address this concern.

Another set of skills studied, similar to 21st-century skills, was that of a global engineer (Goold, 2015; Jesiek et al., 2010). Stressing the importance of tacit knowledge and aligning the engineering activities to societal and economic needs, Goold (2015) found that engineering education hasn't caught up to the multidisciplinary profession that engineering practice has now become. In a study of undergraduate engineering students' perception of both technical and non-technical aspects of engineering practice in an Irish institute, the author found that there are significant shortfalls in the non-technical competencies required for global engineers, whereas such differences were not found in the technical skill requirements.

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Jesiek et al. (2010) found similar results with engineering students ranking lowest among the 15 skills measured, their ability to use engineering to cater to sustainability, the economy, and society's needs. The students ranked themselves highest in their ability in engineering ethics, teamwork, and decision-making. Additionally, even though the students thought that communication and the ability to work in a multicultural team are important skills to possess, they ranked themselves lowest in these skills. This study revealed that students do think that communication is something that can be developed and is not an innate characteristic (Jesiek et al., 2010).

Itani and Srour (2016) conducted a survey among the senior undergraduate engineers of many Lebanese universities to investigate how much of the gap between university education and industry expectation has been bridged. The authors found evidence of what can be termed as the Rosenthal effect, where engineering students who wished to pursue a non-technical or managerial career gave more importance to the non-technical skills and thereby rated highly, both the importance of the skills and their own evaluation of their skill levels. Chan and Fong (2018) have also found that career aspiration is a vital extrinsic motivation for students to develop their professional skills.

Another outcome from the paper by Itani and Srour (2016) was that the students' perception of engineering and the associated technical skills faced a declining trend as they progressed through their degrees. This could possibly mean that students are disappointed with what an engineering degree entails and a realisation that the field is not what they expected. The authors also state that a lack of the requisite non-technical skills may potentially make it difficult for engineers to transition into a senior management role, and even when they do, it could lead to a career downfall or 'derailment'. This link between career aspirations and imparting of non-technical skills is a factor for universities to consider in designing courses.

Perhaps the most important insight that emerged from the literature review was the impact of internships and work placements on student perception. Lee and Chin (2017) found that students in Singapore who take up engineering following the polytechnic pathway are better at meeting the employer requirements than those students who come from the junior college pathway. This is mainly due to the former pathway offering twice the duration of work placement to the students than the latter. Acknowledging that work placements and internships cannot be universally provided to all engineering students without diluting its impact, Thirunavukarasu et al. (2020) suggests universities co-develop courses and subjects along with the industry partners. The authors suggest promoting a mutually beneficial relationship between the universities and the industries where real-life problems can provide opportunities on which academic innovators can work.

Mark et al. (2018) have found that some of the skills that are needed for self-employment, freelancing and thriving in the gig economy for engineering students are only available at the postgraduate level. They found that STEM students are better with digital literacy than non-STEM students, with the latter having a generally better perception of their own employability skills than the former.

Creativity, innovation and problem-solving, factors that are crucial for success as entrepreneurs, were studied in the papers by Gerhart and Carpenter (2008) and Gerhart et al. (2015). In the 2008 paper, the authors studied the change in perception of engineering students on aspects related to creativity after completing a creative problem-solving course. While before the course, the students did not associate creativity with engineering, after the course, there was a significant change in this perception. From associating creativity with only artists and musicians, the students realised that engineers could also be creative. In the 2015 paper, the authors found similar results after the students engaged with a summer camp aimed at promoting creativity among engineers. The authors also found that after engaging with the summer camp, the students were no longer worried about their solutions failing while solving problems (Gerhart et al., 2015), a very useful attitude to possess as an entrepreneur. These

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two papers further reinforce that specific skills can be imparted to the students by designing the curriculum and co-curricular activities suitably.

Discussion and future research

From the systematic literature review conducted, one important insight had emerged when it comes to measuring the student perception of employability skills. There are two perceptions to measure:

1. The skills that engineering students perceive are important for their employability.
2. How the engineering students perceive their skill level.

We feel that it is important for future researchers to measure both in order to tailor the curriculum to suit the student needs. These two approaches to employability skill perceptions are related in such a way that in order to measure students' perceptions of their employability skillset (2), these skills must be described in some way to the students. A suggestion for a combined study would be a survey requiring open-ended responses for identifying important employability skills (1), which could then be analysed for keywords, and students rate their perceived skill for each of these components (2). Semi-structured interviews would also allow students to identify and then rate their skills. Comparing the skills identified in (1) with the accreditation requirements and/or employer expectations would also be valuable.

It is also vital that more studies focus on measuring the perception before and after a particular course that has been specifically designed to improve the students' professional skills or at various points through a degree. Of the seven papers that measured the professional skills after completion of such a course/program, only the papers by Gerhart and Carpenter (2008), Gerhart et al. (2015) and Estévez et al. (2018) measured the 'before' values for comparison.

The disadvantage with self-perception surveys vis-à-vis the inflation of one's own abilities is still yet to be successfully overcome. Chan et al. (2017) and Cruz et al. (2021) are the only authors in this systematic literature review to have focussed on the reliability of the perception survey mechanism. This disadvantage is compounded by the challenge in reliably quantifying the actual employability skills of students. This systematic review has offered insights into the stressors that need to be accounted for in future student perception studies, especially given the COVID-19 pandemic and the restrictions that it has enforced on tertiary education. Of note are the questions surrounding how the students view their skill level when it comes to teamwork, problem-solving and communication in a digital learning medium. It is possible that a lack of face-to-face interaction inside the classroom and challenges faced in offering internships may have resulted in changes in self-perception, with skills such as digital literacy prominently coming to the fore.

This review will form the basis of a future study investigating the perception of students who were forced into an online and remote mode of education and virtual internships due to the pandemic. In the longer run, it would be useful to compare the student perception and engagement across different professions. Professions like legal practice and medical practice do not expect their graduates to be full-fledged professionals from the day they graduate. The employers are part of the transition in their professional identity wherein there is a duration of work placement that helps the medical and law graduates to gain some valuable tacit knowledge. The engineering profession, on the other hand, has moved away from this practice significantly, and as seen from the literature review, employers have started to expect ready-made engineers from universities. It is an opportunity to investigate what this means to engineers as the problem-solvers and the infrastructure builders of society.

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Service-Learning Remotely: Lessons from Delivery in Humanitarian Engineering During the COVID-19 Pandemic

ABSTRACT

CONTEXT

Service learning plays an important role in developing globally minded engineers who are more socially engaged. This paper reviews lessons learned from the development and delivery of an undergraduate final year elective in humanitarian engineering, focusing on experiences drawn from working with industry partners and the transition to online delivering during the COVID-19 pandemic. The unit of study forms the culminating class for students completing the Humanitarian Engineering major at the University of XXXXX.

PURPOSE OR GOAL

Service-learning pedagogy has seen increasing uptake by engineering programs aiming to broaden learning outcomes. For the growing field of humanitarian engineering, service-learning has been a core pillar of how programs are delivered. However, previous research has highlighted the potential risks posed by humanitarian engineering fieldwork and sustainable funding to support international placements is precarious – limiting the number of students who can engage, and potentially, the longevity of such programs. This work aimed to identify best practice in remotely delivering service-learning projects, including their potential to improve student engagement during online delivery.

APPROACH OR METHODOLOGY/METHODS

We use case study methods to examine lessons learned from the development and adaptation of collaborative industry partnerships as part of a series of service-learning projects over three years. Drawing on student evaluation data and unit of study materials, we draw out important considerations when designing international service-learning projects. We cross examine yearly changes to curriculum to identify the impact of pedagogical shifts in delivery and their impact on student learning.

ACTUAL OR ANTICIPATED OUTCOMES

Our results demonstrate the importance of collaborating industry partners not only for the sustainability of service-learning efforts in communities, but also as a medium to expand understanding of the professional context of work with low-income and marginalised communities. We also discuss the benefits of service-learning to partner organisations and communities – namely the development of leadership roles and challenging engrained practices.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The post-pandemic environment offers an opportunity to critically evaluate service-learning delivery modalities and test new methods. Our approach shows promise as a means to scale access to international opportunities for students while mitigating potential negative risks to communities.

KEYWORDS

service learning; humanitarian engineering, COVID-19

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Introduction

The use of service-learning has seen significant growth in the field of engineering education (Bielefeldt et al. 2010), providing a model for engaged educational delivery. Bringle and Hatcher (1996 p. 222) define service learning as *“a credit-bearing educational experience in which students participate in an organized service activity that meets identified community needs and reflect on the service activity in such a way as to gain further understanding of course content”.* The rise of service learning in engineering programs is at least partly an extension of a signature pedagogy (Shulman 2005) focused on project-based learning.

For the consolidating field of humanitarian engineering, service learning has become a core pillar of its identity. The socially engaged focus has been heralded as a pathway to improve gender diversity and equip engineers to meet increasingly complex and interdependent global development challenges (Smith et al. 2020). However, while much of the focus of humanitarian engineering has been on *exposing* students to the principles of socially responsible engineering, there remains comparatively less focus on *‘how’* engineers will be asked to perform these roles professionally. Attracting a diverse cohort humanitarian engineers is no doubt a positive shift, but we need to mobilise and translate this empathetic form of understanding community needs into action. There is a growing disconnect between the passionate cohorts of students pursuing these education programs and career pathways available to them (Litchfield and Javernick-Will 2016). The workplaces that await socially engaged engineering students upon graduation may not be matching expectations, at least in part, because of how we delivery content – a gap that has yet to be fully explored in engineering education research.

A second, and equally important question surrounding pedagogy of humanitarian engineering, is its sustainability – both its social (e.g. Birzer and Hamilton 2019) and economic dimensions – for students and the communities served through curriculum collaborations. Traditionally, the delivery of content has relied on extracurricular activities (e.g. Engineers Without Borders), small and costly modules (e.g. overseas field schools), or through knowledge external to university institutions (e.g. guest lecturers). These characteristics are not necessarily unique to humanitarian engineering, but they do perhaps represent a higher percent of content delivery as compared to other disciplines, placing the attainment of learning outcomes at risk when disruptions arise. There is a need to interrogate and assess how service-learning is delivered, not only to shape more effective learning outcomes, but also ensure the longevity of efforts to train engineers capable of addressing the needs of marginalised communities.

This research aimed to examine pedagogical approaches to better align humanitarian engineering curriculum and practice. We first provide a brief overview of service learning as a pedagogical approach, humanitarian engineering as an emerging field, and gaps in current knowledge in engineering education at their nexus. We then present a case study of the development and delivery of a final year humanitarian engineering elective over three years to explore learning outcomes and lessons from working alongside industry partners to shape student experiences.

Methods

We adopted a descriptive case study approach as our aims were process-oriented (Case and Light 2011; Yin 2018). There are relatively few humanitarian engineering depth electives currently offered in Australia, and even fewer that have been offered for multiple consecutive years. We (both authors) draw on our own experience in the delivery of a unit of study ideal unit to examine the pedagogical approach, student feedback, and lessons relating to the delivery of service-learning in an established humanitarian engineering program.

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The Case: XXXXX

The University of XXXXX currently offers a major to engineering undergraduate students (Thomas et al. 2017). The major is designed around four subjects taken in a student's third and fourth year of study. The first unit of study is a third-year introduction to humanitarian engineering (XXXXX), which provides a broad overview of global development institutions, relevant standards (e.g. Sphere), and the role of engineers in addressing the Sustainable Development Goals. Students are also required to complete a Global Engineering Fieldwork unit of study (XXXXX), which involves an overseas placement, and a breadth elective. The breadth electives include a range of relevant topics including Understanding Southeast Asia (XXXXX), International Project Management (XXXXX), Global Poverty and Education (XXXXX), and Disaster Relief Operations (XXXXX). The fourth unity of study, Engineering for Sustainable Development (XXXXX), provides further depth which build upon concepts covered in the introductory Humanitarian Engineering (XXXXX).

This case study will focus on the development of the final year unit, XXXXX, which forms the culminating class for students completing the humanitarian engineering major. The class was first offered in 2018 and has subsequently been offered in 2019 and 2020. The unit of study intends to provide engineering students with an understanding of principles of engineering for sustainable development. Topics include the history of international development, project tools for working with developing communities, and exploration of current trends in areas of global development practice. Material focuses on the application of engineering in marginalised communities which address complex and uncertain problems using systems thinking, inter-disciplinary approaches, partnerships, and policy. Upon completion, students should be able to:

1. Understand the history and legacy of engineering in development and humanitarian practice.
2. Converse in and critically examine sustainable development theories, frameworks, and debates.
3. Develop sustainable engineering solutions using incomplete or limited data from multiple sources to address complex social, economic, and environmental challenges facing developing communities.
4. Apply engineering toolsets to needs assessment, project planning, monitoring, evaluation, and learning (MEAL) in developing community contexts.
5. Choose participative approaches and tools in project planning, implementation, and evaluation to inform more inclusive engineering designs.
6. Convey engineering analysis to multi-cultural audiences to inform effective technical solutions and policy recommendations.
7. Employ appropriate teamwork skills across project phases to address development challenges.
8. Apply ethical and appropriate judgement in development practice while introspectively examining positionality.

The unit of study was developed with a strong service-learning pedagogical approach. Students work in small teams over the duration of the semester on an engineering design to address a real problem facing a community, with industry partners act as a bridge between students and communities. The first two years the class was offered involved multiple partners, allowing students choice in their projects. In the last year considered in this case study (2020), a single partner was used, and students worked on the same project. Previous partners have involved non-governments organisations, foundations, and engineering firms with projects located in Afghanistan, Indonesia, the Philippines, Samoa, South Africa, and the Solomon Islands. Examples of projects have included the design of a community water system, a bridge feasibility study, flood control assessments, improvements to brick production for safer earthquake construction, improving medical equipment maintenance systems.

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In 2020, the unit was offered entirely online due to the COVID-19 pandemic. The content remained largely unchanged from the first two years of delivery, giving an opportunity to assess the learning outcomes and lessons from delivery which still used an underlying service-learning approach, but relied on remote interactions.

Findings

There have been several lessons from the iterative development of the considered unit of study. Foremost, both students and industry partners reflected in evaluations that it wasn't just the service-learning component alone that led to positive learning outcomes, it was situating this within real-word project boundaries. For example, one student commented, "*This subject teaches engineering in the context of the real world - it's invaluable to learn how to deliver a real project to real people rather than an assignment for marks."* Another student mentioned, *"I think the project was perfect for our skill level and gave an excellent introduction into what a career in humanitarian engineering could look like."* One way this was accomplished was by ensuring that student teams were paired with an industry partner who served as a focal point of contact, but still in the context of a 'community'. This assisted in both logistically coordinating across diverse international project locations with a responsible level of oversight, but also served as an exposure opportunity to professional norms.

An added benefit of using multiple types of partners was greater student awareness of the differences in the operating practices across industries (e.g. non-profit vs consulting firms). However, in 2020, only one partner was used out of necessity due to demands of transitioning content to online delivery in the pandemic. While there was some diminished benefit in breadth of exposure, a single project for all student teams was found to provide an opportunity to explore specific technical, social, and cultural dimensions in greater depth. This also assisted in streamlining logistics in coordinating assessments.

A consistent theme that emerged across multiple cohorts of students is the value they placed on accountability. A student commented, "*The final project was a great experience. Having the freedom to think critically and design solutions on our own- and be accountable for those solutions - was really rewarding."* Much of this was anchored through assessments that aligned with chronological project tasks throughout the semester, guiding students through a project cycle from start to finish in a compressed, but realistic timeline.

Students have overall been receptive to the unit of study approach. Table 1 shows a summary of unit of study evaluations and enrolment numbers for the three years of offering.

Table 1: Unit of Study Survey (USS) Evaluations

Year	Enrolments	USS Score	School	Faculty	University
2018	21	4.79	4.16	4.03	4.10
2019	11	4.61	4.15	4.03	4.11
2020	16	4.78	4.06	4.01	4.11

Note: Evaluations shown on 5-point scale.

Discussion

Our findings have several implications for both theory and practice. Foremost, we need to be careful assigning uniform meaning to 'service-learning' – there are multiple pedagogical orientations that can emerge under this umbrella. While past literature has often placed importance on students working directly with a community, our case study shows that students often retain a socially engaged identity benefit without this direct interaction and there may be similar benefits to working with partner organisations. This is promising for

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considering how humanitarian engineering programs might be scaled. At present many universities currently rely on overseas field placements to achieve similar learning outcomes. There are examples of remotely managed relationships, such as the Engineers Without Borders Challenge offered to first year students, but few of these exist at later candidature stages.

One of the primary criticisms of humanitarian engineering pedagogy is its reliance on international placements (Birzer and Hamilton 2019; Vandersteen et al. 2009). While the student projects in this case were not immune to negative impacts that others have previously raised, relying on established organisations who are working in communities mitigated many of these risks. The academic debate has often focused on the lack of benefit to communities – what surfaced through multi-year partnerships was that there were benefits, but perhaps not what might be expected. It was often not the technical solutions, but rather student's line of inquiry and questions which led to organisations and communities to questioning engrained practices.

While our case study does not provide a direct comparison between learning outcomes achieved through in-person and remote service-learning projects, but it does take an initial step to demonstrate the potential role of the latter. We are not suggesting that community placements be replaced by remote project experiences. Immersion activities have undeniable importance for cross-cultural experiential learning. What we are suggesting is there is a need to more closely examining *where* learning outcomes are best achieved. Given the cost and time required to deliver overseas fieldwork units, it is important to identify where comparable learning outcomes can be achieved.

Conclusion

We have presented a case study of a final year humanitarian engineering elective, examining lessons on the development and delivery. Our results advance understanding of service-learning pedagogy and its evolving role in humanitarian engineering programs. We raise the importance and potential of industry partners to both mitigate identified risk for students working with marginalised communities and expand understanding the professional context of career pathways. Ours results offer recommendations to those seeking to expand humanitarian engineering programs or applying service-learning models in engineering curricula.

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Engaging remote students in traditionally physical experiential learning environments (mechanical workshops)

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CONTEXT

2020 saw many Universities transition learning activities from in person to online or remote delivery methods due to the COVID-19 pandemic, in semester 2 some classes returned to on-campus delivery. MECH1400 Mechanical Construction is a first-year unit of study that introduces students to the engineering design cycle, drawing and machining techniques through an experiential design and build project, utilising traditional mechanical engineering machining equipment such as lathes, mills, and hand tools. In semester 2 of 2020 students were offered the choice of attending on-campus classes or remote offerings, with 41 of 73 students choosing to study on campus (note some were overseas with effectively no choice).

PURPOSE OR GOAL

The purpose of this study was to investigate whether online/remote delivery of learning activities can enable remote students to achieve equivalent learning outcomes as their on-campus peers, particularly as the unit is traditionally taught with experiential learning activities based around a mechanical workshop environment.

APPROACH OR METHODOLOGY/METHODS

This study analysed and compared student results for assessment tasks for on-campus and remote students, plus other factors such as Canvas access rates and class attendance. Informal tutor feedback and end of semester institutional student satisfaction survey comments were examined to gain further insights.

ACTUAL OR ANTICIPATED OUTCOMES

On-campus students had higher average marks for all assessment tasks (7.3% - 13.5%); despite remote students having an average of 29.8% more page views on Canvas.

End of semester student satisfaction surveys indicate that students prefer the physical workshop sessions to online tutorials and workshops, though limited comments were available.

Informal tutor feedback indicated that students were less engaged in the online learning activities, with some online students not attending their "virtual" workshop sessions, and online only tutorials having low attendance for both the online and physical cohorts.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Remote students achieved a final mark for the unit that was on average 9.9% lower than their on-campus peers, despite having a 29.8% higher Canvas access rate. Two conclusions are arrived at: The online learning activities need further development to help reduce or eliminate this difference for the 2021 student cohort and/or further investigation needs to be undertaken to establish why the online cohort are not better engaged with the online curriculum.

KEYWORDS

Remote learning, experiential learning, student engagement

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Introduction and background

2020 saw many Universities transition learning activities from in person to online or remote delivery methods due to the COVID-19 pandemic. By the second half of the year opportunities to return to face-to-face classes existed for many Australian Universities, with the University of Sydney offering many units in both online and/or on-campus modes.

MECH1400 Mechanical Construction is a first-year Unit of Study (UoS) that introduces Mechanical Engineering students to the engineering design cycle, drawing and machining techniques through a predominantly hands-on design and build project, utilising traditional mechanical engineering machining equipment such as lathes, mills, and various hand tools. The unit discussed in this paper follows a previous semester unit (MECH1560) in which students were introduced to basic machining techniques and processes, utilising much of the same machining equipment. In 2020 classes were moved online in week 5 of semester 1, and consequently students undertaking MECH1400 in semester 2 generally had little or no experience with hands on machining.

Experiential (EL) and Problem Based Learning (PBL) can be effective tools for developing engineering knowledge and skills in a mechanical engineering workshop environment (Abellán-Nebot, 2020; Li et al., 2019; Malicky et al., 2010; Wood et al., 2005), improve students social connections and confidence in their learning (Bhute et al., 2021; Pamungkas et al., 2019), and should help achieve many of the learning outcomes for this introductory unit of study, particularly outcomes L02, L03 and L04 as listed below:

- **LO1**. apply statics, dynamics, and thermodynamics analysis methods to real design problems
- **LO2**. undertake a simple design and build project from conception to completion
- **LO3**. apply theory and analysis to real machinery, use of machine and hand tools
- **LO4**. demonstrate basic workshop skills, learning to use machine tools for production of complex parts
- **LO5**. undertake research into existing design as part of developing new design
- **LO6**. place the mechanical engineering profession in historical context
- **LO7**. use self-reflection and critical thinking to improve your learning skills.

Learning activities in this UoS revolve around a central PBL major design project, with groups designing and building a small reciprocating compressed air motor as a team of 3-4 students. 50% of the final marks for the unit are related to this project, as listed in Table 1. The material is delivered weekly via a 1-hour lecture, 1-hour tutorial and 3-hour workshop session.

Table 1 Assessment Structure

Task	Weight	Group or Individual
Ass. 1 Steam engine historical research report	20%	Individual
Ass. 2 Design proposal	10%	Group
Ass. 3 Progress report	15%	Group
Ass. 4 Final report	15%	Group
Ass. 5 Project outcome	10%	Group
Ass. 6 Reflection report	10%	Individual
Ass. 7 Quiz	20%	Individual

Students start the unit with an individual research task related to the historical development of steam and air engines, the materials used, manufacturing processes, basic mechanics,

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and other considerations. The main group design project is introduced in week 3 and consists of 4 deliverables:

1. Design proposal report that provides background information, engineering analysis and material selection to determine component sizing, a machining resource plan and basic engineering drawings of the proposed design solution and a project plan.
2. Progress report provides summary of group progress, an updated Gantt chart, breakdown of required components to be manufactured and resources required, plus fully detailed orthogonal drawings following AS1100.
3. The final report includes elements of the previous reports, plus a reflection on group performance, and final drawings with the addition of an assembly drawing.
4. Project outcome (this is the only assessment task that differed for on-campus and remote students):
    a. On-campus – The students' air engines are tested and assessed for general machining quality, tolerances and surface finishes, aesthetics, and complexity. Devices are required to run for at least 1 minutes.
    b. Remote – Students submitted a Solidworks model that was required to demonstrate full kinematic functionality and theoretically be able to perform if machined. Students also presented a short talk outlining how their device works, why they designed it as they did etc.

The final two individual tasks are:

- Reflection quiz is a self-reflection written report with students' critically reflecting on two learning activities from the UoS, and how they intend to use those activities to improve their learning in the future.
- Quiz is a 48hr take home written task that assessed students' learning in the entire course, including tutorial and lecture material.

In semester 2 of 2020 students were offered the choice of attending on-campus classes or remote offerings, with 41 of 73 students choosing to study on campus. Of the 32 students that chose to not attend on campus classes, 22 were not in Australia (and unable to return).

The only assessment task that was modified for remote students was the final project outcome (Ass. 5), as they were not able to physical manufacture and test their device, and instead were required to virtually "construct" their device in Solidworks and then demonstrate kinematic functionality via a short talk and video demonstration.

Purpose of study

The purpose of this study was to investigate whether online/remote delivery of learning activities can enable students to achieve equivalent learning outcomes as their on-campus peers; and whether remote students are less engaged in the unit, particularly as it is traditionally taught with experiential learning activities based around a mechanical workshop environment.

Methodology

This study analysed and compared student results for assessment tasks for on-campus and remote students; plus, other factors such as: Canvas access rates, attendance workshop sessions (on-campus or online). Informal discussion during and after semester was held with tutors and end of semester student survey comments also examined to gain further insights.

Assessment results

Students' assessment mark outcomes for all tasks were averaged for on-campus and remote students and the results presented with box and whisker plots, showing means and quartiles.

Class attendance

Student attendance was recorded and collated for both on-campus and remote/online workshop sessions.

Canvas access rates

Student use of Canvas was analysed and compared for on-campus and remote students

Tutor feedback

Tutor feedback was sought informally throughout semester during regular meetings and at the end of semester.

End of semester student survey

Student comments from the regular institutional end of semester student satisfaction survey were reviewed for comments of relevance.

Results and discussion

Student assessment task results

Figure 1 presents box plots of the mean marks (mean shown as X) for all assessment tasks, comparing remote and on-campus students, tasks are plotted left to right in the chronological order of completion. On-campus students achieved higher assessment marks for all tasks, ranging from 0.8% (Ass 5 - Project Outcome) to 13.5% (Ass 1 - Historical report and Ass 4 – Final Project Report), however it should be noted that significance tests were not performed. Of the tasks, the requirements were the same for all students except Ass 5 (which could henceforth be excluded from discussion).

Of particular interest is the first assignment – 'Historical Research Report', as it is due early in semester in week 3 and is not dependant on students having attended any workshop sessions; it could be expected that there would be no difference in marks for this task between the remote and on-campus cohorts. Similarly, assignment 6 is an individual written reflection assignment and it could be reasonably expected that this mark would not differ between the cohorts. Comparing tasks 2, 3 and 4 it can be observed that for both cohorts of students the mark increased, possibly as students used feedback effectively to improve the quality of their submitted drawings and written reports (groups were marked by the same tutor for the major project assignments).

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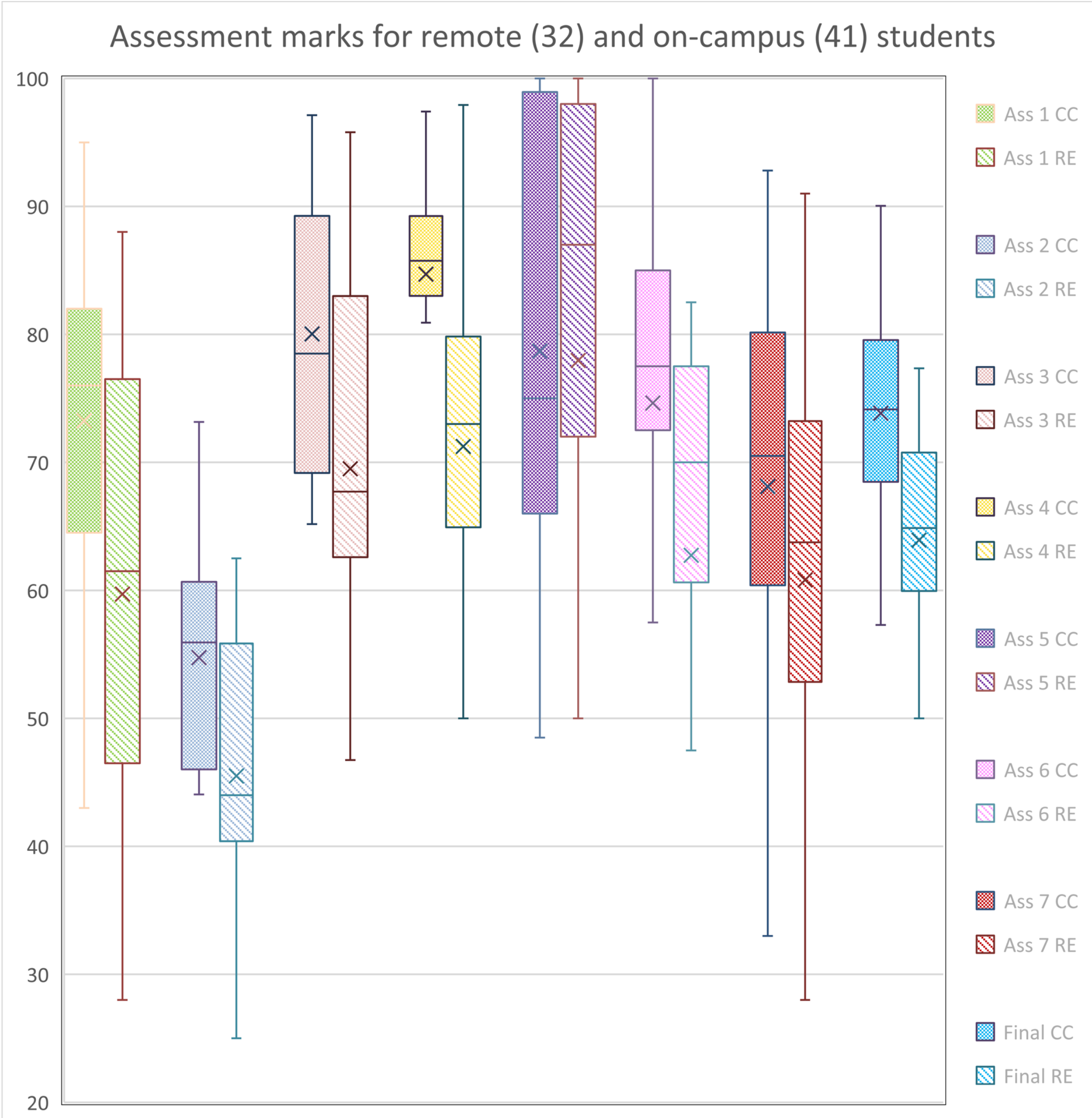

Figure 1 Mark comparison for remote (RE) and on-campus (CC) students for all assessment tasks

Class attendance

Figure 2 summarises workshop session (dedicated for major project work) attendance for both student cohorts. Note that workshop sessions did not start for remote students until week 4; on-campus students were completing general workshop safety inductions and equipment training in weeks 2 and 3. It is apparent from the plots that remote student attendance is lower than on-campus attendance for every week.

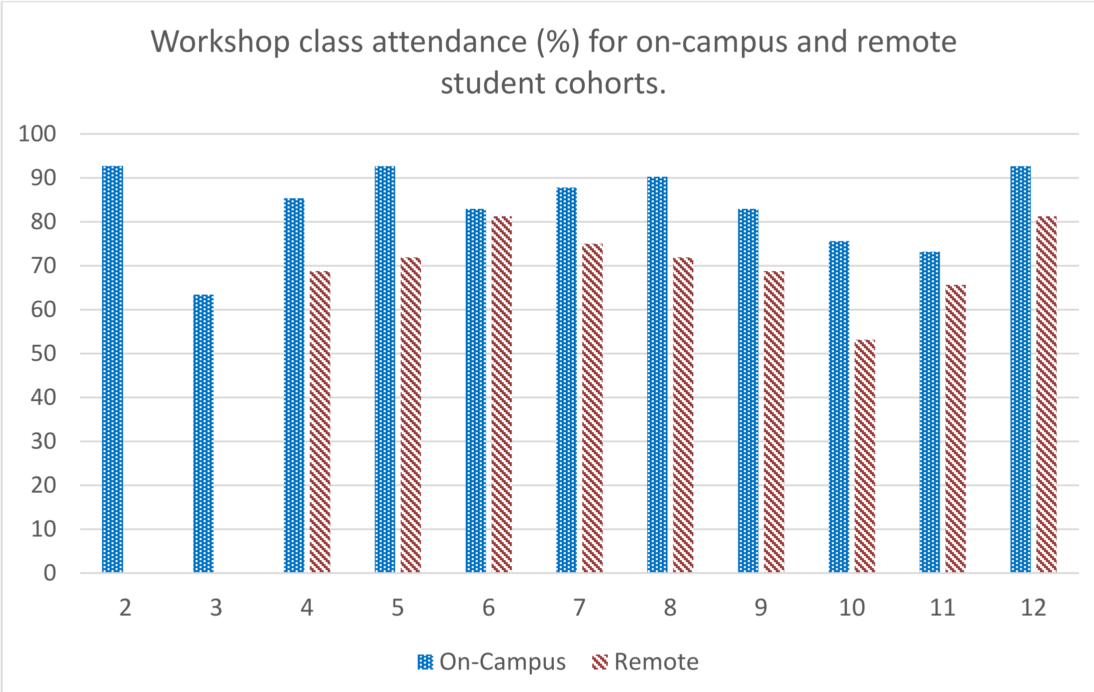

Figure 2 Workshop class attendance (%)

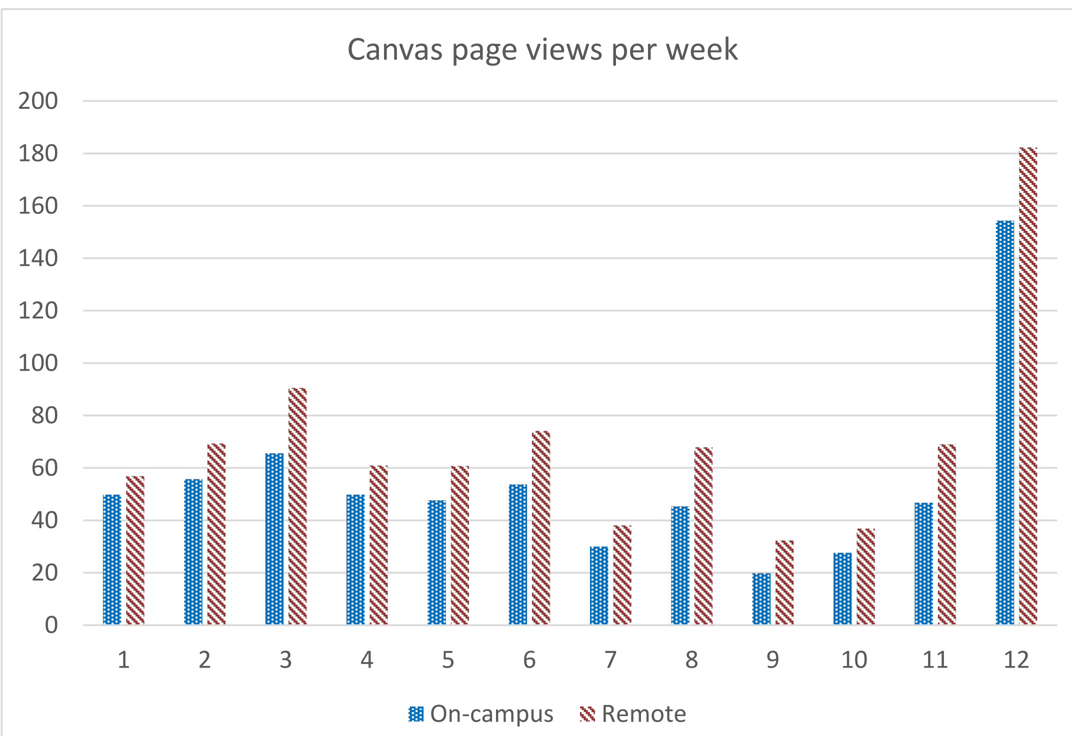

Figure 3 Average weekly Canvas page views per student

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Canvas access rates

Figure 3 plots the average number of canvas page views per student for the on-campus and remote student cohorts for active teaching weeks. Note that remote students consistently used Canvas more than on-campus students, an average of 29.8% more over the 12 weeks.

Tutor feedback

Informal tutor feedback throughout and after semester indicated that students were less engaged in the online learning activities, with some online students not attending their "virtual" workshop sessions. Online only tutorials (different to workshop sessions) that expanded and applied material delivered in lectures had low attendance for both the online and physical cohorts.

End of semester student survey

End of semester student comments from the routine institutional student surveys (USS) were reviewed for relevant comments, with those of most relevance to this study presented below:

Question: What have been the best aspects of this unit of study?

- *Workshop aspect is enjoyable.*
- *The teacher of the workshop taught very well and professionally. He helped me a lot.*
- *The physical workshop was extremely useful and fun.*
- *Give us great many chances of creations*
- *The laboratory, practical stuff was really good, learnt a lot about machining and actual information that will help me in the future*
- *Best unit ive had this year. Made friends learn how to communicate in engineering terms*
- *Making something physically*
- *The fact that we actually make something.*
- *The best aspect of this unit is that we can design our own engine.*
- *in person workshop!*
- *Physical labs. Excellent opportunity to learn.*
- *I have learned a lot throughout the course and had a great time! Our tutor is extensively supportive and is trying to help every single time I have asked a question. We also went over the workshop time since we have too many questions to ask. Our tutor has also helped us outside of the virtual workshop by responding to a number of emails we sent.*

What aspects of this unit of study most need improvement?

- *After returning to school, I hope the teacher can arrange us for more practical operations.*
- *If the tutorials were in person then they would be more helpful and engaging.*
- *More manufacturing guides for virtual pathway if there will be any in the next semester*
- *Online aspects of presentation such as the tuts*

General observations and discussion

On-campus students received an average final mark for the unit 9.9% higher than students studying remotely, and this was reflected across almost all assessment tasks (exception of the project outcomes task which was assessed differently).

On-campus students had an average workshop attendance rate 14% higher than remote students, this is likely because they needed to physically machine their device components and remote students may have only sent some of their team to the online workshop session to seek help from the tutors, though they were all expected to attend.

Remote students however had a 29.8% higher Canvas access rate which is a large difference and may indicate they were seeking more information than their on-campus peers or reviewing lecture and other material more often.

Of particular interest is the mark difference for the individual tasks not directly associated with the major group project, with the on-campus students receiving an average mark 10.9%

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higher in individual tasks than the remote cohort. This is interesting as only the workshop components (group project) had on-campus activities (workshop sessions) so it could be expected that there be no difference in remote and on-campus results for the individual tasks. It is possible that remote students were generally less interested and engaged in the unit due to their experience being entirely online, however, assignment 1 was due at the end of the first three weeks, and it could be reasonably expected (and hoped) that students would not have lost interest in the first few weeks! It is also possible that differences are due to approximately 2/3 of the remote students being offshore with English as a second language; these observations are worthy of further investigation.

For the major project tasks, it can be observed that both cohorts improved their marks for the three group report tasks by 30% (on-campus) and 25.7% (remote) which may indicate that students were learning from the unit and using feedback to improve their teamwork, report writing and engineering drawings skills, a positive outcome.

Another potential reason for the lower mark outcome for remote students is the different environment for teamwork collaboration, online and face to face, though in the authors' experience it is certainly possible for students to participate effectively in teams in an entirely online environment using Zoom, Google shared documents and other collaborative tools.

Conclusion and future work

It is very difficult to replicate all experiential learning outcomes in an online environment, and particularly so when the activities involve hands-on aspects such as using workshop machining equipment. Videos of machining processes can be used but cannot replace a true hands-on experience. Student comments from the end of semester survey indicate they enjoyed the hands-on workshop experience and were potentially more engaged in that activity.

The use of Solidworks by students to create a virtual 3D working kinematic model of their design was beneficial as it improved the students' knowledge and skills with solid modeller packages, helped them visualise their device in 3D simulated motion, thus helping their understanding of basic machine design and functionality.

One alternative to the complete separation of on-campus and remote students would be to create teams of students that combine on-campus and remote students, with remote students observing some of the live on-campus workshop sessions via Zoom or similar technologies. This was not used in 2020 as previous experience has found groups generally need 3-4 members to physically complete their devices in time, and larger groups would potentially mean students may not contribute at the expected level in group report writing, drawings etc.

(Wood et al., 2005) found that many students studying engineering are coming from a background where they have spent more time playing computer games than 'tinkering' with machines and tools, it seems likely that developing virtual resources using gamification could benefit modern students. The 'lathe safety simulator' is one such example http://www.lathesafetysimulator.com/

There are several proposals that could potentially improve the learning experience for remote students in future offerings of this unit (and similar ones):

1. More extensive use of machining videos and in particular ones filmed in the actual student workshop, with their fellow student peers.
2. Potential use of 360degree VR videos to create a better feeling of immersion in the workshop environment.
3. Hybrid groups with on-campus and remote students with live Zoom cross-over sessions for remote students to observe workshop activities.

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Unfortunately, due to COVID-19 related stay at home orders for Sydney from late June onwards in 2021 it was not possible to run physical workshop sessions and the entire student cohort completed their project in an online "virtual" form in 2021. More extensive use of videos and potentially also live Zoom sessions showing workshop technicians machining student designs is being considered for 2021 to help achieve the learning outcomes related to machining. The authors intend to continue this study.

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Impacts of Emergency Online Instruction on Engineering Students' Perceived Cognitive Load during Learning Assessments

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ABSTRACT

CONTEXT

A primarily undergraduate military college shifted from face-to-face instruction to emergency online instruction in Spring 2020 due to the COVID-19 pandemic. We are examining student experiences with the shift using Cognitive Load Theory (CLT), which asserts that learning is hindered when cognitive load overwhelms finite working memory capacity. At the onset of the pandemic, we hypothesized that the need to manage learning in new and changing modalities may increase students' cognitive load and development.

PURPOSE OR GOAL

We seek to triangulate a previous finding that middle-years students experienced more cognitive load demands than either freshmen or seniors during the Spring 2020 semester. In this study, we examine cognitive load experienced by students in sophomore-, junior-, and senior-level civil engineering courses when engaging in various types of summative assessments. Our goal was to understand how academic course level and assessment type (closed-ended vs. open-ended) may have impacted cognitive load among students.

APPROACH OR METHODOLOGY/METHODS

We are engaged in a longitudinal mixed-methods study to explore the impacts of changing modalities on cognitive load and student development during the pandemic. For this study, we measured cognitive load experienced during five assessments administered across civil engineering courses of different academic levels using the NASA Task Load Index (TLX). The TLX is a rigorously-developed instrument that quantifies workload (a surrogate for cognitive load) across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. We used non-parametric analysis to identify differences in cognitive workload by course level and assessment type. We supplemented interpretation of findings through analysis of open-ended questions and focus group transcripts.

ACTUAL OR ANTICIPATED OUTCOMES

Sophomores and juniors experienced summative assessments differently than seniors, a finding that is consistent with our previous publications suggesting that modality changes may have disproportionately impacted middle-years students. Analysis of TLX data showed that sophomores and juniors reported highest time-demand and frustration, respectively, during closed-ended assessments. Open-ended assessments elicited significant frustration among juniors, a trend that was not observed for seniors. Qualitatively, both sophomores and juniors discussed workload-associated aspects of the modality shift more than seniors.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

We seek to further understand the unique experiences of middle-years students as a means for developing recommendations for managing cognitive load during online engineering courses – whether planned or unplanned.

KEYWORDS

Online learning, cognitive load, COVID-19

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Introduction

During the Spring 2020 semester, The Citadel (a public, teaching-focused, military institution in the Southeastern United States) shifted to an emergency online modality to protect the campus community's health and well-being during the COVID-19 pandemic. Prior to the pandemic, all undergraduate engineering programs at The Citadel were administered solely through face-to-face instruction. As such, the mandatory transformation to online instruction was an unprecedented disruption to our model for student learning and development. The pandemic's impact on course modalities persisted past the Spring 2020 semester, as most courses during the subsequent academic year used a hybrid modality.

We have been engaged in a project to understand the impacts of pandemic-induced modality shifts on Citadel engineering students' cognitive load and self-directed learning readiness. Our inquiry into cognitive load changes has been guided by Cognitive Load Theory, which characterizes learning as assimilation of knowledge into one's long-term memory after preliminary processing by short-term (working memory). If the cognitive load associated with a task exceeds short-term processing capacity, then learning cannot occur (Sweller, 2011; Paas, et al., 2003). At the onset of the pandemic, we hypothesized that the need to manage learning during changing modalities may increase students' cognitive load and readiness for self-directed learning (McCune et al., 1990), perhaps with interaction between the two.

To test our hypotheses, we administered a multi-part survey to our students twice during Spring 2020. At midterms, students used the NASA Task Load Index (TLX) to reflect on the workload (a surrogate for cognitive load) associated with face-to-face engineering courses. The TLX assesses cognitive workload across six sub-scales: mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart, 2006). At finals, students used the TLX to reflect on load associated with their emergency online engineering courses. Open-ended feedback was also collected at the end of the semester.

To date, our preliminary analyses suggest that cognitive load and self-directed learning readiness indeed increased over the course of emergency online instruction. Interestingly, we have found that students across academic years may have experienced cognitive load differently, with middle-years students (i.e., sophomores and juniors) reporting an increase in more workload sources than either first-year students or seniors (Watson et al., 2021).

The goal of this study to triangulate our finding of increased cognitive load among middle-years students using additional quantitative and qualitative data (Heale & Forbes, 2013). Specifically, we solicited NASA TLX responses from students enrolled in civil engineering courses to understand cognitive workload experienced during a variety of assessments administered across academic levels during emergency online instruction. Also, we present thematic analysis of select open-ended survey responses and focus group transcripts to generate deeper understanding of students' experiences during the modality shift, especially related to their engagement with summative assessments. In this paper, we will address the following research questions: (1) How might assessment type (closed-ended vs. open-ended) have impacted assessment-level workload across academic classes? (2) To what extent, if any, might assessment-level workload have varied across academic classes?

Methods

Target Courses and Assessments

We explored cognitive workload among students as a result of specific assessments in civil engineering courses across academic levels and assessment types (Table 1). At the sophomore level, workload data was collected in Statics and Geomatics courses. In Statics, students reflected on cognitive workload associated with a closed-ended, regular-semester test. In Geomatics, students reflected on cognitive workload associated with a hybrid assessment, which included closed-ended questions and a self-directed project (Brown et al, 2021). At the junior level, workload data was collected in Introduction to Environmental Engineering for a regular-semester test. At the senior level, workload data was collected in Geotechnical Engineering II and Environmental Lab. In Geotechnical Engineering II, students reflected on load associated with a regular-semester test. In Environmental Lab, students reflected on load associated with composition of a comprehensive report.

Table 1: Summary of courses in which students provided assessment-specific workload data.

Course	Assessment Description	Academic Level	Responses (Total Students)
Statics (CIVL 202)	Third (final) regular-semester test, which included closed-ended questions only	Sophomore	23 (50)
Geomatics (CIVL 208)	Third (final) regular-semester test, which included closed-ended questions and an open-ended, self-guided project	Sophomore	25 (44)
Intro to Env Engr (CIVL 322)	Third (final) regular-semester test, which included closed-ended questions only	Junior	27 (34)
Geotech II (CIVL 410)	Third (final) regular-semester test, which included closed-ended questions only	Senior	21 (46)
Env Engr Lab (CIVL 419)	Comprehensive laboratory report	Senior	10 (42)

Workload Data Collection and Analysis

For each target assessment (Table 1), participants reflected on cognitive workload using the NASA TLX (Figure 1). Through Qualtrics, participants were prompted to provide 0-100 ratings for each of the six workload sources/dimensions: mental, physical, temporal, effort, frustration, and performance. We then computed a Raw (average) TLX score for each student and assessment. We omitted pairwise comparisons required to compute the Weighted TLX score, to shorten survey length and encourage participation. Previous studies (e.g., Hart, 2006) comment that raw and weighted scores usually show similar results.

Subsequently, we explored differences in cognitive workload associated with regular-semester tests administered across academic years during emergency online instruction. Raw TLX scores and source dimensions were compared between Statics (sophomore-level course), Introduction to Environmental Engineering (junior-level course), and Geotechnical Engineering II (senior-level course) using Kruskal-Wallis *H* tests (conducted using IBM SPSS Statistics 27). Distributions of workload ratings were similar for all groups, as assessed by visual inspection of boxplots. For significant findings, pairwise comparisons were performed per Dunn's (1964) procedure with Bonferroni corrections for multiple comparisons.

We explored differences in cognitive workload between closed-ended, regular-semester tests and other open-ended assessments. For students who provided workload ratings for closed- and open-ended assessments, we used Wilcoxon Signed Rank tests to compare Raw TLX scores and source dimensions. For workload ratings, difference scores were approximately symmetrically distributed, as determined by a histogram with superimposed normal curve.

Collection and Coding of Student Challenges

We collected and used qualitative data to understand experiences of our engineering students during emergency online instruction (Figure 1). As part of our larger survey, we asked students to respond to the question: "What challenged you most in your online classes this semester?" Two researchers reviewed each open-ended response (n = 277) to identify which dimension(s) of cognitive load, as defined in the NASA TLX instrument, were impacted by the switch to online learning. An additional code of “general/overall load” was added to capture statements about a change in load that lacked specific language to assign to one of the six dimensions. The researchers tried to assign codes as strictly as possible without reading into student comments; this was particularly challenging for the Frustration dimension, which could be broadly interpreted. They assigned statements to as few codes as possible, but did split up statements to pull out separate challenges that impacted cognitive load. Statements were coded as “none” if they were too vague to determine impact on load.

Focus Group Facilitation and Analysis

During July 2020, three focus groups were conducted via Zoom with engineering students, providing an opportunity to further reflect on their experiences with the switch to online learning (Figure 1). All participants were recruited from the pool of survey respondents. Each session began with a welcome, introductions, and review of guidelines for engaging in the focus group. With participant consent, the sessions were video recorded for purposes of accurately summarizing the focus group discussion and statements made by participants. Focus group questions related to three topics: (1) participants’ experiences with and response to the online learning shift, (2) how others’ responses (e.g., faculty, peers, etc.) helped/hindered their online learning, and (3) participants’ thoughts about the future.

The first focus group included three male, civil engineering majors; two juniors and one sophomore. The second focus group was attended by four male, senior-level participants. Three participants were civil engineering majors, one participant was a mechanical engineering major, and one participant was a veteran. The third focus group was attended by three participants, all women in engineering. Two were junior mechanical engineering majors and the third was a an employed, evening civil engineering student preparing to graduate.

Focus group discussions were summarized by two researchers and were reviewed for themes related to assessment-level experiences. For this paper, we considered overall sentiments of each group and more specifically the reflections of civil engineering students. The majority of focus group participants (7 out of 10) were civil majors and of the civils, all but one participant completed at least one assessment-level survey during the semester.

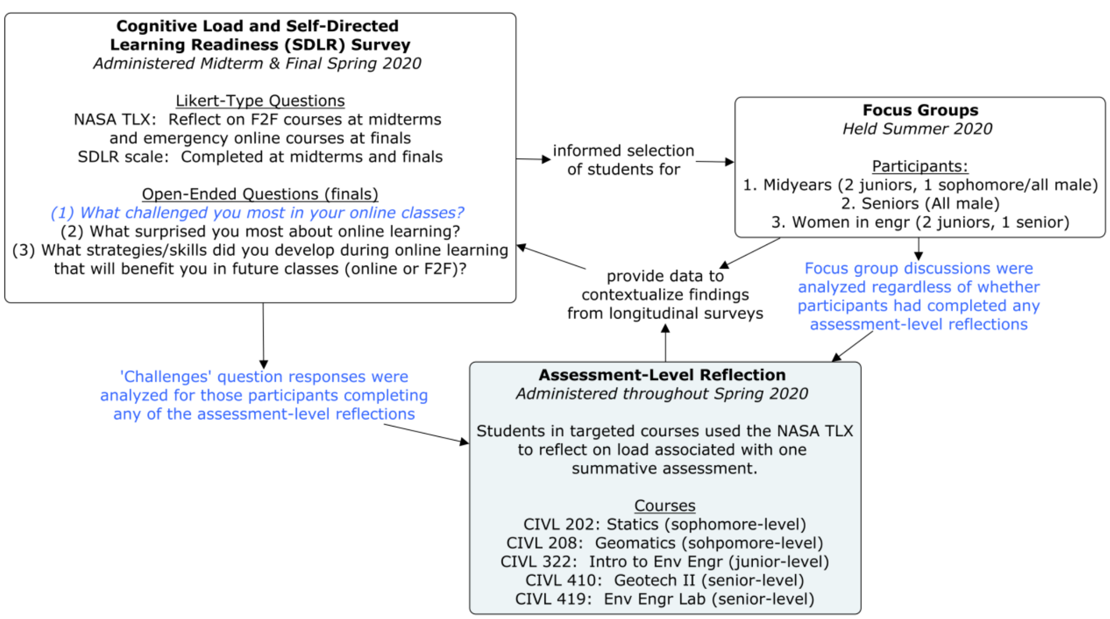

Figure 1. Summary of data sources used to understand student experiences and development during the Spring 2020 semester of the COVID-19 pandemic. Text in blue demonstrates how survey and focus group data are used in the current study to explore assessment-level load.

Results & Discussion

Test-Associated Cognitive Workload

Cognitive workloads (measured as Raw TLX) experienced during closed-ended, regular-semester tests were significantly different between students enrolled in courses of differing academic levels (*p* = 0.041; Table 2). Post-hoc analysis showed that students enrolled in the sophomore-level Statics course (*Med* = 59.0) experienced more cognitive load than students enrolled in the senior-level Geotechnical Engineering II course (*Med* = 54.5; *p* = 0.004).

Temporal demand experienced during closed-ended, regular-semester tests were significantly different between students enrolled in courses of differing academic levels (*p* = 0.005; Table 2). Post-hoc analysis showed that students enrolled in the sophomore-level Statics course (*Med* = 50.0) experienced more temporal demand than students enrolled in the senior-level Geotechnical Engineering II course (*Med* = 20.0; *p* = 0.004).

Frustration experienced during closed-ended, regular-semester tests were significantly different between students enrolled in courses of differing academic levels (*p* < 0.001; Table 2). Post-hoc analysis showed that students enrolled in the junior-level Introduction to Environmental Engineering course (*Med* = 80.0) experienced more frustration that students enrolled in either the sophomore-level Statics course (*Med* = 45.0; 0.018) or the senior-level Geotechnical Engineering II course (*Med* = 15.0, *p* < 0.001).

Other workload sources, including mental, physical, effort, and performance demands experienced during closed-ended, regular-semester tests were not significantly different between students enrolled in courses of differing academic levels (Table 2).

Table 2. Comparing Raw TLX and workload sources associated with closed-ended, regular-semester tests across courses of differing academic levels.

Workload & Source Dimensions	Medians			Kruskal-Wallis *H* tests	
	Statics: Sophomore-Level (*n* = 23)	Intro to Env Engr: Junior-Level (*n* = 27)	Geotech II: Senior-Level (*n* = 21)	*H*(2)	Asymptotic *p*
Mental	75.0	75.0	77.5	00.706	<0.703***
Physical	15.0	05.0	12.5	04.195	<0.123***
Temporal[a]	50.0	45.0	20.0	10.656	<0.005***
Effort	70.0	75.0	70.0	00.678	<0.713***
Frustration[b]	45.0	80.0	15.0	21.074	< 0.001***
Performance	75.0	75.0	82.5	00.072	<0.965***
Cognitive Workload (Raw TLX)[c]	59.0	66.0	54.5	06.381	<0.041***

[a]Soph > Seniors (*p* = 0.004); [b]Juniors > Soph (*p* = 0.018); Juniors > Seniors (*p* < 0.001); [c]Juniors > Seniors (*p* = 0.036)

Student Challenges by Academic Year

Within our larger survey, 16 of 23 students in the sophomore-level Statics course responded to the open-ended "challenges" question. Most students identified keeping up with the work load (effort) or focusing/avoiding distractions (overall cognitive load) as their biggest challenge. No student called out a specific course or assessment type in their response.

Twenty-three out of twenty-seven junior students who completed an assessment TLX also commented on the most challenging part of online courses. Equal numbers of students (*n* = 7) identified mental demand due to difficult concepts or overall cognitive load as the biggest challenge that they faced. Two students attributed their challenge to online testing methods. Students who were already struggling with a course before the shift felt that those courses became more difficult, due to the online environment or the course topics. Several juniors

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also mentioned difficulty focusing at home as contributing to overall higher load. Three students reported that they did not face cognitive load challenges related to courses.

Fifteen out of twenty-one senior-level students completed an assessment TLX and responded to the open-ended challenges question. Seniors less frequently (n = 3) cited challenges with a specific cognitive load dimension than sophomore or junior students. Seniors more frequently reported challenges unrelated to cognitive load (n = 6) such as adjusting to a new schedule or coordinating schedules with teammates. An equal number of students (n = 6) observed a change in their overall cognitive load.

Sophomore-Level Workload and Challenges with Different Assessments

We compared cognitive workload and workload sources for students who completed reflections on both the project-based assessment and closed-ended assessment in Geomatics and Statics, respectively (Table 3). Of the seven participating students, six reported higher cognitive workload (Raw TLX) when engaging in the project-based Geomatics assessment (Table 3). Indeed, the cognitive workload experienced during the project-based Geomatics assessment was significantly higher than experienced during the closed-ended Statics assessment (p = 0.034). Of the seven participating students, six also reported higher frustration when engaging in the project-based Geomatics assessment (Table 3). Median frustration experienced during the project-based Geomatics assessment was higher than experienced during the closed-ended Statics assessment (p = 0.043).

Based on the seven participating students, no significant differences were found between other workload sources when engaging in the project-based Geomatics assessment, as compared to the closed-ended Statics assessment (Table 3).

Table 3. Matched-pairs comparison (n = 7) of Raw TLX and workload dimensions experienced during open-ended and closed-ended assessments administered in sophomore-level Geomatics and Statics courses.

Workload and Source Dimensions	Medians		Wilcoxon Signed-Rank tests	
	Geomatics: Project-Based Assessment	Statics: Closed-Ended Assessment	*z*	p
Mental	85.0	75.0	-1.876	0.061
Physical	55.0	20.0	-1.826	0.068
Temporal	75.0	60.0	-1.194	0.233
Effort	85.0	70.0	-1.841	0.066
Frustration	65.0	40.0	-2.028	0.043*
Performance	50.0	65.0	-1.119	0.263
Cognitive Workload (Raw TLX)	81.0	66.0	-2.117	0.034*

Five students completed both sophomore-level course assessments and responded to the larger survey's open-ended prompts. Each student reflected on a different challenge with online learning and none identified particular courses or assessment types in their response.

Senior-Level Workload and Challenges with Different Assessments

We compared Raw TLX and workload sources for students who completed reflections on both the comprehensive laboratory report and closed-ended assessment in Environmental Laboratory and Geotechnical Engineering II, respectively (Table 4).

Of the seven participating students, six reported higher median workload (Raw TLX) when engaging in the report-based assessment (Table 4). Indeed, the cognitive workload experienced during the report-based Environmental Laboratory assessment was significantly

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higher than experienced during the closed-ended Geotechnical Engineering II assessment (p = 0.027). Of the seven participants, six reported higher effort when engaging in the report-based assessment (Table 4). Indeed, effort expended during the report-based Environmental Laboratory assessment was significantly higher than experienced during the closed-ended Geotechnical Engineering II assessment (p = 0.026).

Based on the seven participating students, no differences were found between other workload sources for the report-based Environmental Engineering Lab assessment, as compared to the closed-ended Geotechnical Engineering II assessment (Table 4).

Six students completed the TLX for the Environmental Lab and Geotechnical Test and also responded to open-ended questions in the end-of-semester survey. Three students noted that the learning mode (online only) was a challenge for them and two students specifically identified challenges working on teams to complete assessments, which may be reflected in the higher overall cognitive load experienced for the lab report.

Table 4. Matched-pairs comparison (*n* = 7) of Raw TLX and workload dimensions experienced during open-ended and closed-ended assessments administered in senior-level Environmental Lab and Geotechnical Engineering II courses.

Workload and Source Dimensions	Medians		Wilcoxon Signed-Rank tests	
	Env Lab: Comprehensive Report	Geotechnical Engr II: Closed-Ended Assessment	*z*	p
Mental	70.0	80.0	-1.063	0.288
Physical	10.0	10.0	-1.131	0.258
Temporal	15.0	10.0	-1.194	0.233
Effort	70.0	65.0	-2.220	0.026*
Frustration	25.0	5.0	-1.472	0.141
Performance	80.0	15.0	-0.272	0.785
Cognitive Workload (Raw TLX)	53.0	41.0	-2.217	0.027*

Focus Group Themes

Across focus groups, participants agreed that the transition was difficult, especially at the beginning. Students faced challenges making the transition, related to technology, scheduling, work load, etc. Student sentiment was mixed, with most students reporting a negative experience with online learning but a couple of students emphasizing positives.

Overall Cognitive Load due to Modality Change

The middle years participants agreed that there was an unpreparedness of the faculty and that the general asynchronous format of classes was not effective. Both factors made it hard for students to keep up with the work. All sophomore and junior participants agreed that keeping a schedule and staying ahead of work was the best advice they could give to students to deal with unforeseen/bad circumstances. Two participants in the middle-years focus group stated that a big challenge related to the shift was lack of structure away from campus. A junior noted that professors held classes in different styles and he had to adjust to each. The seniors agreed that it was an adjustment to shift from relying on professors to learning on their own. As seniors, all of the participants were engaged in courses that required collaboration for assignments. Similar to survey responses, seniors focused on challenges related to coordination/communication rather than greater cognitive load.

Lower Performance Reported by Senior Students

In terms of performance, none of the senior participants felt that their learning improved with online courses, even if their grades did not suffer. Participants noted there was a learning

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curve in terms of what professors expected out of assignments (e.g., more multiple- choice questions) and a lack of one-on-one time with professors or quality feedback on assignments. One student said that once he adjusted to new question formats, he felt his abilities were about the same as before. Although professors tried to make sure students' grades did not suffer, he felt that he did not understand the material as well and had more trouble gauging his performance. The evening senior did not feel as challenged to study for open-notes exams; she may have learned more deeply with traditional testing.

Experiences with Different Types of Assessments

For the juniors and seniors, labs and projects (more common during those class years) were the focus of discussion, particularly related to challenges. The virtual labs were a lot different than at school, and many students found it difficult to grasp the concepts without the hands-on portion. Even when a video demonstration was provided, it was not always effective. In some senior labs, professors sent students data and expected them to figure out the calculations and interpretations without having seen/experienced the experiment. One civil lab was extra challenging because the professor was new and did not have the lab solutions done. Civil students felt that they did not learn much in that lab. These experiences may be reflected in the higher effort and overall load reported on the TLX for the environmental lab.

The seniors, in particular, spent a lot of time describing unique challenges that they faced with projects and labs. For capstone projects, many civil students did not have needed software at home. Although capstone faculty tried to keep the same expectations for projects, it was very different to work together from home and complete the same deliverables. The senior evening student was already working on a capstone project in a small class with only two teams, so she had a different experience. Her capstone team was already using technology to connect, so they just added videoconferencing to further facilitate collaboration. Seniors did not express strong negative feelings about tests.

Non-Cognitive Challenges with Online Coursework

Interpersonal and communications challenges were important factors in students' experiences with the switch to online learning. All underclassmen said that their interactions with their classmates changed after the shift to online learning. The sophomore and juniors observed that their peer interaction became more limited in both length of time and amount of different people. The relationships became more transactional, particularly with respect to project work and problem sets. A junior shared that in his projects, instead of all his classmates working together to do the project, they would just divide up the work amongst themselves. Unlike the underclassmen, the civil engineering seniors did not feel that relationships among classmates changed. Two of the participants noted how close and collaborative their class already was and that everyone continued to help each other online, although they admitted that it was not the same experience as being in person. The third civil senior had a different perspective, noting that if they were no longer having class sessions together, he felt that there would be little communication amongst classmates. Students across class years were missing the "socializing" aspects of on-campus life.

Conclusions

We are engaged in a longitudinal study to understand the impacts of pandemic-induced changes in course modality on cognitive load and self-directed learning readiness among engineering students. The purpose of this study was to triangulate our earlier finding that sources of cognitive load may have varied across students from different academic years during the Spring 2020 shift to emergency online instruction. Through analysis of workload data collected for closed-ended and open-ended assessments administered in courses of varying academic levels, as well as thematic analysis of open-ended student feedback and focus group transcripts, we make the following preliminary conclusions:

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1. Sophomores and juniors experienced higher and/or more varied sources of cognitive workload related to closed-ended assessments, as evidenced by quantitative TLX ratings and open-ended survey responses.
2. Open-ended assessments elicited higher cognitive workload among both sophomores and seniors, based on quantitative TLX ratings and focus group analysis.
3. Qualitative data analysis supported that the shift to online learning elicited less cognitive workload changes for seniors, as compared to sophomores and juniors.

Limited samples size is a limitation of our study. Participation in target courses (Table 1) with closed-ended assessments was reasonable (46% to 79%) which lends credibility to our finding of higher load among middle-years students during those assessments. Our comparison of assessment types within academic classes is not as strong, since only seven sophomores and seven seniors completed TLX surveys for closed- and open-ended assessments. Also, our findings may not be generalizable to groups beyond our institution.

Ultimately, we have now found through a variety of data sources and analysis approaches that emergency online instruction caused varying types and magnitudes of cognitive load among students from different academic years. We are continuing to explore how increased cognitive load, especially among middle-years students, may have impacted their development and performance during the Spring 2020 semester and beyond.

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Emerging Learning Technologies for Education on Sustainability Topics

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ABSTRACT

CONTEXT
In this work, we explore the role that emerging learning technologies (e.g., mixed reality, artificial intelligence, internet of things) can play in engaging individuals to learn about sustainability topics.

PURPOSE OR GOAL
Our primary goal is to answer the question:
How do interactions with emerging technologies support the development of mental models on sustainability topics?
This question comprises two sub-questions along the lines of our conceptual framework grounded in constructionism and mental models for learning:
How and in what ways do physical interactions with emerging technologies engage learners in learning about sustainability topics?
How do the mental models developed as a result of such interactions impact learners' understanding of sustainability topics?

APPROACH OR METHODOLOGY/METHODS
We conducted a technology review, similar to a literature review, to understand the current state of the art in emerging learning technologies. Our review is informed by a conceptual framework comprising the learning theories of constructionism and mental models. Our current review is not limited to a particular age group. In the future, this work will inform technology and intervention design to support undergraduate engineering students in understanding sustainability issues such that they are cognizant of them in their engineering practice.

ACTUAL OR ANTICIPATED OUTCOMES
This work has resulted in a synthesis of emerging learning technologies to learn topics of sustainability. The conceptual framework guiding the synthesis brings to light how hands-on constructionist learning experiences using emerging technologies can help support the development of mental models on an urgent topic of concern. This study also informs future work with undergraduate engineering students who make decisions throughout their careers with implications for sustainability.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
This work is a preliminary exploration of current learning experiences that use emerging technologies for sustainability education and will inform our future technology and intervention development work.

KEYWORDS
Emerging technologies, sustainability, mixed reality, artificial intelligence

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Introduction

Anthropogenic climate change presents an existential risk to myriad human and animal communities across the globe (Beard et al., 2021; Butler, 2018; Ord, 2020; Pontzer, 2021; Richards et al., 2021). Algorithms implemented in digital technologies have the capacity to drive attention, shape beliefs, and affect resource allocation (Barocas & Selbst, 2016; Bessi et al., 2016; DeVito, 2017; Mehrabi et al., 2021; Noble, 2018; O'Neil, 2016; Wachter-Boettcher, 2017). Automated technologies can lead to massive displacements in the workforce and exacerbate wealth inequalities (Acemoglu & Restrepo, 2018, 2019; Allen, 2017; Moll et al., 2021; Peng et al., 2018; Robinson, 1977; Wadley, 2021). In the example of climate change, engineers' activities can range from actions that exacerbate these ecological and social changes (Erftemeijer & Robin Lewis, 2006; Gibbs, 2012; Gorlenko & Timofeeva, 2019; McCartney, 2009; Sengupta, 2017) to actions that mitigate them (Fork & Koningstein, n.d.; Head, 2009; Lawlor & Morley, 2017; Meyer & Weigel, 2011; Sikdar, 2003). In these and similar scenarios, engineers are making decisions that can have far-reaching implications for SESs in myriad ways. Other examples of this work abound throughout the National Academy of Engineering's (NAE) Grand Challenges for Engineering or the United Nations' Sustainable Development Goals (Bleischwitz et al., 2018; Rahimifard & Trollman, 2018). They include impacts on the food-energy-water nexus, securing cyberspace, and developing technologies to address biological diseases.

Ideally, engineers will work to account for effects on SESs in their design considerations. Publications from the NAE emphasize the importance of engineers considering social and environmental impacts of engineering work in their decisions (Allenby, 2004; NAE, 2005). The Accreditation Board for Engineering and Technology (ABET) recognizes the importance of accounting for social, political, environmental, and economic factors in design solutions in two of their accreditation criteria (ABET, 2019). However, despite the importance of engineers considering the impacts of their work on such systems, there is research that suggests engineering students are not prepared to do this (Cech, 2014). On the contrary, Cech's work suggests engineers may dissociate social considerations from technical aspects of their work, a phenomenon termed socio-technical dualism (Faulkner, 2000).

In this paper, we explore how emerging learning technologies can help individuals make sense of topics that constitute broad system-level concepts and have been previously difficult to understand due to complexity and scale using prior traditional hands-on learning approaches. We define learning technologies as those designed or used to enhance the user's learning experiences (Scheffel et al., 2019) by simulating real life contexts, or generating educational models (Kinshuk, 2004). Emerging learning technologies provide opportunities to understand sustainability-related concepts in *virtually* hands-on ways that can create rich educational experiences. This review will inform our future work technology development work, and we are conducting this preliminary exploration because of the lack of similar work grounded in learning theories. The two learning theories of interest are that of constructionist learning (Papert, 1980; Paert & Harel, 1991) (an affordance of some emerging technologies) and mental models (Johnson-Laird, 1983; Morris and Rouse, 1986) (a promising approach to understand mindsets towards sustainability topics).

Approach

The research question guiding our work is:

> How do interactions with emerging technologies support the development of mental models on sustainability topics?

The review is informed by a conceptual framework comprising constructionism and mental models. The conceptual framework is motivated by the promise of constructionist learning

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principles in developing embodied understandings of topics, and mental models in informing how individuals think about complex sociotechnical issues. Keeping the two aspects of our conceptual framework in mind, we ask two sub-questions

> How and in what ways do physical interactions with emerging technologies engage learners in learning about sustainability topics?
>
> How do the mental models developed as a result of such interactions impact learners' understanding of sustainability topics?

Since this review is unique in the sense that much of the prior work in the space of emerging technologies has not been captured in academic literature, we take a non-traditional approach to our review process, by looking for relevant work in both academic and non-academic contexts. This review by no means is a systematic review. The primary aim of this work is to gather sources from a variety of sites to initiate a working understanding of how emerging learning technologies are being used for education on sustainability topics. We carried out searches in the Journal Storage (JSTOR) database, Google Scholar, Google News, and Google more generally using search terms like "vr and sustainability," "ar and sustainability," "iot and sustainability," "sustainability education and technology," and "emerging tech in education" until ten consecutive searches did not meet our search criteria. We concluded our searches on July 21, 2021. Our inclusion criteria for the technology/sources that we share in the next section, included:

- work at the convergence of emerging technologies, sustainability, and sustainability education
- work that reported on new technologies or empirical studies of new technologies (and not popular culture review articles)
- work that represented new and evolving studies, especially when searching Google News

Review

Below, we share the findings from our technology review organized to answer our two questions. Under the sub-heading of "user interaction," we provide the answer to the first research question - How and in what ways do physical interactions with emerging technologies engage learners in learning about sustainability topics? Under "intended outcomes," we answer the second question - How do the mental models developed as a result of such interactions impact learners' understanding of sustainability topics? We also categorize the sources into those that use augmented reality (AR), virtual reality (VR), and Internet of Things (IoT) technologies. Out of all the searches made on JSTOR, Google Scholar, Google News and Google (general), the examples below were chosen because they were the most recent and relevant out of those pertaining to the convergence of emerging technologies, sustainability and education.

Augmented Reality

Technology 1.1. Corona's AR experience to teach sustainability

User interaction: Corona launched an augmented reality experience for World Oceans Week that attempts to raise awareness about personal plastic consumption. It shows users a year's worth of their plastic consumption to demonstrate their footprint and provides tips on reducing individual footprints. Users are asked questions about their consumption habits in the app and given an estimation of their annual footprint. Footprints are visualized by colorful pieces of AR plastic that wash over the physical world before the user is transported to a "polluted paradise" meant to highlight the effects of pollution in nature. Finally, users are prompted to reduce their footprint. (Powis, 2021)

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Intended outcomes: This interaction allows users to visualize a sustainability concept that was previously difficult to demonstrate effectively. Through visualizations, the user is encouraged to generate a more lasting and impactful mental model for their approaches surrounding sustainability. Additionally, the experience provides explicit suggestions for greater personal sustainability, which, when paired with the heavy emphasis on personal impact, will likely leave a more lasting effect on the user than traditional mediums of education. (Powis, 2021)

Technology 1.2. : An Eagle Scout in Lowell gifted his 4th-grade teacher his Eagle Scout project, an AR table that uses sand to create topographical models.

User interaction: Students manipulate sand in a wooden box by hand or with tools. A sensor and projector are used alongside software to generate and project elevation lines and colors to convey the depth of the sand. Students can create their own topography and use hand gestures to generate rain and observe runoff and other environmental phenomena (Bell, 2021).

Intended outcomes: This is a very hands-on application of AR and can help the students easily conceptualize and visualize the concepts they are learning. The students are being taught various environmental topics, including glacial activity, topography, drainage, the water cycle, and flood and drought conditions. AR enables a physical and touchable model to be easily reused and adaptive, making the learning process itself more sustainable as well. The students can generate lasting mental models by drawing connections between physical phenomena and their environmental effects, such as flooding and droughts, relevant sustainability topics.

Technology 1.3. AR Butterfly Gardens

User Interaction: With a smartphone or tablet, the user takes advantage of AR software to observe a virtual butterfly greenhouse with many different species of butterflies projected around their surroundings. The software allows the user to zoom in on specific butterflies with the virtual tracking telescope and allows them to tap on the butterfly to learn more about its respective species. It is also possible for the user to "breed" butterflies and observe their life cycle (Tarng et al., 2015).

Intended Outcomes: Researchers at the National Hsinchu University in Taiwan developed this project intending to increase the public's knowledge regarding insect ecology and the importance of butterflies in maintaining the environment. In recent years, Taiwan has seen an overall decrease in the butterfly population as well as a decrease in the range of species, making this project timely (Tarng et al., 2015).

Technology1.4. “Seeing the Invisible": an AR art Gallery

User interaction: This collaboration between 13 botanical gardens worldwide replaces the traditional gallery or museum setting of art demonstrations with an AR experience. Individuals can view 13 virtual art pieces in AR upon visiting one of the participating botanical gardens from September 2021 to August 2022. The Jerusalem Botanical Gardens organized the project in conjunction with the Outset Contemporary Art Fund. The art itself focuses on themes of nature, the environment, and sustainability and emphasizes the boundaries between art, technology, and nature. The app allows viewers to view AR art galleries when they enter any participating gardens. The experience attempts to replicate the real life experience of navigating a physical gallery, and users are to view the art in the space as if they were physical pieces (Maor & Haring, 2021)

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Intended outcomes: The integration of technology into an artistic product helps to demonstrate the versatility and successful use of AR even outside of its traditional applications. The use of AR makes this art more accessible and sustainable than traditional exhibits, again demonstrating the potential of AR and other emerging technologies to increase access with less potential environmental strain. Finally, the art itself focuses on themes of sustainability and ecological conservation. Viewers begin to develop a more robust and inclusive mental model of sustainability that goes beyond the traditional areas of thought such as education or industry. (Maor & Haring, 2021)

Technology 1.5. AR for Understanding Wildlife and Conservation

User Interaction: With a smartphone or tablet, children watch their reading come to life with an AR support tool designed to enhance their learning of conservation and environmental sustainability. Students may hold their devices to a page to interact with the Panda featured in the book. They can rotate and move objects around and make the Panda bigger or smaller (Lee & Yoon, 2020).

Intended Outcomes: This technology was used to study the extent to which an AR enhancement to a children's book would improve children's understanding of conservation, wild animals, and environmental sustainability. The AR element is intended to encourage a "learner-centered" learning environment. With a broader spectrum of sensory information available to the learner, students can interact with information in a way that works best for them, allowing for full immersion in the subject matter. Combining emotive learning with facts and statistics, this technology aims to better engage children in conservation and wildlife topics, sparking empathy within the child and conversation and collaboration among the group of students using the tool (Lee & Yoon, 2020).

Technology 1.6. EcoMOBILE: Integrating augmented reality and probeware with an environmental education field trip

User Interaction: The EcoMOBILE project combines an AR experience with the use of environmental probe wear during a field trip to a local pond environment. The activities are designed to address different ecosystem science learning goals for middle school students and ultimately aid in understanding and interpreting water quality measurements. Students use the AR application, FreshAIR to navigate the pond environment and observe virtual media and information overlaid on the physical pond. Students can collect water quality measurements at designated AR hotspots. (Kamarainen et al., 2013)

Intended Outcomes: Combined use of technologies promoted student interaction with the pond and with classmates in a more student-centered format than traditional teacher-directed. The AR helped students gain deeper understandings of the principles of water quality measurement because of its ability to help students engage in activities that resemble scientific practice. (Kamarainen et al., 2013)

Technology 1.7.: Comparing VR and AR within the training pipeline of a construction company

User Interaction: This Slovakian study tests how the implementation of VR and AR in teaching construction can add efficiency. The current problem within the school system is the constant pressure to keep up with the forever evolving and rapidly changing world of technology. VR is used in many ways to create real life situations to better equip people for certain jobs that require specific skills. TEL (Technology-enhanced learning) caters toward specific learning goals to help develop higher-order skills, and this, combined with computer science, the researchers believe will create more efficient learning. In the study, a group of students had to assemble an industrial plug, once with paper instructions, once with AR (a

QR code would lead to a floating example that walked the students through the instructions), and once with a VR headset that allowed the students to put it together virtually with virtual instructions (the students were trained prior on how to operate the VR headset). Based on the results, using VR saves time (Gabajová et al., 2019).

Intended outcomes: The study's main goal was to find out how the implementation of new technologies, specifically VR and AR, could reduce time in a construction assembly line (assembling an industrial plug). This new technology will improve the process of acquiring skills, especially in critical thinking. The benefit of the VR training is that it allows the new employees to teach themselves so other, more experienced employees can do their needed work instead of monitoring the new guy. It allows for testing/training virtually first before making any costly/drastic physical changes or mistakes. It saves money and time. The disadvantage is that older generations have more trouble learning the evolving technologies. Overall, the new technologies would create a more efficient training pipeline (Gabajová et al., 2019).

Technology 1.8. Extended Reality (XR) in a business school setting

User Interaction: Traditional teaching methods offer students a cognitive understanding of sustainability issues but tend to lack the holistic point of view several scholars advocate. This article is based on the need to add training on specific skills, reorienting management education to engage with wicked problems through increasingly creative, open, and iterative processes that invite reflection and meaningful redesign. This shift in problem-solving approaches is particularly relevant to complex environmental and social issues such as climate change and persistent poverty. Despite the critical need to engage with such problems, many business schools continue to rely upon the traditional rational-analytical approach in their curricula, leaving students—and future managers—ill-equipped for answering challenges that require new ways of problem-solving. The proposed idea is experiential learning using design thinking. This would facilitate solving problems using empathy, reframing, prototyping, experimentation, testing, and redesign (Andrew et al., 2020).

The use of new technologies like XR could help students develop a more holistic understanding of the problem at hand and allow them to iterate different solutions quickly and in a more cost-effective way. In addition to the compelling case made for expanding the breadth of sustainability-related learning (in terms of stakeholders, time, and disciplines), scholars have also advocated for increasing the depth of engagement with these challenges (Andrew et al., 2020).

Intended Outcomes: XR provides a platform that can amplify empathy, facilitate reframing, shorten design iteration cycles, compress extended time frames, span physical space, and limit downside risks of experimentation by novices (i.e., students); all things that tend to bedevil sustainability education delivered by other methods. The goal of the study was to create an integrative conceptual model that provides guidance for educators engaging with the complex, transdisciplinary, spatially-dispersed, and otherwise wicked problems inherent in sustainability-related challenges using XRtechnologies. Overall, the XR will allow students to get a shaped education through understanding risk management, the design thinking process, and see different stakeholder perspectives (Andrew et al., 2020).

Virtual Reality

Technology 2.1. "Augmented Reality as a Sustainable Technology to Improve Academic Achievement in Students with and without Special Educational Needs"

User interaction: Researchers conducted a pre-experimental study with Chilean high school students, in which students used AR and VR to learn chemistry topics. 60 female participants received pre, post, and follow-up assessments before, after, and a month after undergoing a group learning plan heavily reliant on AR and VR technologies. The students built and manipulated 3D models of compounds using the AR VR Molecules Editor application instead of traditional physical models for teaching molecule structure. They received three 45-minute sessions with the technology, each session with its corresponding activity where the students were either creating, modifying, or identifying molecules and their structure. Students worked in groups of 3-5. (Badilla-Quintana et al., 2020)

Intended outcomes: Researchers wanted to discern whether or not using AR is predictive of improvements in academic achievement and knowledge retention as well as the levels of acceptance and motivation of students surrounding AR. Researchers concluded there is strong evidence AR can improve learning outcomes and retention, as students scored significantly better on their post and follow-up assessments. AR was seen to be a more successful educational tool relative to traditional methods, such as the aforementioned physical models, but it was shown to improve student motivation and enthusiasm. (Badilla-Quintana et al., 2020)

Technology 2.2. VR in a classroom setting

User Interaction: A study was done in Miami, FL, to promote sustainability through virtual reality. The primary objective of this case study was to use a user-centered design (UCD) process to create a virtual reality (VR) educational experience that could instill empathy and encourage behavior change concerning climate change in an American city. Students would use VR technology to personally experience stories from around the globe regarding climate change to help them understand the severity of the situation. This type of emerging technology is becoming more commonly used because of its ability to motivate students and simulate real world experiences. Students would use the VR equipment to learn about global warming and work through solutions (Posluszny et al., 2020).

Intended Outcomes: The study was based on information gathered through literature reviews, interviews with professors who teach about sustainability and also college students, focus groups, and design activities. Research showed that students want to help but don't know how and that seeing the effects on a city close to their home had a significant impact on their intention to help. Storytelling for sustainability creates affordances for users to build social capital and contribute to sustainability conversations by challenging assumptions, creating awareness, and becoming agents of social change. If the VR experience they designed shows how life could look on American soil 50 years into the future, then it is possible that it could spark a behavioral change (Posluszny et al., 2020).

Technology 2.3. VR in a classroom setting

for hands-on learning

User Interaction: Salah et al. (2019) posit that VR can create a new hands-on learning method. VR (headset) can help create complex problems and scenarios the students can work through, make mistakes, and learn. Such an approach can also allow students to teach others (through partner work, presentations, etc.). It could effectively promote learning through teaching (sparks interest in the subject matter), where students can learn to work in teams and individually (Salah et al., 2019).

Intended Outcomes: The goal of using VR in the classroom is to prevent workplace mistakes and close the gap between educational knowledge and practical application. VR can also create a more realistic understanding of a workplace setting to better prepare students with necessary professional skills. It could allow students to become comfortable with more delicate and experimental technologies, experience possible real life situations,

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and prepare them for the workplace. VR can be a solution to allow students to deal with real-life situations in a classroom setting where that is not always possible (Salah et al., 2019).

Technology 2.4. The Influences of the 2D Image-Based Augmented Reality and Virtual Reality on Student Learning

User Interaction: This is a 2016 study from Taiwan to compare the influence of 2D image-based VR and AR in terms of learning achievement and task performance in an inquiry-based astronomy course. In the course, two systems were employed: (VR) Sky Map and (AR) Moon Finder, both simulation systems on a handheld device that allow users to set different dates and times for displaying the moon. Since it was an inquiry-based teaching method, both systems were installed in tablet PCs that provide situational data. In brief, the VR option supports the development of scientific understanding by making students focus on virtual celestial bodies, whereas the AR helps students link virtual elements to real life environments. (Liou et al., 2017)

Intended Outcomes: With the features of the AR system, learners can easily integrate virtual objects and natural environments and ultimately decrease mental load to improve learning. The sense of immediacy in the AR group was higher than in the VR group, improving the students' positive learning experience and concentration. (Liou et al., 2017)

Internet of Things

Technology 3.1. IoT Environmental Monitoring Systems

User Interaction: The GAIA Project, an H2020-funded research group, equips students with a lab kit that consists of various IoT devices, sensors, actuators, and other hardware components (LEDs, resistors, etc.) that can be used to make custom circuits that collect real-time data on energy consumption, lighting, heating, thermal comfort and energy efficiency. Students first brainstorm potential solutions to environmental problems at their school, mock-up and assemble their circuits, and write code that can connect their devices to the cloud to gather data in real-time. Finally, students can analyze patterns and trends in their data with visualization software. Once conclusions are made about the data, students can take action within their school to improve sustainability practices (Mylonas et al., 2021).

Intended Outcomes: As a result of its data-driven methodology and hands-on approach, students are expected to be more engaged with learning about sustainability, particularly because it may directly impact their school's sustainability practices. GAIA (*Green Awareness in Action)*, an H2020-funded research group, intends to introduce engineering, coding, and electronics within the context of sustainability to promote the idea that engineering and the environment are not necessarily at odds when students, like them, make informed, data-driven and environmentally-conscious decisions (Mylonas et al., 2021).

Technology 3.2. Low-Cost Arduino Environmental Monitors

User Interaction: Students work together with the support of educators to assemble small environmental monitors with Arduinos, sensors, and other circuitry/hardware. In addition to having a role in the execution, students have a choice in the design and aim of the project (Alo et al., 2020).

Intended Outcomes: The project, *Ecoinformática para Jóvenes*, or *Ecoinformatics for children*, intends to change students' perspectives on STEM education. Most students in a pre-workshop survey noted fear of the abstract nature and complexity of certain STEM subjects and a fear of the environmental impact of engineering. This project thus aims to help students become more enthusiastic about STEM subjects and knowledgeable about the environment through real-world applications (sustainability, anthropization, climate change) and project-based, constructivist learning (Alo et al., 2020).

Discussion

How and in what ways do physical interactions with emerging technologies engage learners in learning about sustainability topics?

Physical interactions with emerging learning technologies can engage learners by helping visualize phenomena, creating immersive firsthand experiences, developing holistic (system-wide) understanding of phenomena, quickly iterating upon solutions in low-cost ways, providing learners with a broader array of sensory information, and supporting thinking through possible solutions more critically before building them. As with most novel technologies, some learners may be motivated to learn about sustainability topics because they are curious about engaging with emerging technologies.

In the case of physical phenomena such as flood and drought conditions or waste, technology like AR and VR can allow better visualization and help students generate more lasting and realistic understandings. Learning is often more immersive, wherein learners can experience things they're learning firsthand, which could increase retention, understanding, and enthusiasm. The use of new technologies like XR could help students develop a more holistic understanding of the problem at hand and allow them to iterate different solutions quickly and in a more cost-effective way. The broader range of sensory information provided by emerging technologies can enable students to interact with information in the best way they see fit. Communication is more personable to students' needs and preferences. Learners have the opportunity to learn about technology as a producer/developer as opposed to a consumer. They can be encouraged to be creative, think not only about *what* they are creating but *why* it should be created and what impact it will have in improving their environment.

How do the mental models developed as a result of such interactions impact learners' understanding of sustainability topics?

Mental models developed as a result of engaging with emerging learning technologies can impact learners' understanding of sustainability topics by blurring disciplinary boundaries between the technical and the social, by making learning experiences more intimate and relevant for learners, by providing a venue for low-stakes design and implementation of solutions, and by invoking feelings of empathy, urgency, and personal connection. Access to learning and technology often hampers technology-aided learning, and technologies like AR and IoT prove to be fairly accessible financially since they can be accessed from mobile phones.

These technologies and their applications often blur the boundaries between the humanities, sciences, and social sciences, leading to more holistic and universally applicable mental models of sustainability topics. Learners no longer view sustainability topics as solely scientific and are instead encouraged to consider them in non-traditional ways. Immersive technologies such as AR and VR can also be made to be more intimate than traditional teaching mediums. Students can potentially feel more empowered when using emerging technologies to quickly model and create impactful engineering solutions. XR technologies can combine emotive, hands-on learning with facts and statistics to help students *empathize* more with the subject matter and feel a greater sense of urgency and concern. Finally, a good education is only as good as how accessible it is, and AR and IoT have the potential to make good technology-supported learning accessible.

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Promoting Students' Conceptual Change in Statics through Self-Explanation Strategy in a Remote Learning Context

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ABSTRACT

CONTEXT

Statics is a fundamental course in engineering, representing one of the main challenges for students to complete their engineering programs. Statics is also a prerequisite to different subsequent subjects where problem-solving and spatial visualization skills are essential. The traditional teaching of Statics is insufficient for students to achieve successful learning of Statics.

PURPOSE OR GOAL

This study explores how different conditions of worked-examples integrated into a spatial visualization tool named "*Hapstatics*" promote conceptual change in Statics. Students engaged in active exploration of these examples by self-explaining them. These activities took place in the context of remote education due to the COVID-19 pandemic.

APPROACH OR METHODOLOGY/METHODS

This study included 54 undergraduate engineering students enrolled in a Statics course distributed into three groups. Each group wrote self-explanations for each step in a correct, incomplete, or incorrect worked-example in the context of Statics equilibrium. The *"Hapstatics"* tool was used to support conceptual understanding of static equilibrium. Students completed a pretest and a posttest, and the researcher team used inferential statistics to identify possible changes in students' conceptual knowledge.

ACTUAL OR ANTICIPATED OUTCOMES

The results showed a considerable improvement on student conceptual understanding in the posttest for the incomplete worked-example condition. The complete and incorrect worked-example conditions did not show a statistically significant result.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This study suggests that engaging students with a Statics interactive worked-example using a self-explanation strategy may promote conceptual change. We recommend working in strengthening their spatial visualization skills in learning Statics throught the use of spatial visualization tools.

KEYWORDS

Metacognition, Problem-Solving Skills, Statics, Worked-Examples, Self-Explanations

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Introduction

Previous research about engineering students has shown that a good academic performance does not mean that students acquire a proper understanding of fundamental engineering concepts (Foutz, 2018; Montfort et al., 2009; Haron & Shaharoun, 2010). Statics is considered an essential subject for different disciplines, which require critical analytical problem-solving skills, a necessary objective for engineering education. Thus, the course of Statics becomes a supporting pillar for engineering design and applied engineering. Hence, the use of specific teaching strategies for Statics requires great effort and attention (Steif, 2004).

For many students, Statics is an important but challenging engineering course. These beliefs tend to negatively impact their performance in this subject and, therefore, in subsequent ones. Students' study habits, often poor and unmotivated by the prejudices formed around the subject, plus the complex Statics concepts, are constant obstacles for the students' learning process. A correct understanding of Statics enables students to relate the forces with the interactions between the elements, but students often have difficulties perceiving the forces between inanimate objects like Free-Body diagrams (Steif & Dollár, 2005). They also have problems understanding the reactions and forces between the components of structures and machines (Goodridge et al., 2014; Litzinger et al., 2010).

Strengthening students' problem-solving skills will be crucial for comprehending the topics studied in a Statics course. When students try to solve Statics problems, conceptual gaps are reflected in their solutions, resulting from the traditional pedagogical strategies. These are important reasons to reflect on the pedagogical strategies used in Statics and students' prior knowledge.

In this study, we used a spatial visualization tool called "*Hapstatics*" (Walsh et al., 2018), integrated with a self-explanation strategy in the context of remote education. *Hapstatics* allows students to identify the forces and reactions acting on a structure under specific conditions. This simulation was integrated along with self-explanation activities to elicit student metacognitive skills. Metacognitive skills enable students to be more aware of their own learning process (Chi, 2000). This study aims to explore whether this integration support student conceptual change. The guiding research question for this study is:

RQ1: ¿Which of the strategies are most effective for improving students' conceptual knowledge after self-explaining an either correct, incorrect, or incomplete worked-example?

Conceptual Change

Conceptual change is the theoretical framework guiding this study. Conceptual change refers to the process where conceptions are changed or replaced by new conceptions, promoting a restructuring of knowledge (Posner et al., 1982; Strike & Posner, 1992). To promote conceptual change, the teaching strategies must support students to locate and/or externalize their conceptual errors. This process also helps to understand the newly acquired conceptions better and strengthen these through practice (Anderson & Smith 1987, as cited in Vieira et al., 2018). The action to address their own misconceptions is known as "accommodation" (Posner et al.,1982). To optimize the teaching practices in Statics, these should consider students prior knowledge and conceptual gaps, which are a determining factor for students to use adequate conceptual knowledge in problem-solving. The conceptual conflicts existing in students' mental model may enable the conditions to externalizing students' prior knowledge and enabling cognitive accommodation (Schraw et al., 2006).

Metacognition and Self-explanations

Metacognition is a higher-order mental process where students can develop the ability to reflect on their learning products and cognitive processes (Flavell, 1976; Moore & Carling, 1982; Gavelek & Raphael, 1985). Planning, monitoring, and evaluation are three metacognitive strategies involved in cognitive regulation (Brown et al., 1983: Flavell & Markman, 1983). These strategies enable students to learn on their own, acquire better-structured knowledge, increase their motivation for learning, and a greater success in tasks to solve.

Self-explaining is a knowledge-building activity directed by students who generate explanations for themselves, going beyond the information provided, starting, generally, from a written text that makes a procedure explicit, and usually within a learning context (Chi, 2000). Self-explaining helps students identify gaps in their understanding and missing information in the delivered text or studied example, and supports the construction and repair of their mental model. Self-explaining demands to be more aware of their learning process by monitoring their understanding of the material. Thus, self-explaining may help to externalize student comprehension and elicit the development of metacognitive thinking (McNamara & Magliano, 2009. These are critical conditions for conceptual change.

Spatial Visualization

In Statics, students must develop skills for spatial visualization to be able to extrapolate Physics and Statics concepts into problem-solving. Spatial visualization refers to the ability to manipulate an object or geometric figures mentally (e.g., to turn, to twist; Alias et al., 2002). Teachers in different areas of engineering tend to represent 2D and 3D movements using diagrams and inanimate objects. This approach increases the difficulty for students when trying to interpret forces and reactions between elements in contact. Including spatial modeling within the teaching and learning of Statics would reduce students' cognitive load and converge in better results on students' understanding of Statics.

Methods

This study employed a multiple case-study crossover design (Yin,2009) to analyze and compare each case against another. Each case study corresponds to a worked-example type, one for each group of students. The goal is to identify which strategies are most effective for improving students' conceptual understanding in Statics among a correct, an incorrect and an incomplete worked-example. The cross-case study design enables the research team to identify differences and similarities within and between each of the three cases (Khan & VanWynsberghe, 2008).

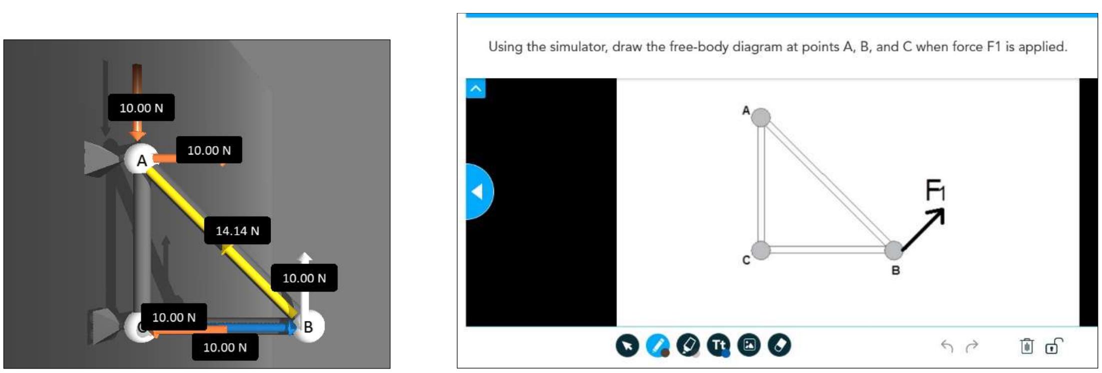
Participants and Procedure

This study included three groups of a Statics course at a private mid-size Latin-American university. A total of 91 students enrolled in this course during the fall semester of 2020 participated in this study. Participants were divided into three cases according to the type of worked-example they self-explained: correct, incomplete or incorrect worked-example. The study started from a pilot phase in the fall semester 2019 (De La Hoz et al., 2020) with the participation of three students in a think-aloud protocol. Later, a subsequent study was implemented during the spring semester of 2020 with 147 students divided in two cases: an incomplete and an incorrect worked-example. The pilot phase offered us a preliminary coding scheme that served as a starting point for the rest of the study. The second phase allowed us to refine our coding scheme and identify the effectiveness of these approaches in a classroom environment.

The procedures for this study include: i) Students first completed a pretest, assessing their conceptual understanding of Statics equilibrium; ii) The incomplete and incorrect worked-example groups completed a spatial visualization activity using the *Hapstatics* simulator (Figure 1); iii) Students wrote their self-explanations for the correct, incomplete or incorrect worked-example of static equilibrium, divided into five steps (Road map, modeling, governing equations, computation, discussion, and verification; Gray et al., 2005). Since students accessed the session remotely, we use the platform *Nearpod* to collect their self-explanations. Figure 2 depicts a section of the complete, incorrect, and incomplete worked-examples; iv) After completing the self-explaining activity, students took a posttest to assessed student conceptual change. The instructor did not provide any feedback to students on their self-explanations before they completed the posttest.

Data Analysis

We used descriptive and inferential statistics to identify: i) Changes on students' conceptual understanding and problem-solving skills after working on the self-explanation and spatial visualization activities: paired t-test; and ii) differences on these changes between each self-explaining conditions: complete, incorrect and, incomplete worked-example: ANOVA.



(a) (b)

Figure 1. (a). View of *Hapstatics* simulator when is applied an external force in joint B. (b). Activity in *Nearpod* platform.

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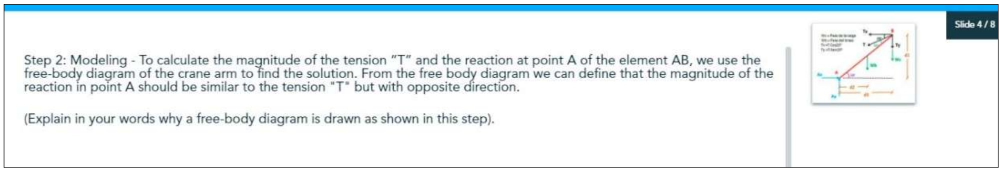
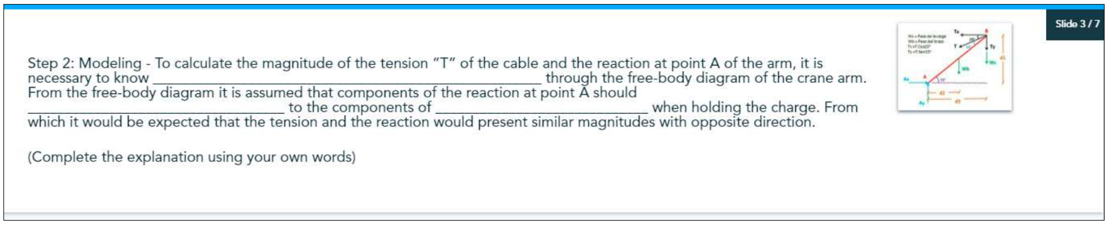
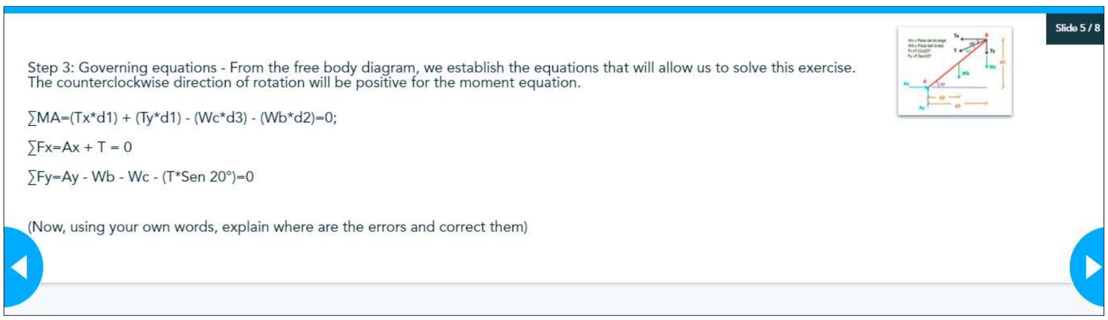


(a)



(b)



(c)

Figure 2. Sections of the complete (a), incorrect (b) and incomplete (c) worked-example in *Nearpod* platform.

Results and Discussion

Although the initial number of participating students was 91, some technological issues related to the particularities of remote education limited their participation in the study. Specifically, student internet connection and their limited technological infrastructure became a challenge for some of the students to complete the procedures of this study. In total, 54 students completed all the activities.

Student Conceptual Change

The first step to identify the possible changes in student conceptual understanding after explaining the worked-example, was to assess the difference between the pretest and posttest scores in each example condition. Table 1 depicts the descriptive and inferential statistics for each group (i.e., the case studies). The results show that students in the incorrect and incomplete conditions had a better performance in the posttest than students in the correct condition. The gain was higher for students in the incomplete condition, which changed from an average score of 40.2% in the pretest to 58.8% in the posttest. Note that students in incorrect condition started with an average score of 58.8% in the pretest, which makes it more difficult for them to show a statistically significant gain in the posttest. Likewise the average score for students in the Complete condition was lower in the posttest, this

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results was not statistically significant. Thus, exploring the complete example did not help or hinder their learning process.

Table 1. Descriptive and inferential statistics of performance test grouped by the example condition.

	Pretest (%)			Posttest (%)			Gain (%)		*t* test			
	Mean	sd	n	Mean	sd	n	Mean	sd	**t*	*df	**p* value	**d*
Correct	40,6	31,6	15	38,6	21,6	15	-2	29	0.26	14	0.79	0.07
Incorrect	58,8	27,2	19	61,6	29,2	19	2,8	21,2	-0.56	18	0.58	0.09
Incomplete	40,2	22,4	20	58,8	27,2	20	18,6	29,6	-2.8	19	0.011	0.74
All	46,8	27,8	54	54,2	27,6	54	7,4	27,6	-1.92	53	0.059	0.2

**t*: test statistics; df: degrees of freedom; *p*-value: probability value; *d*: effect size.

These results suggest that self-explaining incomplete worked-examples support students' conceptual change. Cohen's *d* statistic shows a strong effect size (0,74). Using a one-way analysis of variance (ANOVA), the results suggest that the incomplete condition was more effective than the correct and incorrect condition ($F(3,50)=4.945$, *p* value = 0,037).

RQ1: ¿Which of the strategies are most effective for improving students' conceptual knowledge after self-explaining an either correct, incorrect, or incomplete worked-example?

The results suggest that the correct worked-example is not the most appropriate to promote student conceptual change. Having all the elements from the solution available may fail to engage students in actively exploring the examples. This approach results in limited gain from identifying key concepts and strategies to use them in transfer problems. The incorrect worked-example condition demands more effort and additional background knowledge in students to identify the mistakes in the solution, and propose a correct explanation. This condition may be increasing their cognitive load (Grobe & Renkl, 2007; Booth et al., 2013). Incorrect worked-examples may be helpful for students with the required prior knowledge to identify these errors in the examples as evaluating is a higher cognitive skill.

Finally, the incomplete worked-example condition seems to be the most effective strategy to improve conceptual knowledge in Statics students. Explaining each step of the incomplete solution confronted students with the possibility of assimilating new concepts such as restructuring previously conceived ones (Ainsworth & Burcham, 2007). Incomplete examples may be more appropriate for the type of students who usually take a Statics course for the first time: students with considerable conceptual gaps, limited background knowledge and spatial visualization skills (Steif et al., 2010; Litzinger et al. 2010; Haron & Shaharoun, 2010). Incomplete ideas or sentences inside the paragraphs work as a guide for students when trying to fill the blanks in the explanation. This approach focuses students' attention on specific parts of the example, reducing the cognitive load. Self-explaining incomplete worked-examples creates conflicts in deficient mental models, increasing students' awareness of the learning materials. When students do not understand a topic properly, this approach may promote students' conceptual change.

Conclusions, Limitations, and Future Work

This study explored three worked-example formats (i.e., correct, incorrect, and incomplete) together with an interactive visualization tool to promote student conceptual change in a Statics course. The self-explanation strategy allowed students to be more aware of their learning process and develop a stronger conceptual understanding of Statics concepts. The incomplete worked-example generated the most appropriate conditions to promote conceptual change. The integration of visualization tools like the "*Hapstatics*" simulator is essential for students to achieve a deeper understanding of the physical behaviors illustrated in Statics exercises.

The main limitation of this study involves the remote education context, which constrained the sample size, and students' interaction with the Hapstatics tool. This limitation may have influenced students' average score on the pretest for the incorrect condition, significantly higher than for the other two conditions. Future work will focus on the relationship between the quality of students' self-explanations and their conceptual understanding. We will also look into students' interactions with the "*Hapstatics*" simulator and their approaches to self-explain the worked-examples.

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Engineering in a pandemic: the impact of remote working and learning on quality of work produced

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ABSTRACT

CONTEXT

COVID-19 has shocked the globe since December 2019, with unprecedented international and domestic travel restrictions and self-isolation policies enacted by governments around the world. With lockdown policies in place in hopes of preventing further spread of this disease, there has been a widespread transition into learning and working from home – causing a paradigm shift in traditional working and learning cultures.

PURPOSE OR GOAL

This study aims to investigate the effects of transitioning into remote learning and working on the quality of work produced, specifically by electrical and electronic engineers in Australia. The objective is to identify factors relating to an individual's ability to produce self-defined quality work and identify any emerging themes due to the change in learning and working environments.

APPROACH OR METHODOLOGY/METHODS

A total of six participants, consisting of five students and one senior engineer, was recruited and interviewed. Each brought their own unique perspective on the matter via semi-structured interviews where they were asked questions regarding their learning/working experience before and during remote learning/working. Defining quality working through the epistemology of practice, cooperative work and self-efficacy, and connectivity, the researchers investigated how the ability to produce quality work has been affected due to the change in learning/working environment.

OUTCOMES

The representative data indicated that feedback, open collaboration, and team rapport were the three key contributing factors to quality work during this transition to learning/working remotely. Feedback and collaboration contributed positively to quality work and a strong team rapport further augmented the individual's ability to produce quality work.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This study provides an initial impression on the topic and invites further study to establish a deeper understanding behind the contributing factors towards quality work. Further studies into different engineering disciplines or a larger sample size to establish a larger data set is recommended to extract richer conclusions.

KEYWORDS

COVID-19, engineering practice, productivity, quality of work

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Introduction

The COVID-19 pandemic has plagued the globe since December 2019. As of May 2021, there have been 162 million confirmed cases with approximately 3.4 million deaths worldwide (WHO, 2020). The COVID-19 pandemic has been a point of interest due to its abrupt and widespread impact, forcing extensive lockdown restrictions and forcing many to rapidly transition into working and learning remotely.

As professionals continue to transition into working remotely and communicating through digital platforms, it raised the question of the implications of doing so. Working from home brings comfort and increases productivity (Boland, De Smet, Palter, & Sanghvi, 2020), driven by the ability to be more flexible (Ganguly et al., 2020). However, the question of negative implications of working remotely has been raised, specifically whether communities would erode without physical interaction, whether planned and unplanned collaboration will be impaired, and whether mentorship and talent development will be reduced (Boland et al., 2020). For engineers and related technical professionals, reported challenges in the early stages of the pandemic include lower productivity related to: work-life conflict; fear of the pandemic; evolving regulations and safety requirements; technical challenges, decreased access to field or production sites, and increased complexity of scheduling of engineering activities (Ganguly et al., 2020; Persun, 2020).

Higher education students have also been impacted by the COVID-19 pandemic, with a rapid shift by universities to online education. Digital learning is convenient and may increase student interest and engagement (Kedraka & Kaltsidis, 2020). Increased student performance has been observed, due to changes in students' learning strategies (Mupenzi, Mude, & Baker, 2020). Negative implications of the move to remote learning include emotional implications and concern about future prospects (Aristovnik, Keržič, Ravšelj, Tomaževič, & Umek, 2020; Aucejo, French, Araya, & Zafar, 2020). Engineering education research has considered the impact of the COVID-19 pandemic on student experience and learning outcomes, including student performance in assessments (Gonzalez et al., 2020), and perceived learning effectiveness (Kapilan, Vidhya, & Gao, 2021).

This research explores the effects of transitioning to working and learning remotely through a digital platform on the quality of work produced by electrical and electronic engineers. Quality of work is a key component of the productivity of knowledge workers such as engineers, and is linked to organisational effectiveness and competitiveness (Drucker, 1999). For engineering students, quality of work is central to achievement of learning outcomes, academic performance and perceptions of employability (Rothwell, Herbert, & Rothwell, 2008). The "new normal" of the post COVID-19 era is likely to be characterised by ongoing digital transformation, working, learning, and teaching. Thus, is it important to consider the implications of these changes for engineering education and practice.

Research Objective

The question guiding this research is: What are the effects of transitioning into remote work and learning on the quality of work produced by electrical and electronic engineers in Australia?

Theoretical Framework

To define quality work and its contributing factors, literature relating to epistemology of practice, cooperative work and self-efficacy, and connectivity, was reviewed.

Epistemology of Practice

The epistemology of practice (Raelin, 2007) provides a link between an individual's ability to produce quality work and their ability to self-reflect and practice. This concept can be broken down into three main building blocks: tacit knowledge, critical reflection, and mastery. Tacit

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knowledge is considered to be deep-rooted knowledge that surfaces when actions are considered intuitive (Shirley & Langan-Fox, 2016). In order to develop tacit knowledge, an individual would be required to accumulate experiences or to learn by doing (Raelin, 2007). Critical reflection plays a key role in developing tacit knowledge by making sense of an individual's personal practice (Kuhn, 1988), recognising that practitioners learn to perform through understanding the practical reasoning behind personal conditions derived from lived experiences (Yanow, 2004). Finally, mastery indicates a process of learning through practice and observation of experts to revise the cognitive patterns they have developed in response to changes in environmental cues (Schön, 1991). Expertise is developed by practicing in different contexts (Raelin, 2007).

Cooperation and Self-efficacy

Working cooperatively has been found to increase self-efficacy, that is the self-belief of an individual's ability to produce specific performance attainment (Carey & Forsyth, 2009). As a dynamic trait that changes over time, there are four external sources that contribute to shape an individual's self-efficacy: performance accomplishment, vicarious experiences, verbal persuasion, and physiological and psychological states (Bandura, 1986). A successful cooperative experience was found to enhance student's confidence in performing a variety of behaviours (Raelin et al., 2011), which provides a framework to investigate the effects of working cooperatively in a physical setting compared to a digital setting and whether that has any significant effects on an individual's ability to produce quality work.

Connectivity and Ideation

Björk and Magnusson (2009) provide a framework to investigate the effects of working remotely in isolation, finding that an individual's connection to a network (of information) and quality of innovative ideas generated had a strong relationship. As an individual's ability to generate new ideas is not dependent only on the individual but also on their position with respect to information flow (Allen, 1977), it's notable to investigate how the change in social context and interaction with other individuals due to this change in environment has affected the individual's knowledge (Spender, 1996). Despite the ability to connect with each other more than ever before through the world wide web, by transitioning to a remote working environment the individual may have lost sources of information flow. It is important to understand whether the connectivity and type of connectivity to a network of information plays a vital role in an engineer's daily life when working and/or learning to understand how the shift in working environment has affected an individual's ability to produce quality work.

Research Method

This study adopted a qualitative research approach using semi-structured interviews, facilitating a deeper understanding of the participant's opinions and attitudes relating to learning and working remotely, as human experiences have diverse qualities and meanings (Sullivan & Forrester, 2018).

Interview Protocol

Development of the interview protocol was informed by the three theoretical frameworks: epistemology of practice, cooperation and self-efficacy, and connectivity and ideation. The interview protocol comprised four sections, commencing with general questions that established the participants' experiences before and during remote working/learning and allowed the participant to reflect on their own definition of quality work. This was followed by questions relating to working under a supervisor or tutor; teamwork and self-efficacy, and participants' experiences of interaction and collaboration within teams. By investigating factors related to each theoretical framework before and during remote working and learning, the research aims to identify emerging themes and any other significant factors related to the

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quality of work produced by an individual. The set of interview questions, complemented by additional probing questions, allowed flexibility depending on the participant's response, potentially providing a deeper understanding of each individual experience and perspective.

Participants

Using a criterion sampling approach (Miles & Huberman, 1994), electrical and electronic engineering students and professionals meeting the following criteria were invited to participate in this study.

1. Participants must have transitioned into remote working/learning between December 2019 to time of invitation to participate in the study (March 2021).
2. Participating students must be undertaking their penultimate or final year of their engineering studies, specialising in electrical and electronic engineering

A total of six participants, comprising five students undertaking their master's degree in engineering at a research intensive university in Australia and one senior electrical engineer working in industry, were recruited for the study. Four of five students transitioned to remote learning only as they were not engaged in engineering work during the time period. One student was working as a student engineer in addition to completing engineering coursework, and transitioned to remote work and remote learning. The senior engineer experienced transition from in-person to remote working in a full-time, supervisory capacity.

Data Collection and Analysis

Due to the relaxation of regulations surrounding COVID-19 at the time of data collection, participants were invited to attend the interview either in-person or online through a recorded Zoom™ meeting. With participant consent, interviews were audio recorded and then transcribed through a free to use online software called Otter.ai. Transcripts were reviewed and corrected by the researcher before seeking participant confirmation of the transcript.

An inductive thematic analysis approach was taken. The interview transcripts were thematically coded without a pre-existing coding framework or preconceptions of existing theory (Braun & Clarke, 2006). A multi-step analytic process comprising data familiarisation, generation of initial codes, and search for patterned responses, allowed themes to emerge from the data (Borrego, Douglas, & Amelink, 2009).

Findings

Three key themes were identified: feedback, open collaboration, and team rapport. An individual's ability to produce quality work was influenced by the level of feedback received. This was impacted by the ability to collaborate openly – to be able to bounce ideas off of colleagues and share different perspectives on a topic. Strong team rapport augmented these two factors and had a strong influence on an individual's ability to produce quality work.

Feedback

The change in working/learning environment resulting from the transition into remote work impacted the frequency, volume and timing of feedback received from a supervisor. The quality of feedback provided was found to remain mostly unchanged.

"I did receive constructive feedback both before and after. But I would say the frequency decreased a lot after COVID" – Participant 2.

"I don't think it has changed the quality of work, … because for work I still get feedback, but it just might be later" – Participant 1.

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Barriers to feedback included challenges in reaching out and asking for help when working online. Another participant indicated that asking for help in-person would push the supervisor to answer the question rather than putting it to the back of their minds. The lack of physical gestures in the online environment formed a communication barrier, which impinged the ability to understand the supervisor leading to a negative impact on quality of work.

The senior engineer provided a supervisor's perspective stating the reduction in providing feedback had positive results.

> *"I think it (remote work) probably enhances quality // people don't get the opportunity to come to you to get the answer straightaway. They, you know, have to go find it for themselves, and when they find that answer for themselves, they've learned a lot more than they would by getting spoon fed the result" – Participant 6.*

Participant 3 perceived that an individual's ability to produce quality work is dependent on the relationship with the supervisor rather than the working/learning environment. Most participants described distant relationships with supervisors, and mentions of deep personalized feedback and task involvement was not present for any of the participants.

> *"It's a bit harder to ask for personalized feedback if you don't have any specific class or specific tutor or a lot of one-to-one time because the lecturers and tutors won't actually know who you are and how you're tracking personally" – Participant 3.*

The senior engineer felt that the digital barrier makes it difficult to understand underlying problems within a team. Junior engineers may struggle but no one will understand their struggles as only the result will be shown.

> *"It's very easy to think that they are simply not good at their job and it's hard to understand what sort of assistance is required" – Participant 6.*

The effects on feedback due to the changing work environment on an individual's ability to produce quality work appears to have deep rooted consequences, which may not immediately arise in the short-term. Restricting the intimacy between individuals results impacts feedback and affects the quality of work produced.

Open Collaboration

The change in working environment was found to have varied effects on the level and quality of collaboration. Participant 2 felt that remote working/learning made it easier to organise meetings as physical presence was not required. Collaborating with others did contribute towards higher quality work being produced, but it was independent of whether they were online or face-to-face. There were difficulties in collaborative efforts at first, however these were easily overcome.

> *"We got used to it. So just sending emails, pictures, or uploading it, or screen sharing. So, there are ways around it, definitely. Just a bit more troublesome" - Participant 3.*

Participant 4 provided an opposing perspective, finding it difficult to collaborate in a remote environment and identifying the online platform as a barrier to open collaboration. Participant 5 provided a similar perspective where the remote environment affected the quality of work, creating a 'hold-back' or deterrent to collaboration with other team members.

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"Online, it's kinda like we are less or not that inviting, there's not that warm inviting environment coming in to share and stuff" – Participant 4.

The reliance on collaboration and its effects on quality of work produced appear to depend on the nature of work. Working collaboratively was effective when the task required more capacity – such as problem solving or large quantities of work. Participant 1 noted that the value of collaboration helped when she was unsure and needed clarification or explanation.

For work that did not require collaboration, interactions with others limited the amount of quality work that can be produced. Working individually was effective when the task required concentration. For some participants, the move to remote work provided relief from frequent disruption experienced in collaborative in-person environments.

"I can't recall how many times during the day I'd get 'hey, quickly…', and you know for me it was a very disruptive way as a manager to get any work done being in an open plan office everyone had access to" – Participant 6.

Collaboration between peers and with supervisors was seen as an important factor contributing to an individual's ability to produce quality work. However, in the new remote reality, some participants struggled to collaborate while others continued to thrive. Established routines were broken down, which made it difficult for some to continue producing quality work.

"I guess I was not so focused on work because I wasn't very, you know, like very high intensity because I was at home, so you didn't really – the environment didn't fit you know, the drive." – Participant 4.

The senior engineer provided insight into this juxtaposition, citing proactivity as a key influence. Despite a dire situation, there will be those who continue to thrive:

"Like an extension from Uni, it depends on whether you are proactive and strive for excellence. Because if you do the bare minimum you will end up average. So similar with junior engineers if they're tenacious they will succeed, whereas those who don't will probably struggle." – Participant 6.

Despite the challenges of transitioning to remote work, a common theme was the understanding that the task at hand must continue despite the situation. This manifested intentional collaborative efforts, for example Participant 1 was selective with who they worked with while Participant 4 created a digital space to continue having those working/studying and casual chatting spaces to replicate social warmth. The ability to be proactive, or the lack of, in collaborating with other individuals is therefore identified as a contributing factor towards an individual's ability to produce quality work.

Team Dynamic

The consensus regarding teamwork and quality of work produced was that working in a team, if done right, can result in higher quality work. However, this was conditional upon the team being engaged and aligned – meaning that everyone sought to complete their own tasks and were proactive in doing so.

All participants agreed that if the team were not engaged nor aligned, the team would become inefficient, resulting in poor communication and conflicting opinions, making it difficult to produce quality work within a team.

"There may be conflict in the opinions and there would be a hold back on some of the things that perhaps one person would like to do. Restrictions would be probably a lot if not communicated properly"- Participant 5.

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Participant 2 provided insight to the impacts of the team on everyone's ability to produce quality work, understanding that it is not only dependent on how he worked but instead how everyone works together.

> *"I know that the performance of the team is dependent on how I work with everyone and how the people perform. So, it's less about just me but more about how everyone works together" – Participant 2.*

The same participant found that working/learning remotely made it difficult to establish rapport with the team, which may have affected his ability to produce quality work. In contrast, Participant 1 revealed that she already knew her team members, therefore a change in environment did not affect her team.

A strong contributing factor towards an individual's ability to produce quality work is their ability to communicate openly with others, whether working remotely or physically. However, the change in environment may impact the ability to establish rapport.

The senior engineer provides some insight into this finding. The change in working environment has established a barrier to supervisors truly understanding their team and how they work. Working remotely restricts the ability to mentor your team and junior engineers who struggle may continue to fall behind outside of an engineering environment.

> *"… it's about understanding your team, which can only really come from seeing how they work in person. I think that you can see how they work very quickly when you're working together. But by working remotely, that's probably a downfall to understanding your team member, what working style they are." – Participant 6.*

This supports the fact that rapport is a strong contributing factor towards the ability of an individual to produce quality work, tying into the two previous emerging themes of feedback and collaboration. With strong rapport between peers and supervisors, there is a greater likelihood to collaborate openly and receive feedback from each other – further enhancing knowledge and thus producing higher quality work.

Conclusion

This study aimed to develop an initial understanding of the implications that transitioning to remote work during the COVID-19 pandemic may have on the quality of work produced by electrical and electronic engineers, drawing on three theoretical frameworks: epistemology of practice, cooperative work and self-efficacy, and connectivity, to understand quality work.

Through a process of inductive analysis, three themes indicating the key contributing factors towards an individual's ability to produce quality work when transitioning to working/learning remotely emerged: feedback, open collaboration, and team rapport. The relative importance of the three factors on quality of work varied with the nature of the work. The role of the engineering environment in facilitating collaboration and rapport building for junior engineers and their supervisors was revealed.

The move to remote work during the COVID-19 pandemic has initiated a paradigm shift in working and learning culture. Going forward it is clear that routine and intentional touchpoints with colleagues to develop a deeper understanding of the task at hand and to develop a stronger relationship with one another is equally important when considering quality work. A concept applicable to both remote and physical work and education.

Limitations

With only 6 participants, consisting of 5 students and 1 senior engineer, the representative data set is limited. Further investigation with additional participants is recommended to reach saturation (Lincoln, Guba, & Pilotta, 1985) and refine findings (Tuckett, 2004). The

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participants were undertaking a range of engineering work. This diversity may have influenced the emergence of themes.

Future Work

This study was able to provide an initial insight on the contributing factors to quality work for electrical and electronic engineers. To develop the understanding of how engineers can continue to produce high quality work as the working and learning culture shifts, further research is suggested. Refining this study by focusing on participants with similar industry backgrounds or work histories may assist with strengthening conclusions. Expansion of the study to additional engineering disciplines may result in new emerging themes to be found, further developing the understanding of how engineers can continue to produce quality work. It is also important to consider long-term impacts of this unique situation on engineering students and working professionals as the effects of career shock manifest over time (Akkermans, Richardson, & Kraimer, 2020).

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Developing engineering leadership skills through student-led workshops in the context of engineering grand challenges

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CONTEXT
Strong leadership skills and an understanding of the engineering role in both technological innovation and stewardship are required to address global problems such as the grand challenges. Incorporating leadership skills development and connecting leadership to a broad awareness of socio-technical responsibilities can be complex in what is a very full engineering curriculum. This study describes the creation of co-curricular student-developed and led online workshops as a mechanism to provide engaging and broadly accessible experiential learning activities to address this learning opportunity.

PURPOSE OR GOAL
Through this work, we look to demonstrate that student-developed and led online workshops can effectively and efficiently provide experiential learning opportunities that can build knowledge, skills and attitudes related to leadership development and technological stewardship. Ultimately the goal is to demonstrate an effective and efficient methodology for student engaged learning that can be incorporated in the engineering curriculum.

APPROACH OR METHODOLOGY/METHODS
Undergraduate engineering students created and led 90-minute online workshops that combine leadership skills development (e.g., exploration of values, domains of influence) and an introduction to the Canadian Engineering Grand Challenges (CEGC) such as "Inclusive, safe, and sustainable cities". Workshops are delivered to students at Canadian Engineering schools in February and July (and November 2021 forthcoming). At each workshop, qualitative and quantitative survey data is collected from the participants related to engagement in the learning experience, development of leadership skills, and the relationship to CEGC. The methodology used and resources required to ensure that students create relevant, aligned workshop material is also documented.

ACTUAL OR ANTICIPATED OUTCOMES
The first workshop (February 2021) was delivered to engineering students at two institutions. The second workshop (July 2021) was delivered to engineering students from 4-6 institutions. Preliminary results show high engagement during the workshop, increased awareness of personal leadership development, and strong awareness of the CEGC and their relevance to engineering leadership. The participant survey results from the first two workshops will be analysed. The third workshop (November 2021) will involve engineering students from institutions across Canada.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
Preliminary results indicate that student-led development and delivery of co-curricular workshops are efficient and effective for student learning. Student participants were highly engaged in leadership development and readily connected the concepts to engineering grand challenges and technological stewardship. This shows promise as a methodology for providing access to learning opportunities that are flexible, scalable, and broadly accessible. A next step recommendation is to explore the integration of this methodology into existing curriculum, creating opportunities to enable student engagement in their own learning.

KEYWORDS

Engineering Leadership, Experiential Learning, Lifelong Learning

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Background

Strong leadership skills and an understanding of the engineering role in both technological innovation and stewardship are required to address global problems such as the grand challenges. The "grand challenge" concept started as the unsolved problems in mathematics in the early 1900s, and today is an approach used to focus and inspire professions to reflect on and approach problems of deep societal importance. Incorporating leadership skills development and connecting leadership to a broad awareness of socio-technical responsibilities can be complex in what is a very full engineering curriculum. Supported by the Engineering Deans of Canada (NCDEAS, 2019), the Canadian Engineering Grand Challenges (CEGC) are global but have a uniquely Canadian context. The CEGC provide an opportunity to use the grand challenges as a framework and to develop the student mindset by developing expertise and leadership to bear new ideas and reimagine solutions. This study describes the creation of co-curricular student-developed and led online workshops as a mechanism to provide engaging and broadly accessible experiential learning activities to address this learning opportunity.

Needs and Objective

The engineering education culture is experiencing a shift in context for engineers, with a growing need for leadership and management skills to complement technical knowledge. Leadership skills development needs to be part of the educational content and the engineer's mindset (Jamieson and Donald, 2020). Engineers have a desire to develop sustainable solutions to large complex problems, and in sustainability, and would benefit by having targeted training to address socially-motivated problems that inherently require an understanding of multiple perspectives and disciplines (NCDEAS, 2019). The cultural approach to engineering education is shifting to incorporate socio-technical requirements into curriculum (Martin and Polmear, 2021). Currently, important skills such as leadership, ethics, and reflective practice required for lifelong learning are under-represented in the curriculum given this new cultural context. Incorporating these skills is complicated by an already-packed curriculum. The objective of this paper is to present an innovative process of engaging students in the CEGC to help educate future technology leaders and stewards to critically reflect on the important role they play in transforming our world. Co-curricular student workshops have been growing as a means to address this leadership learning opportunity (e.g., "Troost ILead" n.d.; "Schulich Engineering Leadership Program" n.d.), however the concept of student-developed and led workshops is rare or missing. Specifically, the authors explore this opportunity and learning potential.

Through this work, we look to demonstrate that student-developed and student-led online workshops can effectively and efficiently provide experiential learning opportunities that can build knowledge, skills and attitudes related to leadership development and technological stewardship. Ultimately the goal is to demonstrate an effective and efficient methodology for student engaged learning that can be incorporated in the engineering curriculum. This is important for three main reasons:

- Student engagement in creating their own learning experiences, that is autonomy-supportive pedagogies (Goldberg and Somerville, 2014, 159–62), can be transformative and support life-long learning.
- Mechanisms to address challenging curricula and introduce socio-technical concepts are often missing.
- Success may influence the inclusion of curricular activities in existing programming, from an engineering mindset/content (i.e., socio-technical and CEGC) and methodology (i.e., students teaching students) perspectives.

Student Learning – Experiential and Online

Students see a need for experiential learning opportunities and leadership skills development. At its core, experiential learning follows Kolb's learning cycle comprising: experience – reflection – conceptualization – experimentation (Kolb, 1984). The need and opportunity for students to be engaged in the development of their own learning (Goldberg and Somerville, 2014) inspired our approach towards "for students, by students" in which students developed and led workshops for other students. Learning activities and materials, adapted to an online environment, were designed to draw on abilities from each stage of the process, in sequence, for knowledge construction. This "hands-on learning" for leadership development in virtual environments, which simultaneously helped build digital competency, is a new area to explore. Experiential learning outcomes related to student engagement in their own learning, and student motivation by exposure to the CEGC framework inspire their respective professions and influence their learning.

Leadership Mindset

A review of engineering leadership education suggests six key competencies emerging: communication, innovation, creativity, execution, personal drive, and teamwork (Paul, 2015); while the National Academy of Engineering (2004) emphasized leadership in the "Engineer of 2020", and the "Whole New Engineer" emphasizes leadership and the creative imperative (Goldberg and Somerville, 2014). To inspire curricular change initiatives to address these leadership competencies in the context of sustainability, two special interest groups (SIGs) have emerged in the Canadian Engineering Education Association (CEEA-ACEG). The "Engineer of 2050" and the "Sustainable Engineering Leadership and Management" SIGs facilitate discussion on the identity and attributes of the engineers of the future, who will both shape and respond to future global trends. Focusing on engineering leadership at the intersection of the human and technical requirements brings effective and sustainable operation of these complex systems in our world. Leveraging the CEGC as an application framework will greatly test students as there are no obvious solutions and will require abstract thinking, creativity, and systems thinking to build new competencies. The CEGC framework can also help to emphasize the high relevance of these skills in parallel to the traditional emphasis on technical skills.

Technological Stewardship

By definition, "Technological stewardship is behaviour that ensures technology is used to make the world a better place for all — more equitable, inclusive, just, and sustainable. To accomplish this, technological stewardship calls on those who create and influence technology to step into a responsible leadership role" (Canadian Federation of Engineering Students, 2018). At its core, this definition is also a call to action to students and professionals in technology-related fields to demonstrate leadership at an individual and societal level in addressing the technological needs of their community, all the while continuing to coexist with nature, and increasingly relevant because technology continues to evolve at an incredibly fast pace.

As the focal point of engineering shifts from the technical into the socio-technical realm it drives the need for changes in engineering education to develop technology stewards by advancing new competencies and developing leadership skills. Technology stewards are people with experience of the workings of a community to understand its technology needs, and experience with technology to take leadership in addressing them. Technological Stewardship principles are (Engineering Change Lab 2019):

- **S**eek purpose
- **T**ake responsibility
- **E**xpand involvement
- **W**iden approaches
- **A**dvance understanding
- **R**ealize diversity
- **D**eliberate values
- **S**hared action

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Grand Challenges

The made-in Canada version, Canadian Engineering Grand Challenges, reflect the unique characteristics of Canada and the Canadian engineering education landscape. The CEGC are rooted in the United Nations' 17 Sustainable Development Goals (SDG), which represent the world's call to action to address the challenges and opportunities facing the world and humanity. For the community of engineering educators, considerations about how engineering education might evolve to prepare our students for the many opportunities and challenges that society will face in 2030, 2050 and beyond, are now pressing, and prompting action. The coming decade is the "decade of action" to expedite efforts to meet the global targets for the SDG. Engineers with strong technical skills sufficiently addressed the needs of society in the past century, however, challenges of the 21st Century and particularly the coming decade require both engineering expertise and leadership, in which for example, sustainability in design requires an engineering mindset that incorporates leadership and a view toward technological stewardship. Embedded in future-thinking to reimagine engineering education, the scope of this study leverages the six CEGC (NCDEAS, 2019):

1. Resilient infrastructure,
2. Access to affordable, reliable and sustainable energy,
3. Access to safe water in all communities
4. Inclusive, safe, and sustainable cities,
5. Inclusive and sustainable industrialization, and
6. Access to affordable and inclusive STEM education.

Methodology

The methodology used and resources required for the workshop development "by students, for students" to develop leadership skills in the context of the engineering grand challenges is presented in this section. Undergraduate engineering students created and led 90-minute online workshops that combine leadership skills development (e.g., exploration of values, developing vision, enabling others) and an introduction to the Canadian Engineering Grand Challenges (CEGC) and technological stewardship principles. Workshops were delivered to students at Canadian Engineering schools in February and July 2021, with a third workshop in November 2021 forthcoming. At each workshop, qualitative and quantitative survey data is collected from the participants related to engagement in the learning experience, development of leadership skills, and the relationship to CEGC.

General learning outcomes include: 1) building awareness on the CEGC, 2) developing leadership skills, and 3) leveraging online learning spaces for experiential learning opportunities. Demonstration of these learning outcomes is used to assess development stages of leadership skills and leadership identity, ability to interpret the importance and relevance of CEGC, and engagement of experiential learning activities online. Assessment of the learning outcomes will be analysed and reported in a future publication.

Phased Approach to Workshop Development and Delivery

The development team envisioned a series of workshops that could be applied in local and national contexts, grow in institutional reach, and deepen in CEGC focus as experience was gained in the workshop development and delivery process. This resulted in convening and supporting the delivery of three online workshops in a phased approach, as follows:

- firstly, to students within the two participating institutions,
- secondly, to students recruited through the members of the Canadian Engineering Education Association (CEEA), and

- finally, to students in the wider Canadian engineering education community as a pan-Canadian culminating “Leadathon” event.

Workshop Development

A key element for our success in this process was to hire undergraduate students to lead the process as the core student team to develop and deliver the workshops. In this case, the student team consisted of 3-5 co-op (co-op consists of multiple academic terms and multiple work terms) students over the course of two semesters (Jan-April 2021 & May-Aug 2021) who worked on the workshop development as part of their duties. The total work was the equivalent of approximately 1.5 FTE (0.5 at Waterloo, 1.0 at Guelph).

To complete the workshops, the core student team had or developed the following prerequisite knowledge:

- Constructive alignment with Bloom’s taxonomy
- Engagement in the CEGC, sustainability concepts, technical stewardship principles
- Experience in delivering workshops

The workshop development steps and cycle followed for each of the three workshops are shown in Figure 1.

Figure 1: Workshop Development Cycle

Content Development

The student-led content development included iterative steps, summarized as follows:

1. Brainstorm/Reading Literature: To familiarize with literature and resources.
2. Professor Mentorship: To guide and support students along their learning journey.
3. Refine Content and Select Focus: To narrow the scope to accommodate durations.
4. Lecture and Activity Creation: To build workshop material and hands-on activities.
5. Rehearsal and Revisions: To gather feedback and improve the learning experience.

The base content included four main topics, and a discussion on values as a starting point in each workshop. The topics include: Technological Stewardship, UN Sustainable Development Goals, Triple Bottom Line, and Canadian Engineering Grand Challenges.

Facilitator Selection/Training

The core four-student team, with support from faculty members, underwent a process to recruit student facilitators through an application process where applicants articulated their motivation and interest in engineering leadership and their attitude to support serving as facilitators at the workshop. Selected facilitators were invited to a “train-the-trainer” session delivered by the core team on content, online tools and facilitation techniques. Facilitators were also given an orientation to the workshop content, including a practice run; and training in the online tools for workshop delivery, such as the use of breakout rooms and shared documents such as *Google Sheets;* and practised facilitation tips to engage participants, interact with others, and drive discussions. The outcome of this stage is to define the roles of the facilitators and the timing of workshop activities, in addition to identifying the resources required for running workshops (eg. determine facilitator to participant ratios).

Event Promotion and Participant Recruitment

Workshops were promoted by the core student team through an outreach effort on social media (e.g., *LinkedIn*, *Instagram*), student societies, and faculty networks at the partner institutions, such as the CEEA-ACEG membership. Working with the CEEA-ACEG network was effective in reaching a wider student participation from universities across Canada. To facilitate the registration process for participants from multiple institutions, the core student team also developed the expertise to use online registration tools such as *eventbrite*.

Workshop Delivery

The 90-minute workshop delivery follows a structured format that starts with a discussion of values and the motivation of engineering as a leadership profession. Following this, there is an introduction to the main content theme, followed by a series of content and breakout room activities, and closing with a summary and a key takeaway session. The workshop was intentionally structured to provide a mix of new material and large group reflection in the main room content, small group interaction and in-depth discussion in the breakout room activities.

The general model for the workshop structure is:

1. Introduction (10 minutes)
2. Breakout Room Introductions (5 min)
3. Main Room Content (20 min)
4. Breakout Room Activity #1 (10 min)
5. Main Room Content (20 min)
6. Breakout Room Activity #2 (10 min)
7. Closing and Key Takeaways (15 min)

Workshop Assessment

Upon the conclusion of the workshop, a follow-up survey is sent to the participants (and facilitators in the July workshop). Workshop assessment includes qualitative and quantitative survey data collected from the participants and related to engagement in the learning experience, development of leadership skills, and the relationship to CEGC. The survey distributed to participants also includes general questions about institution, year of study, engineering program, and gender. Participant survey questions are listed in Appendix A.

Observations/Results

The observations and results focus on the development and delivery process for the two workshops delivered. The participant survey results from the workshops and feedback from the faculty observers will be analysed upon the conclusion of the third workshop. The first workshop was delivered in February 2021 to 114 engineering students at two institutions. Preliminary results show high engagement during the workshop, increased awareness of personal leadership development, and strong awareness of the CEGC and their relevance to engineering leadership. The second workshop was delivered in July 2021 to 39 engineering students from 9 different institutions. Canada has 45 institutions that deliver accredited engineering programs (Engineers Canada, 2019). In addition, including the principal investigators, faculty observers from six of institutions also attended the July workshop. The third workshop will involve engineering students from institutions across Canada and take the form of a “Leadathon” where engineering students will work to address selected CEGC.

Based on the first two workshops offered, there are some preliminary observations regarding the workshops include student interest and perception, and faculty interest and motivation.

The distribution of student participation was spread relatively evenly across all levels, from year one through graduating years in engineering programs. Student perceptions of the quality of both the workshop delivery, content and learning were quite high, providing a rating of 4.3/5 for meaningfulness, and 4.2/5 for applicability. Two quotes from participants serve to demonstrate the effectiveness of the workshop:

> *"What I learned from this workshop is that there are two sides to every story. To be an effective leader you must take the time to understand both sides to see the entire picture… a leader should seek to comprehend the benefits and consequences then compare the risk of both sides before coming to a conclusion. – Participant from February workshop*

> *"[The leadership skills developed include] thinking quick, creatively, critically, and profoundly to map CEGCs; explaining and justifying my personal recommendations/thoughts in the breakout sessions, while also listening to others." – Participant from July workshop*

Faculty observers at the second workshop indicated in follow-up conversations that they were highly inspired to engage their students in broader societal challenges, and most notably expressed an interest in collaborating to develop a similar leadership learning approach at their own institutions.

Table 1: Summary of Workshops

	Workshop 1 (Waterloo-Guelph)	**Workshop 2** CEEA	**Workshop 3** Pan Canadian Leadathon (planned)
Timeline	February 2021	July 2021	November 2021
Core student team	4	4	4
Number of institutions	2	9	>10 (target)
No. of participants	114	39	>60 (target)
No. facilitators	18	16	>10 (target)
Duration	90 minutes	90 minutes	3.5-4hrs
Content	Tech Stewardship UN SDG CEGC	Triple Bottom Line CEGC Tech Stewardship	CEGC Tech Stewardship
Activities	Debate on new technology, CEGC prioritization	Concept maps of CEGC and Triple Bottom Line, and Tech Stewardship	Concept maps of CEGC, SMART Goals, Milestone plans, adaptive leadership
No. of breakout rooms	9	7	TBD
Survey response rate	90%	23%	TBD

Analysis and Discussion

An analysis of the impacts on students, facilitators and faculty shows engagement in the workshop development and delivery process on several levels. The core student team, student participants, and student facilitators learning experience demonstrates a desire to go beyond technical knowledge and connect the social context to engineering solutions. The workshop development follows a pedagogical model that emphasizes learning outcomes and utilizes teaching tools and approaches (e.g., concept maps, debates) to embed and strengthen learning in group activities.

The quality and effectiveness of the process was evidenced by our ability to plan, develop and deliver workshops in a compressed timeline, including the outreach for selecting and training facilitators and recruiting participants. The outreach effort and engagement of participants from other institutions was facilitated by faculty across the country and helped promote nationally and was complemented by the core team of students who recruited through their own national networks of student societies. The facilitation carried out by students was a critical success factor in providing greater comfort and engagement of

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participants in breakout sessions and in large group reflections, in addition to peer mentorship experience during the "train-the-trainer" sessions. A continuous improvement process is made possible due to the iterative nature of workshop development and the phased approach to workshop delivery across Canada, also recognizing the meaningful observations from faculty observers. Another critical success factor was the enabling environment in which the core-student team operate within that leverages their experience with the Guelph Engineering Leadership (GEL) program and the UWaterloo's Student Leadership Program.

There is a difference in attendance between the first and second workshops, that may be attributed to the February workshop being held as part of a leadership certificate during the academic year, whereas the July workshop was a one-off independent workshop during the traditional summer break period across most of the participating institutions. In both cases, the unique aspect about this learning model is the self-enrolment which rests on student's own motivation, unlike curricular courses which are mandatory for credits. The participation was generally above our target numbers, with a diverse (across undergraduate years, engineering discipline, and gender) participation across Canada from "coast to coast" as a benefit of the online delivery.

Conclusions and Recommendations

Preliminary results indicate that student-led development and delivery of co-curricular workshops are efficient and effective for student learning. Students were highly engaged in leadership development concepts and readily connected the concepts to engineering grand challenges and technological stewardship. This methodology is promising for providing access to relevant intentional learning opportunities that are flexible, scalable, engaging and broadly accessible. A next step is to explore the integration of this methodology into the traditional curriculum, creating opportunities to enable student engagement in their own learning. The team is exploring the development of online modules, and experiential learning case studies, in addition to toolkits and facilitator guides to encourage wider application of the leadership skills related to the CEGC and technological stewardship principles, and adoptions by institutions delivering online learning inclusive of various Learning Management Systems. Recognizing the high impact of experiential learning, a more ambitious recommendation calls for finding creative ways to include skills such as leadership, ethics and reflective practice required for lifelong learning into existing engineering curricula and connect to graduate attributes (e.g., regulated by the Canadian Engineering Accreditation Board) to address the needs for incorporating these currently under-represented, 21st Century skills in an already-packed curriculum.

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Appendix A

Workshop Assessment survey questions and response formats:

Question	Response Format
On a scale of 1-5, how relevant was this workshop to your leadership development?	Linear scale; 1= Very Irrelevant, 5 = Very Relevant
How important are these topics in your leadership development (Triple Bottom Line, CEGC, Technological Stewardship)?	Linear scale; 1= Not Very Important, 5 = Very Important
List 3 leadership skills or ways that you developed your leadership through this workshop.	Long answer
Which of Canadian Engineering Grand Challenges do you think should be addressed first? (List of 6 CEGC)	Multiple choice selection
Describe why you think this challenge should be addressed first.	Long answer
I found this online workshop engaging.	Linear scale; 1 = Strongly Disagree, 5 = Strongly Agree
I would be interested in attending another workshop or working through an experiential learning module on similar topics.	Linear scale; 1 = Strongly Disagree, 5 = Strongly Agree
What did you like best about this workshop?	Long answer
What suggestions to you have for improving the workshop?	Long answer
Do you have any other comments or feedback?	Long answer

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Learning eco-innovation from nature: an interdisciplinary approach to education in systematic environmental innovation

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CONTEXT

Ecological challenges associated with the global economic development have intensified the need for university graduates that are capable of rapidly finding environmental-friendly solutions to complex problems and can successfully implement eco-innovative concepts. As major negative implication of the technological progress is attributable to its environmental impact, numerous approaches and methods have been developed in the last three decades to support sustainable and eco-friendly product and process development, such as Life Cycle Assessment, Eco-Design, Green Engineering and others. However, engineering curricula still contain too few offers for a structured eco-innovation and development of new solutions providing significant environmental advantages.

PURPOSE OR GOAL

As engineering graduates and specialists frequently lack the advanced skills and knowledge required to run eco-innovation systematically, the paper proposes a new learning materials and educational tools in the field of eco-innovation and evaluates the learning experience and outcomes. This programme is aimed at strengthening student's skills and motivation to identify and creatively overcome secondary eco-contradictions in case if additional environmental problems appear as negative side effects of eco-friendly solutions. The paper evaluates the efficiency of the proposed interdisciplinary tool for systematic eco-innovation including creative semi-automatic knowledge-based idea generation and concept development. It analyses the learning experience and identifies the factors that impact the eco-innovation performance of the students.

APPROACH OR METHODOLOGY/METHODS

Based on a literature analysis and own investigations, authors introduce a manageable number of eco-innovation heuristics with particular focus on the identification of underlying eco-inventive principles used in the natural systems created through evolution. Finally, the paper proposes a comprehensive method for capturing eco-innovation principles in biological systems in addition and complementary to the existing biomimetic methods and other eco-innovation approaches. It shares the experience in application of eco-innovation tools at the Offenburg University, involving students from different years of study and with different knowledge levels.

ACTUAL OR ANTICIPATED OUTCOMES

The proposed educational approach equips students with the advanced knowledge, skills, and competences in the field of eco-innovation. Analysis of the student's work allows one to recommend simple-to-use tools for a fast application in process engineering, such as for example strongest inventive operators for solving of environmental problems. For the majority of students in the survey, even the small workload has strengthened their self-confidence and skills in eco-innovation.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The proposed interdisciplinary eco-innovation tool can be integrated in the discipline-specific subjects and can be recommended for specialists, engineering educators, and creators of eco-innovation methods.

KEYWORDS

environmental education, eco-innovation, sustainability, biomimetics, TRIZ

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Introduction

Ecological challenges associated with the global economic development have intensified the need for university graduates that are capable of rapidly finding environmental-friendly solutions to complex problems and can successfully implement eco-innovative concepts. Numerous approaches and methods have been developed in the last three decades to support sustainable and eco-friendly product and process development, such as Life Cycle Assessment LCA (ISO14040:2006), Eco-Design, Green Engineering, Process Intensification, Process Design for Sustainability, and others. The International Standard Organization defines Eco-Design as “integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle" (ISO 14006:2011). The eco-innovation focuses on the integration of environmental aspects and requirements in the early stages of the innovation processes for new product or technology development to provide significant environmental advantages.

However, these methods frequently don’t belong to the mandatory components of engineering studies today. Moreover, the existing discipline subjects in engineering curricula still contain too few offers for a structured eco-innovation and development of new solutions providing significant environmental advantages. There is often a gap between the students’ competences in sustainable and environmentally friendly product and process development obtained at the engineering universities and the needs of industrial companies and society (Olsen et al., 2018). On the other hand, there is strong evidence that academics can effectively embed teaching eco-innovation heuristics into their existing discipline-based subjects, applying the so-called “infusion” interdisciplinary teaching approach (Belski et al., 2018) to improve creativity and eco-innovation skills of students.

Many researchers, such as e.g., Boodhoo & Harvey (2013), propose to apply the knowledge-based engineering methods of the Process Intensification to overcome negative environmental impacts. Russo et al., (2017) offer 250 eco-innovation guidelines. The Theory of Inventive Problem Solving TRIZ (VDI, 2016) as a comprehensive knowledge-based innovation methodology offers systematic approach and tools for identification and elimination of negative ecological effects. A systematic review of eco-innovation creativity tools based on TRIZ is provided by Livotov et al (2019a). Today, the biomimetics or biomimicry belongs to the established approaches to design for innovation and sustainability (Benyus, 1997). Helfman Cohen and Reich (2019) give a detailed review of current biomimetic design methods for transferring design solutions from nature to technology.

Maccioni et al (2019) analyse 66 eco-design principles and outline that despite the potential to enhance the environmental performance not all eco-design principles lead to the market success due to the secondary problems or engineering contradictions. Russo et al (2015) outline that identification of the engineering contradictions is one of the important aspects in eco-design. In this context, two types of eco-engineering contradictions can be defined in engineering systems: primary contradiction and secondary contradiction. A primary eco-engineering contradiction occurs when the improvement of a non-ecological engineering parameter (e.g. productivity) leads to a deterioration of an environmental characteristic in process or equipment (e.g. air pollution), or vice versa. Consequently, a secondary eco-engineering contradiction is a situation where the improvement of one ecological parameter causes the worsening of another ecological parameter.

In their previous work in the field of engineering education in eco-innovation in process engineering (Livotov et al., 2019b) the authors proposed a number of eco-innovation tools with particular focus on the identification of eco-problems in existing technologies, selection of the appropriate new technologies (knowledge-based engineering), and systematic ideation and problem solving (knowledge-based invention), which are presented in Table 1 (pos. 1-7). Educators can apply one or several tools for their courses depending on time availability, competencies, and skills to be learned or improved, using their own examples or problems. The explanation efforts of educators are considered as low – if a tool requires up to 10

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minutes introduction and its application is almost self-explanatory. The medium efforts correspond to 30 minutes introduction with examples and high efforts correspond as a rule to a two-hour introductory seminar in which the educator has to guide students in each step of the learning process.

In the current paper the authors want to offer two additional eco-innovation tools that could be taught in the stand-alone subjects on sustainability and eco-innovation or through their integration into existing discipline-based subjects. The first analytical method (Table 1, pos. 8) allows one to systematically identify eco-innovation solution principles through analysis of biological systems living in hostile environment. The second creative tool (pos. 9) represents the further development and sematic adaptation of the TRIZ inventive principles (pos. 7) known in the TRIZ methodology for a fast automated idea generation.

Table 1: Eco-innovation tools for integration into the engineering subjects

N	Eco-innovation tool	Application field (skills)	Explanation efforts of educator
1	Identification of eco-engineering contradictions	Problem definition and analysis	medium
2	Process mapping incl. resources analysis		high
3	Ecological Anticipatory Failure Identification	Problem definition and analysis, engineering creativity	medium
4	Sustainable process intensification technologies (database)	Knowledge-based engineering	medium
5	Nine fields heuristic MATCHEM-IBD	Engineering creativity, knowledge-based innovation and invention	low
6	Five cross industry analogies		low
7	TRIZ Inventive operators		medium
8	Biomimetic approach for identification of natural eco-innovation principles		high
9	Automated idea generation with TRIZ inventive operators		medium

Identification of the Natural Eco-Innovation Principles

It can be assumed that the existing biological systems sparingly utilize energy and material resources and have a lesser additional environmental impact, as compared to the human-made products or technologies. Moreover, hundreds of millions of years of evolution have resulted in “natural” sustainable technologies and underlying abstract eco-innovation principles, which can be helpful for problem solving not only in environmental engineering. Such biological innovation principles are termed here as “natural” eco-innovation principles. For example, some orchids and other plants in arid regions have a particular form of CAM-photosynthesis, which allows to reduce their water consumption by 80%, by shifting the carbon fixation phase into the night period with low humidity losses (Zhang, 2016). The derived natural inventive principle here is *accumulation of energy or substances in advance*. Vincent (2017) gives examples of natural inventive principles such as *dynamic equilibrium*, *acclimatization*, or *genotypic change*. Since biological systems, defined as systems of/with living biological organisms, are usually more complex than engineering systems, the technology transfer from nature to engineering requires interdisciplinary knowledge and

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appropriate tools. For example, the *Ask Nature* database of the Biomimicry Institute (Ask Nature, 2021) documents more than 1700 strategies developed by natural systems that achieve different functions. Besides retrieval and analysis of existing bio-inspired eco-friendly technologies or biological strategies from the literature or databases, the identification of the natural principles for eco-innovation can be carried out using problem-driven or solution-driven approaches.

The problem-driven approach can use different algorithms and the function-oriented search to find a biological or natural solution for existing environmental problem. Helms (2009) defines the key phases of this approach: 1 - problem definition incl. functional decomposition, 2 - reframing the problem in universally applicable biological terms, 3 - biological solution search with a set of heuristics, 4 - definition of the biological solution, 5 - extraction of solution principle in an abstract form, 6 - application of solution principle. The solution-driven approach analyses first a biological solution, reframes it in universally applicable engineering terms, and identifies a corresponding engineering problem for solving with the biological solution principle. The authors have made positive experiences with both approaches in introducing eco-innovation tools in Bachelor and Master courses. However, the problem- and solution-driven approaches can be augmented in the field of eco-innovation with a targeted search for biological eco-systems operating under environmental stress, such as for example, high or low temperatures, extreme sun radiation, arid regions, toxic substances etc. Such restriction of the search field makes the biomimetic eco-innovation design process more efficient and targeted and lessens the workload of the students. Table 2 exemplarily presents main steps of the biomimetic approach to eco-innovation for a predefined eco-engineering problem applied in the educational courses.

Table 2: Biomimetic approach to eco-innovation for a predefined eco-engineering problem

Process phase	Description
1. Identification of possible biological solutions	1.1. Definition and classification of environmental stress factors relevant for the pre-defined eco-engineering problem. 1.2. Systematic search for biological eco-systems exposed to environmental stress.
2. Analysis and definition of the biological solutions in identified eco-systems	2.1. Component and function analysis for the eco-system, its sub-systems (bio-components) and super-system. 2.2. Identification of contradictory functions and eco-requirements. 2.3. Identification of the bio-components responsible for resolving of eco-contradictions between opposing functions or requirements.
3. Extraction of biological solution principles in biological terms	3.1. Extraction of concrete biological eco-solutions in the bio-components identified in step 2.3. 3.2. Formulation of abstract biological eco-solution principles in biological terms.
4. Reframing biological solution principles in universally applicable abstract engineering terms	4.1. Transformation of abstract biological solution to eco-engineering using universally applicable technical terms. 4.2. Definition of the underlying abstract engineering solutions and abstract natural inventive principles. 4.3. Assignment of the inventive principles to the corresponding eco-contradictions.
5. Application of the biological principles and development of the bio-inspired engineering solution	5.1. Development of bio-inspired eco-solution (product or process). 5.2. Anticipation of possible new secondary problems and eco-contradictions. 5.3. Optimization of existing eco-solution or application of other biomimetic inventive principles and solutions.

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Vincent (2017) outlines that a trade-off between two contradicting requirements belongs to a central concept of biomimetics. Using the function analysis in the phase 2, it is essential to identify all bio-components with their functions and strategies for adaptation to unfavourable or hostile environment. Trade-offs, conflicts of goals or eco-contradictions identified and explored at step 2.2 can point towards possible concealed bio-solutions. For example, for a plant in arid regions, the reduction of water losses by transpiration and larger leaf surface area for photosynthesis build a pair of contradictory requirements. The surface structure, form, position, colour, biochemistry, or other properties of the plant leaf could give an answer, how a bio-system responds to this challenge.

The following example illustrates the application of the eco-innovation tool to a problem of the coastal erosion protection. In accordance with Flowers and Colmer (2017) mangroves are salt-tolerant trees, also called *halophytes*, adapted to life in hostile environment under the low oxygen conditions. They contain a complex salt filtration system and complex root system to cope with saltwater immersion and wave action. Van de Riet (2019) explored how the irregular mangrove root's structure reduces turbulences in coastal area and proposed geometrically similar artificial barriers as a solution to prevent the coastal erosion. The identified eco-innovation principles for the given problem are a) application of irregular structure in hydrodynamic systems and b) reduction of turbulences.

In the context of the further procedure, table 3 illustrates the application of the solution-driven biomimetic approach on example of mangroves. The eco-innovation principles are extracted by functional analysis of bio-components. Most students use enthusiastically the creative solution-driven approach in the courses and believe to employ it in their graduation theses later.

Table 3: Examples of eco-innovation principles identified in the mangroves eco-system

Bio-component	Function	Natural inventive principles
Pneumatophores	Absorbing oxygen from the air and water: pipe-like structures sticking out of the mud act like snorkels	Simultaneous absorption of substances from gas and fluid
Roots and stems	Mangrove roots and stems have special tissues which act as a barrier to salt	Use in parallel different technologies to block or extract harmful agent
Fresh leaves	Extraction of the salt underneath the mangrove leaves: special glands concentrate salt and excrete it to the surface	Use different sides or parts of an object for competing operations: extraction of salt and photosynthesis
Leaves, flowers, fruits	Concentrating and removal the salt: salt can be moved to old leaves, flowers, or fruits which then drop off, taking the concentrated salt with them	Apply biodegradable waste to remove harmful substances
Seeds	Protect reproductive function from environment: seedlings germinate, and start developing on the tree and survive in seawater for year or more	Isolate sensitive processes from hostile environment in time and in space

Our practical experience confirms that the identification of eco-innovative solution principles in biological systems adapted to hostile environment enhances both the creativity and the systematic way of inventive thinking. However, its application requires moderate to significant workload that can limit its integration into existing discipline-based subjects. Generally, a creation of the database of the natural eco-innovation principles, extracted from biological systems and strategies, can be considered as a promising direction of innovation research.

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Automated Idea Generation for Eco-Innovation

As experimentally confirmed by Belski et al (2018) the inventive principles and heuristics of the Theory of Inventive Problem Solving TRIZ (VDI, 2016) help systematically enhance the ideation performance of students and specialists. One of the latest enhanced versions of the 40 Inventive Principles, as one of most frequently used TRIZ heuristic, has been proposed by the authors (Livotov et. al, 2019a) and contains 160 inventive elementary sub-principles for idea generation. This version is continuously complemented and extended with recently identified natural eco-innovation principles as described in previous section of the paper. Based on meticulous analysis of 155 new technologies, 200 patent documents, numerous industrial case studies and scientific literature the authors identified the statistically strongest elementary inventive for eco-innovation and eco-design in general and for reduction of energy and material consumption and losses in particular. These recommendations allow one to select from 160 inventive sub-principles the 15…30 statistically strongest inventive heuristics for fast and targeted idea generation.

However, a practical application of inventive principles often requires a concentrated, creative, and abstract way of thinking that can be challenging especially for newcomers to TRIZ. For example, the abstract term “object” used in the principles may be understood as a system, system component, substance, process or process step, or any other material or virtual object. Also, the abstract definition of “action” can be understood as function, positive or negative effect or any interaction between the objects. Therefore, the outcomes of ideation work depend on a certain interpretation of the abstract terms.

Moreover, some of the inventive operators are more specific and can be clearly assigned to at least one of nine MATCEM-IBD engineering domains: M - Mechanical, A - Acoustic, T - Thermal, C - Chemical, E - Electrical, M - Magnetic, I - Intermolecular, B - Biological and D – Data or Information processing. On the other hand, there is also a group of generally formulated *universal* inventive operators, which are independent of any engineering domain and hence could require additional analysis and reflection by their use. A part of the universal operators forms a group of the inventive operators for Design.

The experimental study carried out by the authors confirms that the less abstract and problem specific formulation of TRIZ inventive principles can visibly improve idea generation outcomes of engineering students both in the quantity of ideas and their variety. The breadth over the nine MATCEM-IBD domains has been essentially enhanced while applying the less abstract principles. In 194 experiments conducted at the Offenburg University the students generated nearly 1.5 times more ideas with the semantically modified and thus less abstract inventive principles than with the classically formulated TRIZ Inventive principles. This positive effect was observed by the students from different years of study independently of their knowledge level or difficulty of the problem.

In order to make the application of inventive principles faster and easier for the students without prior skills in TRIZ, authors propose a semantic transformation defined as a collection of rules that specify how inventive principles can be represented in a less abstract form as a finite number of automatically generated solution ideas. In accordance with (Livotov, 2021), in order to initiate the automated ideation for a pre-defined problem, it is only necessary to formulate the following problem-specific categories: Working tool, Target object (affected by the working tool), Useful action, Harmful effect. The semantic transformation then generates up to 170 solution ideas distributed over the problem definition categories as follows: Working tool (83 ideas); Target object (30 ideas), Useful action (47 ideas), Harmful effect (10 ideas). In the practice, the top 15…30 automatically generated ideas with the highest statistical ranking deliver at least 3…6 workable solutions of the eco-engineering problem.

Table 4 illustrates the outcomes of the automated idea generation for the problem on how to reduce the energy transfer losses of the wireless inductive charging of the smartphones. It presents exemplarily 7 of 50 ideas with the high statistical ranking for reduction of energy losses out of total of 170, with the *inductive coil* as working tool, *smartphone* as target object,

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wireless *energy transfer* as useful action, and *energy losses* as harm. A systematic identification of high-quality and rapidly implementable solution ideas can be performed in accordance with their engineering domains, low to medium abstraction level and higher statistical ranking. Table 4 also illustrates how the automatically generated ideas are assigned to the engineering domains.

Table 4: Automatically generated ideas to reduce transfer losses of the wireless charging

Automatically generated solution ideas	Abstraction level	Engineering domain
Change mechanical or surface properties of inductive coil like density, roughness, strength etc.	Medium	Mechanical
Change electrical, magnetic, or electromagnetic properties of inductive coil like conductivity, magnetism etc.	Medium	Electro-magnetic
Pre-arrange inductive coil so it can come into action at the most convenient position and without losing time	Medium	Universal
Divide inductive coil into several independent adjustable parts or sections.	Low	Design
Remove the disturbing parts or substances from the smartphone responsible for energy losses	Medium	Design
Change the temperature of smartphone by heating or cooling	Low	Thermal
Apply automatic control and artificial intelligence to optimize wireless energy transfer	Medium	Digitizing

Concluding Remarks and Outlook

There is a scientific and practical demand to structure the existing and continuously growing body of knowledge in the field of eco-innovation, including best practices, examples of case studies, etc. The authors argue that the enormous potential of biomimetics for eco-innovation is not yet fully exploited. Therefore, the presented paper advocates the need for identification of new abstract biological inventive principles for eco-innovation. The future research should be focused on creation of the database of natural abstract eco-innovation principles complementary to the inventive principles known in the TRIZ methodology and other approaches to the knowledge-based innovation for promoting, sharing and reuse of innovation knowledge.

The proposed educational tools equip students with the advanced knowledge and competences in the field of eco-innovation. For many students in the survey, even the small workload has strengthened their self-confidence and skills. The authors also wish to suggest that engineering educators need to consider embedding the proposed tools into their professional activities. The future research should be focused on further development of learning resources, such as standard guidelines, interdisciplinary examples, best-practice recommendations, and on further optimization and computerization of the educational eco-innovation toolbox.

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Voice in first-year engineering design report writing: An academic literacies investigation

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ABSTRACT

CONTEXT

When students enter into engineering study, they are required to take on the ways of knowing and doing that characterise their chosen discipline. One of the primary means of doing so is through the writing they produce and, in engineering, one of the main genres of writing that students might produce is the design report. The design report, as a genre, is governed by certain conventions and requires unique ways of constructing an authoritative 'voice'. This is because it requires that students move from what is given (specifications and constraints), through what is already known (in the literature) in order to develop something 'new' (a proposed design).

PURPOSE OR GOAL

The aim of this research paper is to investigate how first-year mechanical engineering students demonstrate 'voice' in design reports submitted for assessment within an introduction to engineering design module. More specifically, attention is given to three areas in which 'voice' in an engineering design report is enacted: framing the design problem, synthesising the relevant literature, and demonstrating creativity during the concept generation and selection process.

METHODOLOGY

The design reports of first-year students who provided consent to participate in the present study were collected. Design reports were collected over a period of three years. In total, over 50 design reports were collected over this three-year period. These design reports were analysed using the technique of content analysis, which entails systematic analysis of the characteristics of a selection of texts. In this research, the characteristics of interest pertained to how students engaged with certain writing practices required within a design report such as, for example, describing the design concept selection process.

OUTCOMES

Analysis of the first-year design reports reveals the different ways in which first-year students demonstrate 'voice' (or not) through the various generic sections of an engineering design report. At the point of framing or understanding the design problem and context, a minority of students experienced challenges in this regard. However, students struggled to situate the literature in conversation with their particular design objectives and to engage in design as a creative process, rather than just a technical one.

CONCLUSIONS

The outcomes of this study may be used to inform ways to enhance engineering students' engagement with the techniques of design and design writing. Engineering students' literacy practices reflect their engagement with and understanding of engineering tasks and activities. While much attention is given to engineering as a structured and objective enterprise, limited attention is paid to engineering as a creative act in which the design engineer exercises substantial agency.

KEYWORDS

Engineering design; academic literacies; student writing; voice in academic writing

Introduction

When students enter into engineering study, they are required to take on the ways of knowing and doing that characterise their chosen discipline. One of the primary means of doing so is through the writing they produce and, in engineering, one of the main genres of writing that students might produce is the design report. The design report, as a genre, is governed by certain conventions and requires unique ways of constructing an authoritative ‘voice’. This is because it requires that students move from what is given (specifications and constraints), through what is already known (in the literature) in order to develop something ‘new’ (a proposed design).

However, to achieve mastery of this genre and construct an authoritative ‘voice’, engineering students must be able to navigate this shift (from given to new) in a non-linear and iterative manner. This is because the stages of engineering design do not progress in a linear fashion i.e. engineering design is iterative in nature. This means that the students must demonstrate that they are able not only to communicate the specifications and constraints as well as analyse the literature, but also to use these to inform, justify and revise their decision-making in the process of developing something 'new'.

The aim of this research paper is to investigate how first-year mechanical engineering students demonstrate ‘voice’ in design reports submitted for assessment within an introduction to engineering design module. More specifically, attention is given to three aspects of ‘voice’ in an engineering design report: demonstrating understanding of the design problem and context, engaging with literature, and claiming agency in the design process (through concept generation and selection).

Literacy in engineering (design)

Barton and Hamilton (1998) argue that there are different literacies associated with different domains. This is because literacy practices are patterned by social institutions and power relations, with some literacies becoming more powerful than others (Barton and Hamilton, 1998). Individual’s literacy practices are subject to change as new ones are acquired through informal and formal learning (Barton and Hamilton, 1998).

Barton and Hamilton (1998, p. 8) further define literacy events as "activities where literacy has a role” in that the idea of an event always presupposes a social context in which that event takes place, thus reinforcing the fact that literacy is situated. Texts are crucial to literacy events and the study of literacy is thus, in part, the study of texts and how they are produced and used (Barton and Hamilton, 1998). Thus, Barton and Hamilton (1998) define literacy as a set of social practices that are observable in events which are, in turn, mediated by written texts. However, design reports, unlike other literary genres, are often not easily accessible apart from internal reporting in industries. This creates a challenge for students to master those sets of social practices in the case of design literacy. As a consequence, students do not have a number of examples to study. Thus, students are reliant on two primary modes, namely guidelines for design report structure learnt through instruction in design courses and as presented in textbooks on engineering design.

Very few first-year students can be said to have mastered academic discourses. Instead, Paxton (2007) argues that they are in a process of acquiring those discourses and their current stage in that process is one of ‘interim literacy’. Interim literacies refer to the transition from the literacy practices of the school and home to those of the university (Paxton, 2007). The authors observed in a previous study (Simpson and Bhamjee, 2017) that first-year engineering design students were in a state of interim literacy. These interim literacies represent an interim stage in the students' lives as their identities begin to shift as they become more closely apprenticed into academic discourse. The notion of interim literacies suggests that the acquisition of academic discourse does not occur in a simple, straight-forward manner (Paxton, 2007). In another study, the authors (Simpson and

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Bhamjee, 2019) found that fourth-year students had overcome many challenges that first-years faced. However, the fourth-years still demonstrated a number of other challenges in terms of developing mastery of design literacy.

Interim literacies can inform teaching in that they tell us who our students are and where they come from, discursively speaking (Paxton, 2007). They inform transformation, because they force us to acknowledge that certain identities are privileged over others within institutions of higher education (Paxton, 2007). Because of this, certain students remain in an interim stage of academic literacy acquisition, which explains why so few 'working-class students' are successful at university and even fewer progress to postgraduate study. Interim literacies go some way towards explaining how education can serve to perpetuate social inequality (Paxton, 2007). Furthermore, an understanding of interim literacies forces university staff to acknowledge that academic literacies need to be mediated (Paxton, 2007).

This is particularly important in engineering design, where literacy is multimodal in that engineers utilize graphics and mathematics in conjunction with written text to construct meaning (Johri et al., 2013). Navigating the interplay between these modes is critical and core to meaning-making in design literacy. This is evident in the increased incorporation of computer-aided drawing (CAD) and computer-aided modelling (CAM), tools that first-years are not exposed to yet, in design reports in place of hand-drawings and 'hand' calculations.

Voice in academic writing

Our interest in voice in engineering design report writing stems from a seminal argument (amongst literacy scholars) made by David Bartholomae in 1985, that of 'inventing the university'. Bartholomae (1985) argues that when students write, they are required to take on the particular ways of knowing, selecting, evaluating, reporting, concluding and arguing that characterise each discipline within the university. That is, they have to (re)invent, through their writing practices, their chosen discipline.

This is tied to the notion of voice, because students are required to 'speak' as if they are design engineers (for example), even before this is true. This means, as Bartholomae (1985) points out, that students must, at least initially, bluff their way through (what Gee, 1996, later called 'mushfaking'), which causes problems, particularly in the ways students write. These problems stem from the fact that student-writers must assume the right to speak with authority, even before they truly possess such authority (Bartholomae, 1985). This remains true throughout their studies, and perhaps into the first few years of their career. Indeed, the focus of this research paper is on the sense of authority with which students write in their design reports.

This is in line with Paxton's (2007) notion of interim literacy. As Paxton (2007) argues, interim literacy can manifest in several ways: students may overuse 'informal' or colloquial language, they may try to borrow or mimic disciplinary discourse in ways that seem clumsy to experts, or they may simply avoid using specific terminology because of a lack of familiarity or comfort with it. Importantly, when students engage in 'fact-telling', this is another characteristic of interim literacy as such students are drawing on the writing practices that allowed them to succeed in school (Paxton, 2007).

In the literature on voice in academic writing, the concept of voice is often conceptualised in either of two ways: as individual expression and/or as participation (Lensmire, 2000; Kamler, 2001). Our concern is with the second aspect, voice as participation in the design practices associated with engineering, rather than with voice as a vehicle for individual expression. Voice as participation allows for recognition of the fact that there is no single, unitary voice that one 'possesses'; instead, students' writing voices are situated and multiple and may vary across contexts and texts (Lensmire, 2000; Kamler, 2001).

However, Lensmire (2000) offers a more nuanced understanding of voice that considers students' interim literacies. He argues that voice is about 'becoming'. In this view, voice is a

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project: crafted over time and undertaken agentively by students. Engineering students are thus expected to appropriate the resources of engineering design report writing and assimilate these in order to develop their ‘engineering design voice’. However, very few students will do this without some formal induction into the particular resources of engineering design report writing, and student agency is often stifled within engineering pedagogy rather than consciously developed, because of a focus on formal content and procedure.

Finally, the literature on academic writing highlights a number of formal, linguistic avenues for the study of voice in writing. In particular, Ken Hyland (1998, 2000, 2012) has examined how voice and stance in academic writing are constructed through linguistic strategies such as hedging, boosting, attitude markers, and relational markers amongst others. Lillis (2001) also refers to the notion of ‘addressivity’ which refers to how a student’s text demonstrates their sense of their addressee. In this particular research paper, our concern is not with these specific linguistic aspects. Rather, we are concerned with how students’ engineering design reports demonstrate participation (or not) in engineering design practices as measured through the ‘authority’ with which they use an engineering design voice in their reports.

Research Design

The design reports of first-year students who provided consent to participate in the broader study of which this research paper is part were collected. Design reports were collected over a period of three years. In total, over 50 design reports were collected. The number of students in the module varied between 92 and 115 over this three-year period. Each student over the three-year period was provided with an informed consent form and informed that their participation was voluntary and anonymous. The informed consent was based on the ethics approval that was sought and granted by the university.

These design reports were analysed using the technique of content analysis, which entails systematic analysis of the characteristics of a selection of texts (Neuendorf, 2002). In this research, the characteristics of interest pertained to how students participated in, or engaged with, certain writing practices required within a design report such as, for example, describing the design concept selection process.

The design reports were submitted for the individual design project in a first-year introduction to engineering design module. The brief for the project each year was to design a clutch system (including coupled shafts) for a passenger car, bus, and one tonne truck, respectively. Whilst the vehicle type varied over the three-year period, all other aspects of the project were identical. The students were required to submit a design report that documented the entire design process. The brief required that the report not exceed fifteen pages excluding front matter and appendices (such as manufacturing drawings). At the point where this assignment was introduced, the students had undergone a semester course introducing engineering design and an engineering drawing module and as such, were familiar with the engineering design process and development of engineering drawings. The theory related to design of friction clutches and shafts was introduced in the module.

Framing the problem

The first discursive move required in the engineering design report activity was for students to demonstrate their understanding of the problem by accurately framing it within the context for and objectives of the design. A majority of students, across all three cohorts, were able to do this in a manner that displayed strong design voice, or agency.

For example, Figures 1 and 2 are extracted from two student-participants’ design reports. As can be seen in these examples, the students clearly and succinctly report on the objective of the design report (“This report presents…”; “The aim of this report is to…”). In addition, they locate this objective in a real-world problem and do so from an assumed position of authority

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("Even the highest quality and most durable clutch is subject to operational wear and tear…"; "There is a need for a mechanical device…"). These students' use of simple, declarative sentences, and their confident assertions - that *all* clutches are subject to wear and tear (Figure 1) and that 'machines' (or mechanical devices) such as clutches exist to simplify everyday activities - demonstrate their confidence in their understanding of the design problem, rationale and objective, as well as the real-world implications hereof, albeit that, particularly in the case of Figure 2, these attempts at locating the real-world significance of the design problem are somewhat clumsy. In both cases, there are some grammatical issues and, in Figure 1, the introduction is rather short and does not fulfil all the generic conventions associated with an introductory section. However, these are structural and surface-related features that, while important, are of less concern in this research paper than the assured position from which these students write.

INTRODUCTION

This report presents the design of a friction clutch system of a manually operated passenger car. Even the highest quality and most durable clutch is subject to operational wear and tear therefore this design entails to reduce the amount of wear on a daily used clutch system of a passenger car.

Figure 1: Extract from design report - student clearly frames the objective

INTRODUCTION

In our everyday lives we always try to simplify things and to reduce the amount of effort we put in to everything we do. If we are able to do this the life becomes easier. Machines exist to make it easier for people to do work, or to do the work required for people. A useful machine reduces the cost and does the work required faster.

For a car it is desirable to be able to change the speed without having to shut down the car's engine. For example, a car needs to temporarily stop at a red traffic light and resume motion when the light is green. There is a need for a mechanical device that can allow this type of motion to occur without having to shut down or damage the car's engine or any of the shafts. This report contains information and the design of such a mechanical device.

Problem statement

Cars are required to have the ability to change the speed at which they travel without having to shut down the engine. This gives rise to the need for a mechanical device that can allow smooth changes in the amount of power transferred without disrupting the engines motion.

Aim

The aim of this report is to design mechanical device that enables interruptible power transfer between the engine's crank shaft and the transmission shaft(**clutch**). This includes the analysis and design of the shafts associated with the clutch system.

Scope and limitations

This report will focus mainly on the design of a friction clutch system that is used in a passenger car. It will not cover the design and analysis of any other type clutch system. The design will focus mostly on the passenger car clutch design and will briefly cover the information, analysis and design of the coupled shafts that are used in the clutch system. The detailed design of the crank shaft, drive shaft, gearbox and linkage mechanisms associated with the clutch are beyond the scope of this report.

Figure 2: Extract from design report - student frames the objective and contextualises its real-world significance

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Some student-participants, however, struggled, even at this initial hurdle, to articulate the given design problem with confidence and accuracy. Often, students would not include any background discussion pertaining to the design problem or objectives. For example, in Figure 3, an example is shown of a student-participants' report that begins with the fact that "There [are] 3 types of couplings". In this example, the student offers no context for this assertion, and no indication of the overall aims and objectives of their report. Instead, they move directly into 'fact-telling', suggesting a lack of voice, agency and participation in the design process, even from the very beginning. This, however, was not the norm, as most students were able to articulate a clear design goal and context.

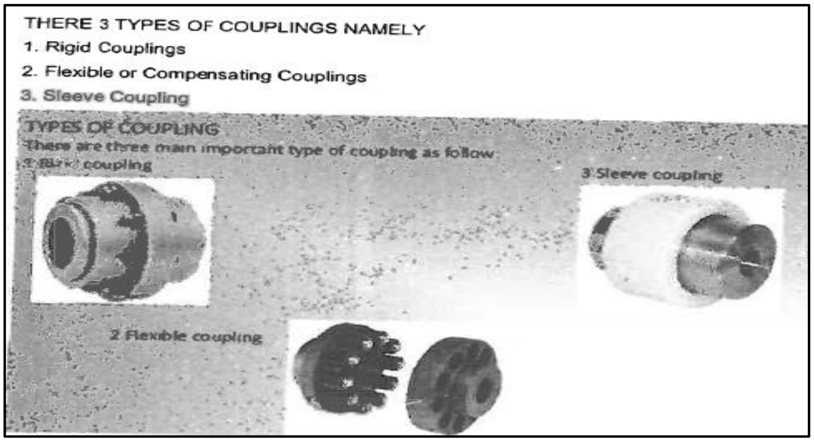

Figure 3: Extract from design report - student does not frame the problem and moves directly to 'fact-telling'

Synthesising the literature

While most student-participants across the three cohorts that were included in this study were able to locate their design report in a clear design goal and context, and many were able to formulate this design goal in relation to a real-world problem, a sizeable number of these student-participants struggled to maintain this design voice into discussion of the literature, or existing research related to clutch design. A complexity in the genre of the design report is that the literature review is not a critical analysis of the state-of-the-art in literature to highlight a 'research gap' as is the case in research report writing. Instead, in the design report, the literature review is a study of available solutions to the design problem and an analysis of the benefits and shortcomings of the available solutions. This must then be leveraged by the engineer in the design process when conceptualising potential solutions, selecting an appropriate solution and developing that concept into a working and effective solution to the design problem. Navigating this complexity is essential for students to construct an authoritative 'voice' in design report writing.

Figure 4 is an example of a student-participant that is able to relate the literature to their specific design problem and context. This can be seen in their relation of the idea of the centrifugal clutch to automobiles (the specific design context in that year) in the last four sentences of the paragraph. However, this is in sharp contrast to Figure 5, in which the writer resorts to list-making and summary and, in so doing, renders their agency, and their design voice, invisible. As Kamler and Thomson (2006) note, when the writer's voice becomes invisible, discussion of the literature becomes mere summary. In our study, we found that an extreme manifestation of this, but a common one, was an over-reliance on bullet-point listing of 'facts' about clutches.

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> Centrifugal clutches activate automatically when they reach high speeds that course a centrifugal force large enough that they reach the inner surface. These types of clutches are usually used to regulate the motion of motor pulleys, mainly because the activate at high speeds. This enable them to be able to keep rotational speeds above a specific minimum. This type of clutch could be used in an automobile, given that the springs have a low enough stiffness. However, some complicated linkage mechanisms and bearing would have to be used enable changeable power transmission. This type of clutch would be more difficult to make and would have to be custom made for all engines types with different output speeds and it would cost more to maintain. This type of clutch is not ideal for automobiles.

Figure 4: Extract from design report - student relates the literature to their specific design problem and context

> Advantages of diaphragms.
>
> a. It's compact, less parts, less weight, less moment of inertia. Less maintance required and less assembly effort.
>
> b. Suitable for high engine speeds, as centrifugal force does not cause an imbalance as it does on coil springs.
>
> c. Low pedal force, less friction, better clamping force on friction facing does not decrease as it wears (it becomes more efficient).
>
> There are currently three different types of pressure plates: The long style pressure plate, the Borg and Beck style pressure plate, but nearly all street-legal clutches use the diaphragm style.
>
> - Throw-out bearing - Provides a link between the rotating clutch assembly and the static clutch fork and transmission. It will also absorb the force to release the clutch and also reduce wear between rotating and non-rotating components.
> - Actuator lever - it absorbs the pressure from the clutch pipe and transmits it to the release lever.

Figure 5: Extract from design report - student relies on list-making and summaries

The literature review section, therefore, constitutes the first challenge faced by a majority of student-participants with respect to maintaining a 'designerly' voice in their reports. This is perhaps not surprising; as Kamler and Thomson (2006) further note, albeit with respect to postgraduate writing, the task of reviewing extant literature is to identify the ideas, principles and/or methods that are pertinent to the objective or goal and contribute to the motivation for the project. Kamler and Thomson (2006) locate the literature review section as a prime site for 'identity work', as writers need to locate themselves in relation to the literature. Depending on what literacy practices students bring with them, this process is easier for some students than it is for others.

Creativity and concept generation

Concept design is arguably the stage where agency and voice stand out the most in design literacy. In this phase, the student must leverage that which is given (problem, specifications and constraints) and that which is already known (from literature) to inform the conceptualisation and development of potential solutions to the problem. Furthermore, the student must use a combination of creativity and technical knowledge to develop unique and practical solutions to the given problem. Beyond that the student must be able to explain the operating philosophy and pros and cons of the concepts. Lastly, the student must provide an

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objective opinion regarding which of the potential solutions is most viable to develop further as a final design.

A majority of students, across the three cohorts, struggled to meet the requirements to generate unique concepts, discuss their operating philosophy, merits and shortcomings as well as to provide an objective concept selection process. However, a sizeable number of students did demonstrate signs of agency and voice, and given intervention could demonstrate such clearly. That is not to say that none of the students clearly demonstrated agency and voice at this point, but that unlike in the earlier phases of the report, here it was more of an exception.

Concept generation and selection thus constituted the second point at which a majority of students' 'design voices' faltered. Moreover, there were particular patterns that a large number of student design reports followed in this section. In its most extreme form, this meant that students failed to generate any concepts, selecting one (or more) from the literature without consideration of the context or design problem. In such circumstances, students circumvented the need for creativity, and reduced the process to mere selection amongst alternatives provided by the literature. In this way, students avoided full participation in the design process.

In other instances, students did not engage in concept generation or selection, but did present a final detailed design. In these instances, creativity was backgrounded in favour of the more familiar practices associated with calculation, which was required as part of the detailed design. In these instances, students engaged in selective participation in the design process.

In those instances where students did develop discrete concepts, they often struggled to put forward an objective system through which to select a final concept for detailed design. In these instances, the students either applied unstated assumptions or personal preference, and the concept selection process remained hidden to the audience. There were very few instances, if any, where students revisited the design problem and literature to generate criteria and evaluate their solutions against those criteria. In some instances, students used scoring or ranking methods (often by way of a matrix), but there was seldom discussion of how the scoring was applied. These students show attempts at full participation in the design process, but greater development is still required in this regard.

Conclusion

In this research paper, we have identified three areas of an engineering design report in which first year students struggle to demonstrate voice or agency in their writing and, therefore, full participation in the engineering design process. The first of these is at the point of framing or understanding the design problem and context. However, only a minority of students experienced challenges in this regard. What we have shown is that the other two areas present as more significant points at which students' design voices falter. In the first instance, many of the student-participants whose design reports were analysed in this research struggled to situate the literature in conversation with the particular design objective. Furthermore, students' design voice and agency was even less present in the concept generation and selection process - where students struggled to engage in design as a creative process, rather than just as a technical one.

Of course, we do not expect first-year students to be expert designers. However, we do expect them to have gained some level of expertise by the time they graduate. And, we recognise that this expertise will not be developed without conscious mediation of the literacy practices through which engineering design is accomplished. Moreover, as Jacobs (2007) argues, the development of student academic literacies should not be confined to the first year only. Instead, attention needs to be given to what resources students bring with them into higher education - and to the fact that these resources may reflect high levels of social inequality prior to entry into higher education. Attention also needs to be given to how these

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resources can be augmented throughout the curriculum in a way that fosters greater equality of participation. An engineering graduate that is clearly able to articulate a real-world design problem and draw on the literature and their own creativity to solve that problem should be the end-point of an engineering degree programme.

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Comparison and analysis of leadership and management competences in first year engineering design courses.

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CONTEXT
The increasingly complex nature of societal sustainability and related technical challenges requires engineers to develop, deliver, communicate, and steward effective engineering solutions. The development of leadership and management competences in engineering students is key to building their capacity to work in this context now and in the future. In contrast to math and engineering science, which is carefully scaffolded in the curriculum, non-technical core competences are often left as 'experiential components' in team based design courses, work integrated learning or co-curricular activities. There is a need for engineering educators to have tools and frameworks that can be used to design, plan, assess and compare learning activities that support the progressive development of professional and contextual skills in the engineering curriculum.

PURPOSE OR GOAL
This study describes the application of a leadership management development model (LMDM) as a content analysis tool to assess the intentional development of leadership and management competences in the engineering curriculum, specifically in first year design. An analysis methodology is developed, and through the application of the original framework, an updated version was constructed. Engineering educators can use the framework to quantify and assess leadership and management learning activities as they are developed through the curriculum.

APPROACH OR METHODOLOGY/METHODS
The authors have developed an LMDM (Jamieson & Donald, 2020) based on a domain of influence leadership model and a transformational model of management functions. These models were utilized in the analysis of two large first year engineering design courses at two universities. Course activities were described, mapped to leadership and management frameworks, and categorized according to the engineering graduate attributes as defined by the national engineering accreditation body. The syllabi were compared and analysed on many aspects (e.g., self-leadership, societal impacts, relationship management) with a series of comparative charts and tables.

ACTUAL OR ANTICIPATED OUTCOMES
An analysis process and taxonomy is developed to assess and compare the learning activities of the two courses with respect to the development of leadership and management knowledge and skills. As a result of the mapping, process improvements were made to the LMDM. This information provides relevant insights both within and between programs that can act as an evidenced-based frame for improving the courses with respect to leadership and management development content.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
Preliminary results indicate the model is effective at capturing and comparing engineering leadership and management functional coverage in the engineering curriculum. Ultimately the authors hope the framework can help engineering programs develop, plan, and assess undergraduate professional and contextual skill development in learning activities and the curriculum. We hope to support the development of non-technical engineering skills at the same level and rigour as technical skills.

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KEYWORDS

Engineering Leadership, Engineering Design, First Year

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Introduction

Identifying engineering leadership and management activities and skill development in the curriculum can be challenging. In this work we examine the utility of a leadership and management development model (LMDM) framework, developed by the authors, to enhance the understanding of leadership and management skills in the engineering curriculum. Using the LMDM and the Canadian Engineering Accreditation Board (CEAB) Graduate Attribute (GA) frameworks we analyze and compare the content of the first-year undergraduate engineering design courses at two different Canadian universities: the University of Alberta (UofA) and the University of Guelph (UofG). Each course is common to all first-year students and provides an introduction to engineering and design.

In addition to demonstrating the utility of the LMDM framework as an effective tool for gaining insights related to leadership and management competencies in the first-year courses, the purpose of this study is to provide an initial benchmark for course improvement and further development work. The LMDM can provide an evidence-based understanding of the extent of exposure in the two courses to leadership and management competencies critical to the sustainability mindset. The resulting analysis is useful in articulating the relevance of learning in the context of engineering practice.

Background

The CEAB GA are based on the International Engineering Alliance (IEA) Washington Accord graduate attributes. These GA are briefly presented in Appendix A and capture the outcomes of leadership (GA6) and project management (GA11). Beyond the limited description provided in the CEAB GA, instructors have little guidance to develop leadership and management curriculum to prepare content, learning activities, or students for the transition to future engineering practice. Faculty with industrial practice experience may rely on their own engineering leadership and management experiences, however the GA don't offer a connection to an engineering leadership and management framework or to the cross disciplinary interactions found in practice. A framework connected to the GA outcomes is required for relevant course and program content analysis and development.

Targeting the development of a sustainable engineering mindset in students alongside the technical competencies, a leadership and management development model (LMDM) was proposed in previous work (M. Jamieson & Donald, 2020) as an engineering leadership and management competency framework for course and program development. The framework utilizes a leadership domain model with expanding levels of influence from self to team to organization to society. The non-technical skills captured in the CEAB GAs, such as GA 7-Communication, are required across all the leadership domains of influence. The management model originally proposed to support the LMDM structure was Birkinshaw's management model framework (Birkinshaw, 2010), which addresses the organizational continuum from bureaucratic to emergent and identifies management functions that are relevant in the context of addressing increased corporate responsibility with growth targeted to sustainable development; namely, managing across, managing down, managing by objectives, and managing motivation.

Both of the first-year design courses examined in this study include students from all the engineering programs offered at the institution. At the UofA, all students are admitted to first year engineering and select their discipline after completing their first year. At the UofG, the majority of the students are admitted directly to their discipline. The UofG intentionally establishes teams composed of students from different program disciplines. As all UofA students are undeclared, students form teams based on project interest. At the UofA, the design course is intentionally transdisciplinary where all students examine societal problems through an engineering practice lens situated in a complex world. At the UofG the design course is intended to be an interdisciplinary build-design experience and the design process is also intentionally transdisciplinary. Definitions of transdisciplinary and interdisciplinary are provided in Appendix B.

Both courses introduce the students to professionalism and engineering ethics. Ethics is often under-represented in the engineering curriculum (Martin & Polmear, 2021) yet it is part of the professional skillset that overlaps the engineering leadership and management domains (M. Jamieson & Donald, 2020, p. 5). Engineering leadership, management, professionalism, and ethics are critical to sustainable development as engineers need to evaluate the technical options in the context of developing sustainable solutions and evaluating technical and nontechnical design criteria. Martin and Polmear (2021) also identify the shifting focus of the engineering curriculum towards the explicit inclusion of socio-technical and professional skills. In addition, they also identify challenges in transitioning from the historical technical focus to a more holistic engineering education.

Methodology

The two first-year design courses compared were ENGG 160 (UofA) and ENGG*1100 (UofG). The UofA course was redeveloped for the second time as a gamified course. The UofG course has been offered for over 5 years in its current form. Activities for the most recent course iterations were described, mapped to the LMDM framework, and categorized using the CEAB GA. A team of six researchers carried out the comparison, developed the LMDM management function adaptation, and finally the content analysis and comparison. Two of the researchers were the LMDM developers and course instructors. Engineering co-op students comprised the rest of the team. The UofG co-op students had taken the course as students. The UofA co-op students previously assisted with course gamification and implementation. All members of the analysis team were very familiar with one of the two courses and much less familiar with the other course. The learning outcomes (LO) from both courses were previously mapped to the CEAB GA. An analysis process was developed through joint consultation and the steps of the process are outlined as follows:

1. **Describe:** Describe each course so that teams become familiar with each course.
2. **Compare Courses:** Review descriptions and syllabi to analyze the course structure and learning objectives for the courses. Report structural similarities and differences.
3. **Map and Compare GA:** Map graduate attribute coverage in the course learning activities overall and on a weekly basis. Separate and analyze the content in the courses by the structural elements (e.g., lectures, projects, labs, assessments).
4. **Map and Compare Leadership Domains:** For the course overall and with respect to the course structural elements, analyze the learning activities and map to the LMDM leadership domain levels students are exposed to and/or required to practice in activities. Identify gaps for discussion and validation.
5. **Map and Compare Management Functions:** Repeat Step 4 for the LMDM management functions.
6. **Validate Content Analysis:** Teams review and cross check the other teams work related to the GA, leadership domain and management function mapping.

Steps 1 and 2 were completed by the whole team, steps 3, 4 and 5 were completed by the teams most familiar with the courses, and step 6 was completed by the whole team.

As the method for content analysis was being tested the team noted challenges mapping the LMDM management functions. The original LMDM framework considered multiple organizational engineering management levels and used Birkinshaw's model (2010). While this model is useful in the context of developing an engineering mindset to support transformational goals (e.g., sustainable development, diversity, culture change) it proved less useful for course and program content analysis. We found the management function language used in Birkinshaw's continuum of traditional and alternative principles difficult to apply to learning activity analysis and classification. To complete the mapping of the course activities we felt that descriptors more aligned with project management were required.

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Four commonly accepted functions of management are planning, organizing, leading and controlling (McDonald, 2010; Schraeder et al., 2014). Leadership as a management function in the LMDM would be confusing because leadership is contextualized as a full set of influence domains. We chose to replace leadership with directing. The original descriptors mapped to the new descriptors as follows: managing across - activities, plan; managing down - decisions, organize; managing objectives, control; and managing motivation, directing. A revision of the LMDM was constructed to include a general management function framework as shown in Figure 1. The management functions of plan, organize, direct, and control are well aligned with the original model, translate directly to engineering practice and are more easily applied to learning activity classification. Using this updated version of the LMDM engineering educators can use the framework to identify and assess leadership and management learning activity in individual courses and subsequently programs. The management functions were arranged in the order students would typically apply them in project development and management in our courses and represent increasing managerial task complexity and progression at the team and project level.

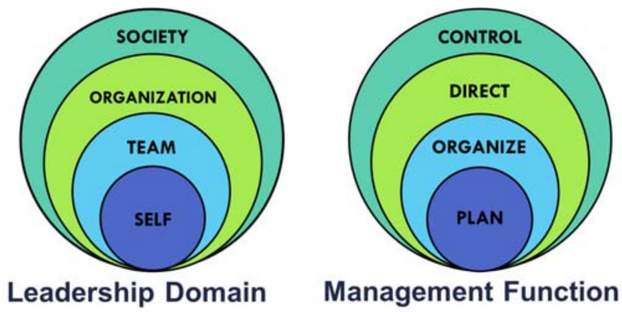

Figure 1 - Analysis Frameworks - Leadership Domains and Management Functions

Results

Course Description (Step 1) -The UofA first year design course (ENGG 160) has one in class synchronous lecture hour, one online asynchronous lecture hour, and one asynchronous online seminar hour per week. Enrolment is typically 1200 in three sections and the course is delivered in the second term of first year prior to selecting one of the 14 different engineering programs offered. ENGG 160 utilizes competency based grading in a gamified format and is offered as a credit/no credit course. Students complete the course activities and collect badges to pass the course and gain credit. Course activities, including a team design project, are aligned with five badge categories (sustainability, design, teamwork, safety, and learning). Learning activities consist of short video lectures, readings, quizzes, team and project based assignments including reflections and evaluations. A student must meet the requirements for all the badge categories by earning milestone badges leading to earning the category badge. Completion is achieved when all badges are collected. Students receive feedback on attempts and during project development so that students who do not meet competency targets may resubmit their work.

The UofG first year design course (ENGG*1100) delivery structure consists of 2 hours of in-class lectures, 2 hours of design lab/studio activity and 2 hours of computer lab activity. Enrolment is typically 400 and the course is delivered in the first semester to the entire first-year cohort comprising 7 different engineering programs. Lectures are delivered in one large section of 400 students, and the computer labs are typically sized at 50-60 students. The course is supported by additional video materials and formative practice modules. In the lectures, the engineering profession, the responsibilities of an engineer and the engineering design process is introduced. Students learn computer aided design in the computer labs and the design labs are utilized for the development and implementation of the major team project. Much of the computer lab and lecture material is integrated into the delivery of the major team project, and a variety of graded written assignments related to ethics, professionalism, sustainability, and design are also delivered.

Course Comparison (Step 2) - Both courses share many common learning outcomes as shown in Figure 2. A structural comparison of the two courses is presented in Table 1. A central component of each course is a semester-long team design project. The UofA focuses on a community design project in a transdisciplinary context (Jamieson et al., 2021) and the UofG focuses on the design of an autonomous model vehicle that must meet client specified functional, aesthetic and sustainable design requirements, as well as demonstrate performance in various challenge events (Stiver, 2015). The autonomous model vehicle is a "Teddy Bear Wheel Chair" (TBWC). Teams are composed of students from across all engineering programs with no specified discipline-specific responsibilities in the project.

Figure 2 - Comparison of learning outcomes and course themes for two courses

The UofA has a transdisciplinary team focus (Dykes et al., 2009) and the UofG has an interdisciplinary team focus. Both courses use a transdisciplinary design process. The UofA design process uses the following stages: Planning, Concept development, System level design, Detailed Design, Implementation and testing, and Production as developed in a collaborative research project where 71 professors across 8 disciplines provided input (Butt et al., 2018). During the last course iteration when sustainable development principles were incorporated into the course content an additional stage was added to the design process: Recycling and Reclamation to better connect the transdisciplinary design process to the circular economy, sustainability, and a circular flow of resources.

Table 1 - First-year course structural comparison

Course	U of A ENGG 160	U of G ENGG*1100
Main Project/ Prototype	Problem Framing and Conceptual Community Based Design Project Prototype Assignment	'Build-Design' Project (TBWC) Prototype Demonstration
Project	11 Progressive Assessments	8 Progressive Assessments
Format	Blended Lecture-Seminar	Face to Face Lecture-Lab
Weekly Hours	(3)	(6)
Team Size	6 to 7	4 to 5

The UofG project design process is presented in lectures and built into the scheduled team project deliverables. After prototyping and final design stage completion, students report on elements of the process and details of the design. Students learn requisite skills and the design process in parallel. For example, 3D CAD software is used to produce detailed drawings after the prototypes and final designs are complete and design elements such as safety calculations and life cycle analysis are completed for the final design. This "Build-Design" approach captures the iterative design process, versus a traditional design build.

Map and Compare Graduate Attribute (Step 3) - The GA distribution for both courses is shown in Figure 3. Both courses develop all 12 of the GAs (Figure 3a) and consistently progress GA development throughout a 12-week term (Figure 3b). The most frequent GA noted in both courses was GA 6 (individual and team work) consistent with students working in teams and reflecting on the team progress throughout the courses. For ENGG 160 the next most frequent was GA 7 (communication) and for ENGG*1100 it was GA 5 (engineering tools). For ENGG 160 this is explained by the progressive weekly project update assignments completed by the design team and handed in for feedback. For ENGG*1100, communication is also strongly represented as a result of additional sustainable design and innovation essay assignments. In ENGG*1100 there is a focus on competency development in engineering tools, particularly computer aided design and in prototype design and build. The engineering tools component is less prominent in ENG 160 as this aspect is included elsewhere in the program. In ENGG 160 societal impacts, professionalism, ethics, economics and sustainability (GA 8-11) are seen more frequently than in ENGG*1100 as students are engaged in the problem framing and sustainable conceptual design of the challenging community problem projects, and ENGG*1100 focus on the autonomous vehicle build-design.

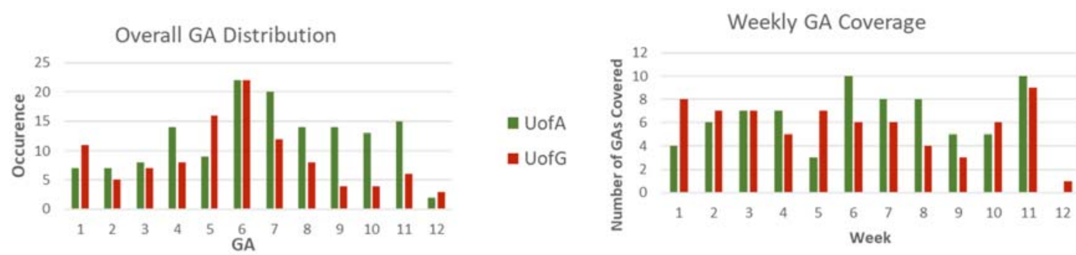

Figure 3 - Graduate Attribute Overall (3a) and Weekly (3b) Coverage Comparisons

Map and Compare Leadership Domain and Management Function Content (Steps 4 & 5) - The leadership domains and the management functions presented in Figure 1 were used to classify the learning activities and analyze the project schedules of the UofA and the UofG first year design courses. For example, an exercise related to self-reflection on personal contribution and performance would map to the “Self” leadership domain, and an activity related to developing a schedule of project activities would map into the “Plan” management function. The overall summary and comparison of the classification of learning activities with respect to the leadership domain distribution, and with respect to management functions are shown in Figure 4 and 5 respectively.

The course structural elements, namely, lectures, project work, and supporting content were further analyzed and the resultant lecture and project activity mapping are shown in Figure 6.

Lectures: The UofA lecture components focus on the transdisciplinary design process, professionalism, ethics and project management with a strong emphasis on society. The UofG lecture components emphasize team and self-leadership. The lectures primarily focus on team development topics and with a balanced approach to the remaining domains of self, organization, and society.

Design Project: The UofA societal impact project is framed around a community need (e.g., housing, transit, energy) and the UN SDGs. Students consider stakeholder impact and sustainability. The UofG project, the design of a Teddy Bear Wheelchair, is product development focused on a specific client need balancing performance and sustainability.

Supporting Content: Supporting content was variable between the two courses and included activities such as computer labs, videos, readings and case studies. The distribution of the leadership and management function activities was similar between the two courses with differences noted between societal and self-leadership.

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Validate Content Analysis (Step 6) - Weekly progress was discussed within the research team and comparisons of how activities were classified were reviewed. This step was crucial to our process and at times required review of activity classification and reclassifications for consistency.

Figure 4 - Leadership Domain Course Content - Overall

Figure 5 - Management Function Course Content - Overall

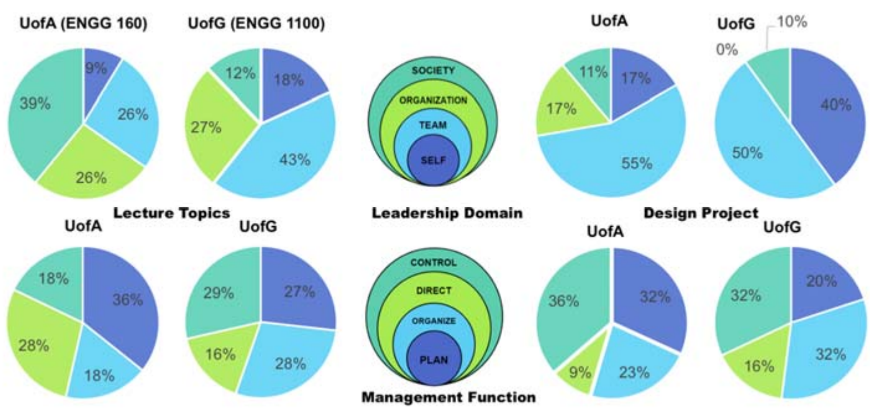

Figure 6 - LMDM Comparison - Lecture Content and Design Project

Discussion

As a result of the mapping process improvements were made to the LMDM by revising the management functions to plan, organize, direct, and control. Benchmarking the two first year courses using the modified LMDM provided a framework for course comparison with respect to leadership domains and management functions relevant to engineering practice and GA development. The analysis provided insight into both the design courses and the extent to which engineering leadership and management were incorporated. Both courses included learning activities across all management functions and leadership domains. It was found that each of the introductory design courses consistently capture all the GA both weekly and overall. The LMDM appears to be a useful method to connect engineering leadership

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domains and management functions to the GAs and to engineering practice. As the LMDM maps to all the GAs it would appear this method could be leveraged to assess other courses, especially design and practice based courses.

Beyond the lectures and the project, the supporting content had variable LMDM coverage. The UofA supporting content was set up to support the development of the project design and the stages of the design project process. The UofG supporting content addresses student development needs to better prepare them for using the engineering tools required for the programs. Although the focus is different, both institutions have addressed student preparedness and lay a foundation for engineering design, leadership, and management in the context of sustainability. We note community projects with a sustainability focus contributed significantly to the difference observed with respect to the societal and organizational leadership domains between the two courses.

Conclusions and Recommendations

The content analysis process development was a collaborative effort that yielded a comparison of the learning activities in the courses. The LMDM mapping comparisons can be used to reflect on the curricular content distribution. Based on the two courses analyzed, it appears that the design project topic may influence the leadership domains student activities encompass, and that the course project structure itself has more impact on the management functions. The management functions did not seem to be dependent on the project topic or phase of the design processes focussed on, however the leadership domains were focus dependent. The UofA focussed on problem framing and conceptual design where the UofG course provided a build design experience for students. Overall both courses gave students experience in all management functions, leadership domains, and graduate attributes.

Overall, the LMDM framework allowed us to effectively analyze the course content for leadership, management, and the connections to GA coverage. The LMDM allows for a structured approach to obtain a greater depth of understanding of the leadership and management competences than can be gathered using only GAs. This can aid in comparing non-technical content both within and across courses and programs. The use of the LMDM provides an initial benchmark that will inform course improvements for both course instructors and supports the goal of building a foundational engineering mindset in first year.

Preliminary results indicate the model is effective at capturing and comparing engineering leadership and management functional coverage in the engineering curriculum. We plan to apply the model to additional engineering courses to refine the LMDM itself and gain insight into the engineering curriculum from the leadership and management perspective. Ultimately the authors hope the framework can help engineering programs develop, plan, and assess undergraduate professional and contextual skill development in the curriculum at the same level and rigour as technical skills.

Acknowledgements

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Appendix A – CEAB Graduate Attribute List

1. A knowledge base for engineering
2. Problem analysis
3. Investigation
4. Design
5. Use of engineering tools
6. Individual and teamwork
7. Communication skills
8. Professionalism
9. Impact of engineering on society and environment
10. Ethics and equity
11. Economics and project management
12. Life-long learning

CEAB. 2020 Accreditation Criteria and Procedures. Engineers Canada.

Appendix B – Definitions

Transdisciplinary: the intentional combination of individual expertise in one or more disciplines to create a new discipline and perspective for solving (design) problems.

Interdisciplinary: the intentional cooperation of individuals from different disciplines to solve a (design) problem by developing a shared understanding.

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Instilling problem-solving competence in undergraduate engineering students

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CONTEXT

One thing that all types of engineers have in common is that they are expected to solve unfamiliar, complex problems. Although the development of problem-solving skills are generally implied throughout undergraduate courses, employers complain that engineering graduates are not meeting their problem-solving expectations. Explicit development of problem solving skills within undergraduate engineering degrees may help to bridge this gap.

PURPOSE

The broader study in which this work-in-progress paper is located explores how the teaching and learning of undergraduate mathematics can instil problem-solving competence in engineers. This paper develops the theoretical framework for developing, implementing and assessing a pilot problem-solving unit, arguing that engineering mathematics modules offer advantages as a home for a unit to explicitly teach problem-solving.

METHODOLOGY

A pilot problem-solving unit will be implemented, reviewed and adapted within a second-year engineering mathematics module. Data collection methods include interviews with students to understand their views of problem solving and observations of students' interactions with the problem-solving unit activities and materials. Analysis of qualitative data will inform improvements needed in problem-solving skills and the facilitation of these skills to engineering students within the context of undergraduate mathematics modules.

ANTICIPATED OUTCOMES

A working definition of problem solving has been summarised from literature and this definition can guide the measure of impact of the planned intervention. The anticipated results of the intervention study are that direct problem-solving skills learning can be facilitated as part of an undergraduate course at university, and that mathematics courses offer a sound framework for these skills to be successfully taught to engineering students.

CONCLUSIONS

The literature on problem solving indicates that problem solving skills can be developed and that these may need reinforcement over time and in different contexts. This research will provide support for the claim that the abstract context of mathematics courses may be helpful in developing transferable problem-solving skills in engineering students. Further research can explore whether a problem-solving unit is necessary for engineering students to be competently qualified and if the appropriate place for a problem-solving course to be implemented is within an undergraduate mathematics course. Furthermore, good practice between universities will help to develop students as competent problem solvers and ready to solve problems upon graduation into the profession.

KEYWORDS

Problem-solving, engineering, mathematics, graduate outcomes

Introduction

According to dictionary definitions of engineering, the outputs of an engineer involve the creative application of science and mathematics (Smith, 2021), as well as "the design and manufacture of complex products" (Merriam-Webster, 2021). How does the engineer achieve this? Engineers achieve their outputs through continuous, creative problem-solving.

Problem solving is a skill that is developed throughout a lifetime. However, employers of engineering graduates want team members who can competently deal with the frequent problem-solving challenges they will face (Haron et al., 2019; Wolff, 2017). Graduates with robust problem solving abilities seem more likely to be employed, and to be satisfied with their contributions to the engineering workplace.

Background to research

To give a bit of background to how the need and idea for this research came about, some background on the first author is given. Privileged to have received one of the best education in engineering on offer in South Africa, she started her career as an industrial engineer in South Africa and in Zambia. Interestingly, she and her engineering graduate colleagues felt incompetent to practise as new engineers and to immediately add the value expected of them. There was a perception in the workplace that feeling incompetent is not unexpected and that graduate engineers are hired for the ability to think and solve problems, not necessarily for their technical know-how. The motivation for this study is directed by the broad question, how can undergraduate engineering students be best educated to contribute to industry upon graduation?

Problem Solving in Mathematics

Much of the work carried out on mathematical problem solving draws on decades of work by George Pólya. He emphasises the importance of action in describing problem solving as, "To search consciously for some action appropriate to attain a clearly conceived, but not immediately attainable aim" (Pólya, 1962, p. 117). Liljedahl et al. (2016) confirm and conclude that the activity of mathematics is to solve problems. Reflecting on their activities while problem solving helps to develop problem-solving skills for the future and is the last step in Pólya's (1945/2004) broad-brush heuristics for the problem-solving process: (1) understand the problem, (2) devise a plan, (3) carry out the plan and (4) look back.

Badger et al. (2012) suggest that a mathematical problem is a question whose procedure for attaining an answer is uncertain. It is worth mentioning that a mathematical problem is not necessarily experienced in the same way by two people. One person's knowledge and experience will differ from another, hence one person's routine question might be another person's problem. A mathematical problem is thus audience dependent. A certain group of students in a first-year undergraduate mathematics module will find something to be a problem, that second-year students should not find problematic anymore.

Students can't learn how to problem solve unless it is established and known what they already know about problem solving. This statement is supported by David Ausubel's dictum that what a learner already knows is the most important single factor that influences learning (Ausubel, 1968). Students are to learn how to grapple with problems to ensure that problem solving activities are not a negative experience on the whole.

In undertaking problem-solving a student needs to develop both intellectual and temperamental qualities. Students need to (Badger et al., 2012):

Firstly, identify essential steps and work out a strategy.:

- Seek out relevant knowledge and bring it to bear.
- Use structured and logical arguments.

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- Carry through a plan accurately using a sequence of linked steps.
- Know when to turn back in a dead end and try a different tack.
- Organise, present, and defend their solution.
- Submit a solution to the scrutiny of the teacher or their peers.

> Then explore the consequences of their solution, ask further questions, experiment with hypotheses and conclusions, try out generalisations.

Lecturers are critical in enculturating students into practicing problem solving by not presenting problem solving in a hidden curriculum (Bergenhenegouwen, 1987), but rather promoting and sustaining varied mathematical thinking. Rather than basing mathematics learning and teaching on memorized rules for computation, teachers need to be guided by the question: what do proficient problem solvers do as they solve increasingly complex problems? (Pólya, 2000). Students need to be put in unfamiliar situations with problems that are novel to them, but the expectation is that they must tackle the problem seriously on their own (Badger et al., 2012).

Paul Halmos (1980) sums up the importance of problem solving in mathematics by noting that problems are at the heart of mathematics, and that mathematics in its essence consists of problems and their solutions. Engineering prospectuses of South African universities have revealed that mathematics courses offer no explicit modules on problem solving, rather it is implied that problem solving skills will be acquired in these courses. This highlights the gap present in explicit problem solving skills instruction and further motivates the importance of this research.

A Problem Solving Definition

The following definition of problem solving is based on numerous descriptions and the first author’s experience when working as an engineer, and is a starting point for this study on problem solving:

> The process of problem solving requires someone to take the initiative to undergo an iterative process of finding solutions to a difficult or complex issue (from the perspective of the problem solver), by firstly questioning the problem and the necessity and the validity of it and then creatively unpacking and defining the problem requirements, whether it be individually or collaboratively, matching requirements to known tools, thus coming up with an implementable, systematic strategy to implement a first solution to the problem(s), analyzing the effectiveness of the first solution(s), reworking the solution(s) if necessary and then implementing the final solutions. Problem solving requires the individual to not be risk-averse and to not be afraid of failing, but rather embrace the iterative nature of problem solving. It is also important to note that a clear vision of how the entire problem should be solved is not necessary at the start, rather one problem requirement should be solved at a time and ‘bridges should be crossed’ as and when the problem solver gets there.

Research Question

This research study addresses the research question: How can problem-solving skills be instilled in students within the context of an engineering mathematics module in a South African university?

Methodology

The literature on problem solving in mathematics supports the plan to develop, implement, review and adapt a virtual pilot problem solving unit as part of a mathematics module at the University of Cape Town. A qualitative action research study will inform improvements

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needed in students' problem-solving skills and the facilitation of these to engineering students within the context of a second-year undergraduate mathematics module. The first author will facilitate a problem-solving unit within the course convened by the second author. Action research (McNiff, 1988/2013) and reflective thematic analysis (Braun & Clarke, 2020) are suitable methodologies for this research due to the involvement of researchers as participants.

Action research is defined as "a disciplined process of inquiry conducted by and for those taking the action" (Sagor, 2000, p. 3). The purpose of using action research as the primary research method for this research is to develop an intervention suitable to the context and responding to the actual rather than perceived needs of the participating students and lecturers. The method is feasible as access to students and lecturers in a mathematics module for engineering students is available, which allows for good quality primary data to be collected.

The problem-solving unit will be implemented in a second-year Vector Calculus Course with one contact session per week for three weeks. The contact time will be done virtually during the students' tutorial time. In order for students to engage properly with the problem-solving unit, the successful completion of this three-week unit can replace their lowest two tutorial marks in the semester. Before the implementation of the problem-solving unit, an initial interview or questionnaire would be conducted with each participant individually and these results compared with a final interview or questionnaire conducted at the end of the unit.

During the problem-solving unit, data collection will include individual and small-group interviews, voice recordings of students during problem solving tasks, and reflection of observations of students. This data will be transcribed and analysed by means of Reflexive Thematic Analysis using the software NVivo that streamlines this process. The analysis process will follow the below iterative process (Braun & Clarke, 2020):

Phase 1: Data Familiarization and Writing Familiarization Notes

Phase 2: Systematic Data Coding

Phase 3: Generating Initial Themes from Coded and Collated Data

Phase 4: Developing and Reviewing Themes

Phase 5: Refining, Defining and Naming Themes

Phase 6: Writing the Report

Due to the current, global COVID-19 pandemic, the implementation of the pilot problem solving unit as well as the data collection will need to be done virtually. Locating the study in a mathematics module will open participation to students from all engineering departments. The success of the pilot project relies on the buy-in of the faculty and students that are part of the study.

Each aspect of the problem-solving definition developed in the theoretical framework will be used as an indicator of problem-solving ability. Tasks in the problem-solving unit will be designed to draw on all aspects of the problem-solving definition. The definition will also be a standard against which to assess students' problem-solving abilities. The indicators of problem-solving ability could thus be defined as:

- Problem solving is performed as an iterative process.
- Students feel confident in their ability to solve problems and therefore feel confident to take initiative to tackle a problem.
- The necessity and the validity of the problem needs to be questioned at the outset.
- The goal of problem solving is to find solutions to issues that are difficult or complex from the perspective of the problem solver.
- Problem solving is a creative process.

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- Problem solving can be done individually or collaboratively.
- To understand a problem, a problem needs to be unpacked and problem requirements defined.
- Problem requirements need to be matched to known tools to solve the problem.
- An implementable strategy needs to be developed to solve the problem(s).
- Once the first solution is implemented, the effectiveness of it needs to be analyzed.
- The solution(s) need to be reworked if necessary and then implemented again.
- Problem solving requires the individual to not be risk-averse and to not be afraid of failing, but rather to embrace the iterative nature of problem solving.
- A clear vision of how the entire problem should be solved is not necessary at the start of the problem-solving process, rather one problem requirement should be solved at a time and 'bridges should be crossed' as and when the problem solver gets there.

Limitations

The limitations of this study prevent the results from being broadly generalised to all engineering students and contexts. The rich data collected from this small-scale qualitative data will allow for a close interrogation of students' problem-solving abilities, however the data in the first action research cycle will only be gathered from one class in one engineering mathematics module at one university. The subsequent action research over different semesters will involve different students, and the participation of future students and convenors cannot be guaranteed. Having a history of high achievement, and despite assurance that there will be no penalty to grades for participating, students may give what they think the 'right answers' are in interviews, which may contradict observation data.

Conclusion

The anticipated results of this study are that a need for direct (as opposed to implied) problem-solving skills learning exists for engineering students; direct problem-solving skills learnt through methods based on social constructivism (which furthermore builds students' effective communication and teamwork skills) can be facilitated as part of an undergraduate course at university; and finally that mathematics courses offer a sound framework for these skills to be successfully taught to engineering students.

Engineering students need to be confident in their problem-solving skills in mathematics modules, in their future modules and in the workplace. Furthermore, good practice between universities needs to be shared in this regard to maximise the ability of graduating engineering students to be competent problem solvers and ready to solve problems upon graduation into the profession.

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Where are we at with combined engineering degrees?

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ABSTRACT

CONTEXT

Combined degrees (also referred to as double or dual degrees) allow students to complete two degrees concurrently, widening their learning experiences and broadening their skills, which leads to engineering graduates with greater diversity in skills, who are often well regarded by industry (Shallcross & Wood, 2002; Fleming et al., 2010). With an increasing need for breadth of knowledge and skills in graduate engineers, the ACED Engineering Futures 2035 Scoping Study (Crosthwaite, 2019) suggests some models (including combined degrees) that could contribute to a greater shift away from the current range of program structures that focus solely on engineering. There are nevertheless some concerns around the combined degrees, particularly around the merits of technical depth vs breadth of knowledge and experience, as well as the subsequent industry-readiness of graduates. Furthermore, there have been many calls for integration across the two degrees of combined degree offerings (Russell et al., 2008; Moulton, 2011); however, little has changed.

PURPOSE OR GOAL

The aim of this study is to explore and discuss the current opinions around combined engineering degrees, particularly in terms of the following themes:

- depth vs breadth in engineering degrees
- industry-readiness of combined engineering degree graduates
- integrating the components of the combined engineering degrees

APPROACH OR METHODOLOGY/METHODS

A literature review on combined engineering degrees was conducted. This was expanded with data from University of Sydney participants in the form of semi-structured interviews with academics (n=5), as well as an online survey of current and graduate combined degree students (n=14). Although a small sample from a single institution, our data nevertheless highlights a range of current opinions on combined degrees.

OUTCOMES & CONCLUSIONS

Both the existing literature and our data suggest that, although the combined degrees are regularly suggested as a means to develop well-rounded engineering graduates of the future, there continue to be concerns around the utility of the degrees in developing technically-competent engineers and there is little impetus for significant structural change to the degrees. More can be done to explore opinions from other institutions and identify in what ways the responses in this study are influenced by institutional structures; however, this paper highlights that there are nevertheless a number of concerns with the combined degrees that need to be addressed by the engineering education community.

KEYWORDS

Combined degrees, industry-readiness, depth vs breadth

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Introduction

Prior to the 1980s, Australian engineering students who wished to complete a second undergraduate degree needed to undertake both degrees separately, usually taking 7 to 8 years; however, since then, the introduction of combined degree programs has given students the opportunity to concurrently complete two degrees within a shorter period (Shallcross & Wood, 2002). According to Engineers Australia's (2019) accreditation criteria, combined degrees take substantially less time than the two component degrees as there are content and learning experiences that may validly be counted towards both qualifications. This often falls under the approximately 10% of the engineering degree that is "*more of [engineering-specific content] or other elective studies"* (approximately 1 semester).

The range of undergraduate engineering combined degrees currently offered in Australia broadly include those with Science, Arts, Business, Law, Architecture, Project Management and Design. The full-time duration of a combined degree ranges from 5 to 5.7 years for combined degrees other than Law, and 6 to 6.7 years for combined degrees with Law. In the case of non-Law degrees, some universities' combined degrees offerings are a flat 5 years (e.g. The Australian National University, Monash University and The University of Sydney), whereas other universities' combined degree offerings vary in length depending on the non-engineering component (e.g. UNSW's engineering degrees typically combine with: Science in 5 years; Arts in 5.5 years; and Commerce in 5.7 years). Regardless of institution, Engineering/Science degrees are all 5 years in length due to the Science degree's capacity to contribute to the Engineers Australia's (2019) accreditation criteria of "*underpinning mathematics, science, engineering principles, skills and tools appropriate to the discipline of study and qualification*".

Students enrol in combined degree for a variety of reasons including enhancing career prospects, uncertainty around which career they wish to pursue, widening their breadth of learning, as well as completing an engineering degree while also pursuing other subjects of interest (Shallcross & Wood, 2002; Lever et al., 2011). Much of the university marketing around combined engineering degrees also draws on these points, e.g. UNSW indicates the combined degree will help "*develop your skills in two separate areas, achieving more in less time and opening the door to more opportunities*" (UNSW, n.d.) and The University of Queensland comments that a combined degree is an opportunity to "*[d]ouble your skills and your opportunities*" (The University of Queensland, n.d.). Furthermore, according to Lawrence (2020), high school students tend to be more aware of the non-engineering degree of a combined engineering degree as contrasting with, rather than building upon, the engineering degree.

Combined degree programs can drive increases in student enrolments in engineering. Crosthwaite (2019) has indicated that, at some institutions, the engineering graduates from combined degrees outnumber graduates from the single degree. They also have a positive impact on gender diversity in engineering, e.g. the introduction of combined degrees at the University of Melbourne increased female enrolments in engineering to an all-time high of 28% in 2002 (Shallcross & Wood, 2002). Similarly, data from Lowe et al. (2018b) at the University of Sydney showed that 55.45% of female engineering students complete a combined degree compared to 43.85% of male engineering students. Most notably, female engineering students dominated in combined degrees with Architecture, Arts and Medical Science, while the only engineering combined degree that reported a higher proportion of males was an Engineering/Commerce degree.

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Methodology

In this study, we explore and discuss the current opinions around combined engineering degrees, particularly in terms of the following themes:

- depth vs breadth in engineering degrees
- industry-readiness of combined engineering degree graduates
- integrating the components of the combined engineering degrees

In addition to a review of the literature on combined degrees, we supplement views from existing research with data from University of Sydney participants in the form of academic comments from semi-structured interviews (n=5), as well as current and graduate student comments from an online survey (n=14 combined degree students). Responses included below are labelled A1–5 for the academic comments and S1–14 for student comments. Although a small sample from a single institution, our data nevertheless highlights the gamut of opinions on combined degrees demonstrated in previous literature. The ethical aspects of this study have been approved by the HREC of the University of Sydney 2020/493.

Discussion

Depth vs breadth

Combined degrees offer students breadth of learning and opportunity to build upon a greater variety of skills as they can concurrently complete subjects from two different faculties (Shallcross & Wood, 2002). It can be argued that the non-engineering degree in a combined engineering degree program can greatly benefit the engineering component—and vice versa—and assist in producing graduates with a greater diversity of skills to better meet the diversity of engineering practice as outlined in ACED Engineering Futures 2035 Scoping Study (Crosthwaite, 2019). As also indicated by Crosthwaite (2019), technical skills and competency will continue to be required by the engineers of the future and therefore will continue to be a requirement of the engineering curriculum; however, the question around depth vs breadth that is evident in engineering education more broadly is particularly obvious in the combined degrees.

Moulton (2010) argues that combined degrees can prevent students from achieving sufficient depth in their area of study, making it more difficult for students to continue into postgraduate research. Furthermore, combined degree students may not have the same opportunity to gain generic and critical thinking skills as the subjects and electives that offer this may be removed due to the integrated structure (Moulton, 2010). However, Lever et al. (2011) argues that combined degrees enable further development of transferrable skills such as professional communication, professional values, conduct and judgement and information skills. With engineering degrees often criticised for not adequately teaching students non-technical skills, a second degree appears extremely beneficial (Lever et al., 2011). However, it is important to consider what the non-engineering degree offers:

> *"it very much depends on exactly which options they pick. I don't think it's like combined degrees per se improving skills… the basic accountancy stuff is probably even less engaging than what we do [in engineering]… and if they're doing economics there's probably more chat, discussion and generic kind of skill gain"* [A3]

Similar sentiment was noted amongst the combined degree students, e.g.

> "*a maths degree has the ability to be completed with little to no communication with the remaining cohort*" [S14, Engineering/Science]

> "*I believe the assignments in the business school and my major (finance) are less collaborative by nature because the industry places more emphasis on individual achievement… I believe this 'mindset' hinders the development of professional skills*" [S7, Engineering/Business]

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> "*little to know (sic) group work so teamwork was not learned by many students, culture was not collaborative*" [S10, Engineering/Law]

in comparison to:

> "*there has been a much stronger emphasis on presentations than my engineering degree, encouraging growth in professional communication skills*" [S1, Engineering/Business]
>
> "*most of my subjects revolved around presentations, group activities and seminar-style classes…. Also, the nature of an Arts degree was that I would work with students from across various fields, and it was both interesting and challenging to work within and through different communication styles/thought processes/methods of working- but super applicable in practice*" [S2, Engineering/Arts]
>
> "*written communication skills and [interdisciplinary] effectiveness highly developed*" [S10, Engineering/Law]

This highlights a need to consider the engineering combined degrees as individual degrees, each offering a different approach to the combined degree and thus contributing to the development of potentially quite different aspects of an engineer's professional skills and identity.

There are also concerns that the breadth offered by a combined degree may also lead to cognitive overload, i.e.

> "*a bit of a double edge sword because they are more intense – students need to switch their thinking and learning multiple times a day – whether that impacts their quality of learning overall?*" [A1]

However, Russell et al. (2008) note that some students find the swapping between the two disciplines of a combined degree helpful and believe that it keeps them from being bored with either discipline. The divergence in these two views is perhaps explained by Lowe et al.'s (2018a) findings that, while higher-performing students tend to benefit from broader learning, lower-performing students could struggle with broader learning. In terms of the impact on their engineering capabilities,

> *"For some students they need that narrower focus to perform well enough to be really competent and therefore to be a good engineer… for better students, they can cope with that diversity without losing that strength and then the diversity helps them take the steps beyond that"* [A2]

In addition, it is unclear if combined degree students have better opportunities to develop their professional skills in their non-engineering degree or if their proficiency in their professional skills is what leads them to choose a combined degree, e.g.

> "*the fact that they recognise broader disciplines means that they have that breadth of interest to do a combined degree*" [A2]
>
> "*I think people who do arts degrees are assumed to have the soft skills required for professional settings*" [S6, Engineering/Arts]

Nevertheless, regardless of which degree a student chooses to combine with their engineering degree, the breadth does have value in widening perspectives, e.g.

> *"I think they all help just being exposed to different disciplines with different cultures*" [A2]

This suggests some of the value of a combined degree is in the development of desirable graduate attributes (such as versatility, adaptability, flexibility) that are not necessarily encapsulated in the Engineers Australia Stage 1 Competencies.

Industry-readiness

Fleming et al. (2010) interviewed 30 engineering-focused organisations on their willingness to employ graduates with combined engineering degrees and found mixed employer perspectives. Some employers preferred dual degree engineering graduates for their greater

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breadth of knowledge and skills. However, other employers suggested that there was little difference between single degree and combined engineering graduates, and that academic results, engineering skills and industry experience were considered more important than a combined degree.

Fleming et al. (2010) also noted that some employers perceived the completion of a dual degree as an indication of greater academic ability due to higher entry requirements. Lowe et al.'s (2018a) findings also indicate that combined degree students tend to continue their strong performance during their studies at university, with combined degree students at the University of Sydney having an average course mark that was 6 marks higher than the single-degree students over the period 2006–2016. Thus, combined students may be more appealing to employees due to their perceived academic capacity, rather than due to the breadth of their knowledge, i.e.

> "*because the ATAR requirements are higher [for combined degree students], potentially they are more likely to get a job if the criteria for success is based on intelligence*" [A4]

> "*the industry are keen to employ [combined students] because they are smart students so they make excuses for their lack of technical skills and… 'we are going to train them up on the technical side'* " [A3]

Nevertheless, the wider perspective that a combined degree can generate has strong potential to build interdisciplinary effectiveness. This appears to be well-recognised, e.g.

> "*combined degree students tend to realise that there are different ways of seeing the world rather than a single narrow engineering lens… single degree students can think it's all about the engineering and other disciplines don't have much to offer so they don't need to engage with them*" [A2]

> "*combined students are more open-minded and are prone to accept that things can be different and approached differently*" [A5]

> "*there has been a stronger focus on framing organisations from a big picture perspective*" [S1, Engineering/Business]

This is in line with employer perceptions that combined degree students tend to have better generic and broader skills (Fleming et al., 2010). Furthermore, combined students may be better equipped due to their broader knowledge base,

> "*combined degree students might be better just because they have that slightly broader knowledge base to draw on their engineering work if they choose to go into engineering*" [A1]

This agrees with Lawrence (2020) who noted that, even though industry indicate that graduates can learn quite a lot on the job, engineering graduates would benefit from a widening of the broader knowledge base, particularly from complementary areas of expertise such as design.

There is some concern that the lack of engineering electives (technical content and technical depth) that combined degree students complete may have an impact on their readiness for industry, i.e.

> "*combined degree students do not do elective engineering units so you cannot say that they are well equipped for entry into professional engineering… the question really is "are the students actually being equipped for the real challenges of the future?" and the combined degree students, because they're doing less, are less so in my opinion*" [A3]

This echoes Moulton's (2010) concerns around combined degrees preventing sufficient depth for technical competency and should not be dismissed because,

> "*there are some engineering roles where a single degree student may be better equipped because they are so immersed in just engineering so they have built better technical capabilities*" [A2]

Nevertheless, some consider the trade-off between elective engineering units and non-engineering units as acceptable,

> "*one of the distinctions between single and double degree students is that the single degree students have done that extra three or four electives. I don't think that matters one iota at all… look, they've missed out on some theory. They'll pick it up in five seconds*" [A4]

This appears to reflect Lowe et al.'s (2018a) findings that combined degree students are generally higher-performing students, suggesting they may be better equipped to learn and adapt on the job. This is also in line with Fleming et al.'s (2010) findings that combined degree students may be favourable to employers because of a greater willingness to work outside of their technical areas. This adaptability appears increasingly important, particularly if some graduates find that,

> "*university curriculum is largely irrelevant to what is actually required in the profession*" [S12, Engineering/Business]

There are also indications that, while technical capability may be valued at graduate level, career advancement may be tied to the broader skillsets that combined degrees offer, e.g.

> "*[civil engineering]'s not a career where there's a huge amount of advancement opportunities within the context of being a technical person and the ladder for advancement in the broad construction industry is by branching out into project management, a bit more finance, managerial*" [A4]

This is similar in sentiment to some employees who see the technical capacity as a necessity in the short term but acknowledge that the knowledge and skills from the non-engineering degree could be advantageous later in one's career (Fleming et al., 2010).

Integrating combined engineering degrees

As indicated above, there are a wide range of experiences associated with the combined engineering degrees. It is this diversity of options that makes combined degrees attractive to students but is also ultimately problematic for engineering educators and accreditors in that it creates the need for diversity in the approaches to managing and accrediting them. There has been over a decade of calls to better integrate the two components of the combined degrees (Russell et al., 2008; Moulton, 2011). However, current practice is to focus on only teaching and evaluating the engineering component of the combined degrees. Since the engineering component is regarded as a standalone degree, there is limited interest in learning about other degree components or in recognising their contributions to an engineer's professional capacity. This is highlighted in the fact that,

> "*very few of us have an understanding of what the students do in their second degree at all…all of their science degree and all of their arts degree is elective and so we've got very little understanding of all of that*" [A4]

This stems from the combined degree structure effectively being two degrees run in parallel and, as noted by Russell et al. (2008), this results in an administrative structure, rather than a pedagogical one. This can result in logistical difficulties in elective availability and timetabling, as well as complexity in finding appropriate academic advice, which negatively affect the combined student experience. Although there is some sense of joint ownership, the responsibility often falls to one discipline to administer. For example, at the University of Sydney, the Faculty of Engineering administers most combined engineering degrees, which may suggest that the onus is on engineering educators to drive change in the combined degrees. However, it is ultimately not solely in the hands of engineering educators as refinement and better integration of combined degrees would inevitably require input from educators from both sides of the combined degree.

Until 2021, the engineering component of the combined degrees at the University of Sydney had fewer units than the standalone degree. Changes to the combined degree will bring it closer to the standalone engineering degree and Engineers Australia's accreditation requirements for 3.5 years equivalent of engineering units. How exactly this will affect the combined engineering degree lengths remains to be seen, but it is likely that this will shift towards a model where the length of the degree depends on the non-engineering degree.

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This greatly simplifies the accreditation process, but perhaps undermines the attraction of the combined degrees as shorter and more financially viable. It also continues the tradition of treating the two degrees as separate entities, rather than using the opportunity to trial a more cohesive pedagogical framework for the combined degrees. The shift to increasing the number of engineering units has been supported by staff members at the University of Sydney as they believe that these changes will improve the technical depth of the combined degree students. This approach is also in line with academics' perception of the low value attached to risk taking (Reidsema et al., 2021) and the greater number of students impacted by investment of time and resources in changes to the engineering degree—taken by both single degree and combined degree students—over the combined degrees.

Industry has suggested that combined degrees could benefit from courses that link the two components of a combined engineering degree (Lawrence, 2020). Combined capstone or thesis units have been proposed (Moulton, 2011); however, when this was proposed in 2017 at the University of Sydney, discussions identified several concerns. It needs to be acknowledged that:

- some disciplines do not necessarily mesh well
- the overlap may be restrictive on the student's options to choose their project
- staff may not be able to support the project due to a lack of expertise (perceived or otherwise)
- non-engineering staff may not have time and resources to support a student whose capstone enrolment is outside of their faculty

Furthermore, units that engage non-engineering disciplines in engineering units often run into difficulties with longevity due to being sustained by individual staff members, rather than resulting from a wider cultural shift within the faculty staff (Crosthwaite, 2021). Lawrence (2020) also emphasises the need to not rely solely on combined degrees as a mechanism for diversification, but to also collaborate with other disciplines on the future engineering curriculum. Towards this end, combined degrees do highlight the top-down issues around ownership and responsibility (and ultimately student dollars) that will continue to overshadow bottom-up approaches to implementing more diverse curricula.

This also raises the question of whether students themselves would benefit from greater connection or overlap between the two components of a combined degree as greater connection has potential to negatively impact the combined degree student experience. For example, some students may use the non-engineering degree to take a 'break' from engineering (Russell et al., 2008). Also, given that Palmer et al. (2015) have reported that less than half of Australia's recent engineering graduates work in the engineering profession, it is clear that not all combined engineering students plan a career in engineering in the long term and see a combined engineering degree as a way to manage career uncertainty (Shallcross & Wood, 2002). In these cases, units that connect the two degrees may not be desirable. In fact, when Russell et al. (2008) asked a range of combined degree students (although not necessarily from engineering) what was missing from their degree, only 38% indicated integration of the degrees as a concern. This is perhaps reflected in resistance against developing professional skills within the engineering degree from students also studying non-engineering degrees that have a strong focus on transferrable skills development, such as:

> "*I think the uni should just focus on teaching engineering*" [S6, Engineering/Arts]
>
> "*I don't think it's really the university's responsibility to teach this stuff*" [S5, Engineering/Project Management]

This parallels Lawrence's (2020) point that engineering combined degrees often default to "*automatically aligned fields and those which can be viewed as complementing Engineering*" despite the potential to use the non-engineering degree to augment the engineering degree. Furthermore, for some stakeholders, the combined degree graduates "*represent 'a loss to engineering' if they do not practice in the field*" (King, 2008). These views are engineering-centric and suggest that we as engineering educators need to keep in mind that, for some students, it is not necessarily the case that the non-engineering degree exists to further the engineering degree, but that the engineering degree exists to further the non-engineering degree. This may be particularly the case at the University of Sydney, where:

> "*the proportion of combined degree students … is higher [than a nearby university in Sydney]. I think that's partly because you are much more likely to come to USyd to do a combined degree because of the second degree being better*" [A2]

and it merits investigation of other institutions in future to establish how dependent on the University of Sydney context these opinions are.

Conclusion

So, where *are* we at with combined engineering degrees? There continues to be the following concerns:

- the debate around the development of depth vs breadth in combined degree graduates, which mirrors the lack of agreement over depth vs breadth in the single engineering degree (as indicated by Crosthwaite, 2021)
- a need to recognise graduate attributes that are developed through breadth of study (e.g. versatility, adaptability, flexibility)—and are increasingly required by engineering graduates—in the Engineers Australia Stage 1 Competencies
- a need for greater recognition that, although engineering graduates may not immediately benefit from a combined degree, there are great benefits for their long-term careers and for the discipline overall
- the segregation and siloing of the two components of a combined engineering degree, which will require a top-down approach from Engineers Australia accreditors and teaching & learning leadership
- concerns with the workloads in creating cross-disciplinary units, as well as the longevity of such units, which will require investment and long-term support from teaching & learning leadership
- a lack of clarity around the impact of integration of the two components of the combined engineering degrees upon the student experience and how students might react to this, which could be addressed by future research

In this paper, we have highlighted the key issues currently associated with the engineering combined degrees, demonstrating that there is still much that can be done to improve combined engineering degree offerings. Given that engineering faculties reap significant benefits from offering combined degrees—such as higher enrolments, attracting students that are higher-performing or from more diverse backgrounds—opportunities to improve combined degree offerings should, at the very least, be reviewed by faculties.

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An Online Peer Assessment Method in Computational-based Engineering Courses: combining theoretical and computer tools

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ABSTRACT

CONTEXT

As its name suggests, peer assessment involves each student to take active part in providing feedback and in some cases, evaluation of the learning outcome of their peers. Peer assessment can introduce several advantages to the learning process such as increasing the student motivation, critical thinking and development of qualitative and quantitative arguments. This research proposes a peer assessment method for computational-based assignments and describes the process of implementing it in an online "Structural Analysis" subject.

PURPOSE OR GOAL

Some experts have criticised peer assessment procedures and questioned the ability of students to provide reliable evaluation. There are concerns raised in the literature on the usefulness and reliability of student peer reviews including inconsistency in the feedback and quantitative assessment marks. This study aims to implement an online tool to increase the engagement and partnership of students in the virtual environment and replace some of the lengthy computational processes with computer-based tools. The goal of the proposed method is also to increase the reliability of peer assessment activity by providing evidence-based evaluations.

APPROACH OR METHODOLOGY/METHODS

The design of the peer assessment task has been implemented in a second year "Structural Analysis" subject on the topic of "Analysing Indeterminate Structures". The delivery of this task was examined in a methodological approach as well as an executional approach. In the methodological approach, benefits were investigated, and comparison was made with previous peer-assessment procedures. The execution of this task which includes a combination of manual calculations and computer methods is outlined using available LMS tools.

ACTUAL OR ANTICIPATED OUTCOMES

The method proposed in this study introduces benefits to student learning and engagement in theoretical computational-based topics. This method is built on suggestions to mitigate some of the downsides of peer assessment reported in previous literature. For instance, to escape the double volume of computational effort, to reduce the reluctancy of students and to eliminate the potential errors they make in evaluating the computational work of their peers, the assessment phase is proposed to be done using a "Structural Analysis" computer software.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Online peer assessment combining theoretical methods and computer-based approaches has provided a means to overcome some of the shortcomings traditionally associated with this approach. These improvements include an increase in the level of consistency and reliability of peer-assessment results compared to traditional approaches. The implementation of the method also shows approximately 25% increase in student active participation.

KEYWORDS

Computational-based courses, peer assessment, online teaching

Introduction

Assessment of Computational Engineering Subjects

Engineering assessment is conducted mainly in the form of engineering design projects and invigilated examinations. Engineering assessment methodologies generally include descriptive designs, observations and meta-analysis and experimental designs (Olds, Moskal, & Miller, 2005). Engineering education is progressing towards interactive teaching approaches and a number of innovative methods such as project-based learning, research-oriented approaches, flipped methods and collaborative projects have been introduced and adapted in engineering design assessment (Bell, 2010; Sankaranarayanan et al., 2020). While these techniques have shown significant improvements in evaluating student learning experience of engineering concepts and their practical applications, the assessment of computational theory-based topics have remained mostly in the same conventional form.

Engagement in the online space

Before the occurrence of the COVID-19 pandemic, engineering education was taking a slow pace towards online education, e-learning and implementation of ICT in teaching practice (Banday, Ahmed, & Jan, 2014). With the recent transition to online teaching, much of the literature has focused on increasing the engagement of students virtually and how to efficiently design and transfer content to the online or blended space (Muller-Karger & Steiner, 2020; Vogel Heuser, Bi, Land, & Trunzer, 2021). Mainly, the importance of online tool implementation and student evaluation is discussed in these research publications.

For a successful online assessment design, there needs to be an effective level of collaboration between the students and educators as well as the availability of fundamental support and virtual facilities. While the majority of institutions use a type of online learning management system, taking advantage of the full capacity of the online facilities might be prevented due to the lack of familiarity or insufficient time for teachers to move in this direction (Christie & Jurado, 2009). Among the many approaches in education engagement, Peer Assessment (PA) has been identified as a great method in engaging students in online engineering theoretical courses (Bishay, 2020).

Peer Assessment

Overview

As its name suggests, peer assessment involves each student to take active part in providing feedback and in some cases, evaluation on the learning outcome of their peers. Peer assessment can provide valuable learning benefits not only to the assessed students, but also to the assessors themselves which can enhance the learning outcomes. Peer assessment can increase the student motivation (Magyar & Haley, 2020), boost the level of critical thinking as well as the qualitative and quantitative arguments developed on the concept (Usher & Barak, 2018). Peer assessment helps students gain a deeper understanding of the topic and learn from their peers' mistakes which can encourage them to self-reflect and self-improve.

Peer Assessment in the engineering context

Feedback is given in a variety of different ways, including peer evaluation of individual performance, or group work (Bezuidenhout, 2020), and can include formative or summative feedback. The assessed learning can be based on soft skills, hard skills and technical skills (Zhang, 2012). Although assessment in the engineering discipline requires covering a combination of the above skills, the majority of peer assessment activities previously described and designed focus on soft skills rather than technical knowledge. Examples of these types of peer assessment methods include evaluation of writing in engineering

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(O’Mahony, 2021), journaling, and oral presentations (Petchamé et al., 2020). Peer assessment of technical skills, however, is an important skill in the career of engineers, enabling students to review and identify errors in design documentations, manual and computer calculations of engineering projects. A reason that can contribute to a lower interest in using peer assessment in technical topics is the complexity and lengthiness of the processes and the high possibility of errors encountered in the assessment procedure.

Some research is found in engineering education focusing on the peer assessment of technical skills. A meta-assessment project-based peer assessment process was developed requiring student groups to work on a part of two projects and perform a peer assessment on the two projects in which they contributed (Wengrowicz, Dori, & Dori, 2017). Hersam et al. conducted a peer assessment by forming an evaluation committee by students evaluating the project conclusions of other groups and assigning a score based on a defined marking criteria which was mostly focused on soft skills and 20% on technical accuracy (Hersam, Luna, & Light, 2004). In a computer programming course, students critically judged and marked other students’ scripts. In this work, an automatic test system was used to help check the assessment process by running each student assignment against various test inputs (Sitthiworachart & Joy, 2004). A peer assessment task was implemented in a civil engineering subject based on marking a traditional problem-based assignment or tutorial against a worked solution to evaluate students’ knowledge in large class settings (O'Moore & Baldock, 2007).

Bishay (2020) introduced a peer assessment task as part of a teaching method of Finite Element Modelling (FEM). The results of this study compared the exam scores of a traditional FEM course with those of the novel approach including a peer assessed project which showed a significant improvement and higher engagement compared to the traditional approach. A project-based chemical engineering course including peer-evaluation strategies also showed enhanced learning outcomes and quality of teaching and learning based on student survey results (Cifrian, Andrés, Galán, & Viguri, 2020).

The proposed method

Implementation in a “Structural Analysis” subject

A PA method was designed and delivered in a “Structural Analysis” subject in a second year Civil Engineering bachelor program. The assessment task included various phases to cover a combination of learning outcomes of the subject. The preliminary phase of this PA task was completing the teaching session of a manual Structural Analysis method used for finding the internal forces and moments in an indeterminate structure called the “Slope-deflection Method”. This prepared students for initiating the task and provided them with an understanding of the manual computational methods. Once the manual calculations are covered in the topic, the PA process is initiated. Various phases of the PA activity are outlined in Figure 1.

The design of the peer assessment task was done using the workshop activity on Moodle. Once the initial Moodle settings were complete, the Analysis question was released to students and the PA activity moved to the second phase. Each student was provided with a question unique in its input parameters, but all questions were kept consistent in the level of difficulty. Students were required to complete the assigned question using the manual computational methods of the “slope-deflection method”.

Upon completion of the submission phase, students were trained in a structural analysis software as an alternative method to conduct structural analysis. It is important that the sequence of the manual and computer-based learning sessions is kept in line with the PA phases. At this stage, the peer assessment phase was made available on the workshop activity. Following certain guidelines and examples on assessment strategies, students used the computer software to perform an accurate evaluation of their peers’ manual

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computational submission based on their assigned question inputs. The assessment criteria and outputs to be assessed were broken down for students in a structured way to elicit a more diverse feedback procedure (Hicks, Pandey, Fraser, & Klemmer, 2016). These included the evaluation of the deflections and internal forces (bending moments and shear force values) at specific locations in the structure. The evaluation results as well as the computer-based evidence were provided and submitted by students at the end of the assessment phase.

This method combines two learning outcomes in a single task. The peer review process is also part of the assessment due to being considered an independent learning outcome in developing technical learning skills in students. During all phases of the task the instructor accesses and reviews submissions and a final feedback is provided to all students on their manual calculated submissions as well as the computer-based evaluations.

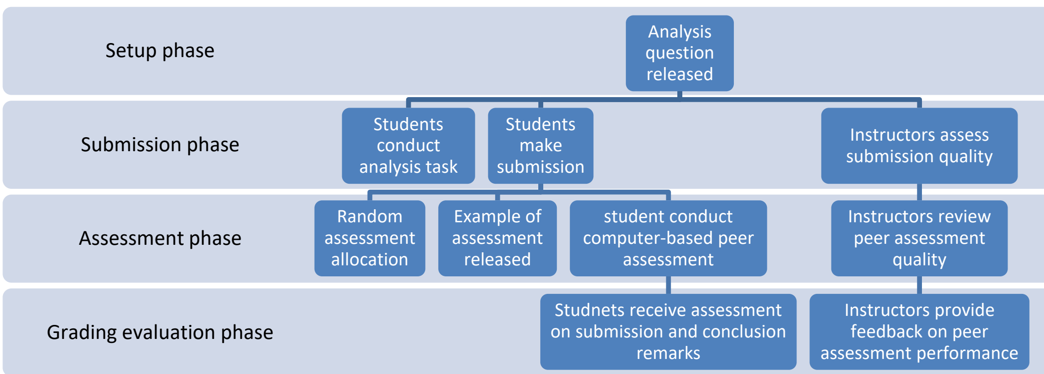

Figure 1: Peer assessment process flow chart

Analysis of the method

Some experts have criticised the peer assessment procedures for students and questioned the ability of students to provide reliable evaluation (S. E. M. Meek, L. Blakemore, & L. Marks, 2017). The concerns raised by this study on the usefulness of student peer reviews are in the form of inconsistency in the feedback as well as quantitative assessment marks. It is shown that only 43% of grades provided by students were within 5% of the tutor’s grade. An extent of biased assessment has also been observed, where student with high quality work tend to provide a higher quality of feedback compared to students who did not do well. Furthermore, some experts criticised the ability of students to provide a reliable assessment and reported inconsistencies in feedback and quantitative marks (S. E. M. Meek et al., 2017). The peer assessment process was also found to fail in achieving the expected benefits (Naveh & Bykhovsky, 2021). As opposed to the higher final marks reported by Bishay (Bishay, 2020), Naveh and Byskhovsky (2021) mention that “this [type of assessment] might have contributed to lower grades in the course”.

The proposed PA activity in this study employs methods to eliminate or alleviate the effect of a number of issues raised by previous researchers and also those observed in the delivery of technical assessments by the author. The issues along with the proposed strategies are listed in Table 1. Some of the proposed methods were adopted based on suggestions arising from previous research literature, while others are an inclusive result of the present PA activity. The novel approach of combining a computer-based Structural Analysis task with the peer assessment process has provided an effective opportunity to overcome some of these issues. A major concern lies within the reliability of peer assessment when it comes to technical and manual computational topics. Using a computer software tool reduces the risk of errors and provides a certain level of consistency among the revisions. The use of computer methods will also provide the assessed students and also the instructor, with acceptable evidence on the evaluation which can enrich the learning experience. Furthermore, this reduces the students' time spent on the evaluation phase and makes the task more interactive while incorporating a second learning outcome of the course. Finally, the instructor will spend an efficient amount of time on the overall revision of the manual calculations as well as the assessment outcome by taking advantage of the computer-based evidence.

Table 1: Issues associated with PA and proposed methods to tackle them

Issues associate with PA	Methods employed to address issue
Bias in marking and lack of trust (Matinde, 2019)	Automatic (Søndergaard & Mulder, 2012), random and blind assessment allocations (Naveh & Bykhovsky, 2021)
Mechanisms for distributing assignments and collecting reviews (Søndergaard & Mulder, 2012)	Use of the Workshop tool on Moodle (Naveh & Bykhovsky, 2021)
High possibility of error in manual computational courses	The use of a computer software for accuracy of evaluation
Minimising the influence of ''rogue'' reviewers (Søndergaard & Mulder, 2012)	Detailed layout for qualitative assessment (Cifrian et al., 2020), evidence-based software assessment process
Inconsistent marking (Sarah E. M. Meek, Louise Blakemore, & Leah Marks, 2017)	Assigning more than 1 assessor (Naveh & Bykhovsky, 2021), evidence-based software assessment process
Motivating students to complete the reviews (Zhang, 2012), reluctancy of students in participating in peer assessment due to the high volume of work (Matinde, 2019)	Replacing theoretical methods with computer calculations in the evaluation phase to increase student motivation and speed up the process
Negative feeling of students in spending time and being bored (Matinde, 2019)	Reducing the scale of assignment/project (Bishay, 2020), defining the purpose clearly and improving students' perception (Matinde, 2019)
Time spent by the educator for the final assessment	Use of evidence-based software assessment process to increase speed
Technicality of assessment criteria	Introduction of numerical criteria based on the software results
Maintaining validity and reliability in the grading (Zhang, 2012), preventing student errors even in computer modelling	Introducing methods to check validity or address discrepancies in computer methods
Detecting and preventing plagiarism (Søndergaard & Mulder, 2012)	The use of randomised inputs for each student (Matinde, 2019)
Some students have mentioned while they consider these tasks important, they do not have enough time to work on them (Staubitz & Meinel, 2020)	Peer assessment is part of the subject learning outcomes and is also assessed

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While the use of computer modelling to evaluate manual calculations increases the level of accuracy and reduces possibility of errors, there is still a possibility of errors being made in the process of creating the models and defining the inputs in the software by students. To avoid this, students were asked to perform and provide a series of checks on the computer-generated results. These checks are based on basic Structural Analysis theories such as the equilibrium of forces and moments and the validity and compatibility of signs, directions and values of deflections and forces.

It was previously observed students lose interest and the level of engagement reduces in calculation-based topics. While the use of theoretical procedures predominantly results in a reduction in the engagement and interest of students, the implementation of the proposed interactive PA method showed a noticeable increase in the level of engagement, interest and activity of students. A session including parts of the PA activity at least 25% increase in the level of student participation and the overall engagement was observed. This was obtained from a total of 30 enrolled students and the level of engagement was based on the student activity and number of interactions made in the session in which parts of the PA activity was implemented. Furthermore, in giving the feedback as part of the PA activity, students provided arguments as to why and to what extent the manual calculations were conducted correctly which involved an increased level of critical thinking regarding the calculation of internal force values, diagrams, and deflection outcomes. This also resulted in an enhanced learning experience for their own understanding of the manual calculations necessary for the “Structural Analysis” procedures.

Limitations of method and further suggestions

This study focuses on the design and implementation of a peer-assessment task for evaluating the technical knowledge and hard skills in a calculation-based engineering course by incorporating computer-based methods. While the method of implementation is described in detail, further studies are required to provide insight on the students’ perspective on their experience throughout the PA activity. It is suggested that a survey is designed and distributed among students participating in the PA activity to evaluate their learning experience, engagement, level of confidence during the computer modelling as well as the assessment phases of the task. Furthermore, a quantitative analysis of this method from the student results in the proceeding assessments is recommended to be examined which can provide a better understanding of the general effects of this novel assessment method.

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Framework for enhanced professional practice in engineering programs.

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ABSTRACT

CONTEXT

As indicated in "Engineering Futures 2035: Engineering Education Programs, Priorities & Pedagogies" commissioned by the Australian Council of Engineering Deans (ACED), engineering programs need greater focus on practice to deliver the future expected graduate outcomes. Final-year research projects, capstone courses, and other forms of work-integrated learning (WIL) are particularly useful to expose engineering students to professional practice. In final-year research projects, engineering students work on real-world problems similar to those in professional environments and the workplace, but not in a way similar enough to professional practice. This paper proposes the integration of activity theory and social learning theory as a theoretical framework for final-year research projects in engineering degrees. Activity theory provides a lens to better understand human learning through interactions with people and artifacts, while social learning theory models learning through observing and imitating behaviours. Both theories have been previously used for understanding human behaviours, relationships with technology and interaction design.

PURPOSE OR GOAL

The goal of the paper is to provide a theoretical framework for final-year research projects in engineering programs to recreate professional non formal ways of learning that prepare students for WIL placements. Often in engineering programs, final-year research projects, are supervised and assessed focussing on the problem and the thesis. Problem solving and reporting are valuable skills for WIL, but other additional aspects, such as professional and personal attributes, are as important for successful professional experiences.

APPROACH OR METHODOLOGY/METHODS

The paper analyses how a final-year research project course can be structured and informed through the lens of both activity theory and social learning theory for better preparation for professional practice.

ACTUAL OR ANTICIPATED OUTCOMES

The anticipated outcome is a deeper, theory-informed immersion of engineering students in professional practice, leading to a better preparation for their WIL placement.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The findings will inform the design of activities in final-year engineering research projects to support development of personal and professional skills within engineering programs in order to enhance students' preparation for professional practice.

KEYWORDS

Final-year engineering research projects, work-integrated learning, engineering futures, future engineer, activity theory, social learning theory.

Introduction

Final-year research projects, capstone courses, and other forms of work-integrated learning (WIL) are particularly useful to expose engineering students to professional practice. As indicated in "Engineering Futures 2035: Engineering Education Programs, Priorities & Pedagogies" commissioned by the Australian Council of Engineering Deans (ACED) (Crosthwaite, 2021), engineering programs need greater focus on practice to deliver the future expected graduate outcomes.

Often in engineering programs, final-year research projects are supervised and assessed focussing on the problem and the thesis. Problem solving and reporting are valuable skills for WIL, but other additional aspects, such as professional and personal attributes described in international engineering competency standards, are as important for successful professional experiences.

Students undertaking individual final-year research projects might encounter challenges in WIL placements, which often require professional skills including teamwork, and they could benefit from incorporating a group component in their projects. Moreover, struggling students undertaking individual final-year research projects could potentially benefit from group work by imitating behaviours from their peers and gaining confidence in their abilities through peer support.

The goal of this paper is to provide a theoretical framework for final-year research projects in engineering programs to recreate professional non formal ways of learning that prepare students for WIL placements. This paper argues that it is beneficial to develop professional and personal attributes while undertaking a final-year research project course for better preparation for WIL placement.

The paper describes how a final-year research project course can be analysed and structured through the lens of both activity theory and social learning theory, which are used as a theoretical framework to inform the design of activities in final-year engineering projects with the aim of developing personal and professional competencies that will better equip students for their WIL placement. Both theories have been previously used for understanding human behaviours, relationships with technology and interaction design.

Final-year research projects and WIL

In engineering programs, there are final-year research projects aiming to introducing students to research practice through project planning and management, different research methods, and self-reflection. In final-year research projects, engineering students work on a specific real-world problem similar to problems found in professional environments and the workplace. There are individual and group projects. The latter normally include components to assess individual achievement of learning outcomes.

WIL in engineering programs includes different forms to introduce students to real life practice and hands-on professional experience, such as internships, capstone research projects, or work placements, by which students apply knowledge and skills acquired throughout the engineering program in a comprehensive way. A work placement may provide students with the opportunity to develop professional skills, attributes, and competencies. WIL in a work placement can be assessed using a work log and a WIL report describing and evaluating the engineering experiences and reflecting on the developed competencies for a graduate-level professional engineer.

Activity theory

Activity theory (AT), also known as cultural-historical activity theory (CHAT), provides a lens to understand human learning through interactions with people and artifacts, and analyse any contradictions.

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Activity theory was established by Lev Vygotsky (1978) and has evolved through the works of Alexei Leont'ev and Yrjö Engeström (Engeström, 2001) resulting in three generations.

In the first generation of activity theory, which was based on Vygotsky's work, the idea of mediation was created and analysed using the triangular model of subject, object, and mediating artifact (tools), shown in Figure 1, (Engeström, 2001).

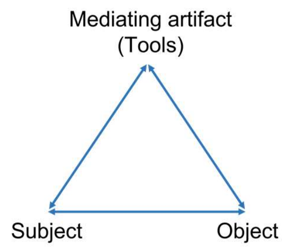

Figure 1: First generation of activity theory. Adapted from (Engeström, 1987)

In the second generation of activity theory, which was based on Leont'ev's work, the triangle was expanded to include the collective part of an activity and the artifacts: rules, community, division of labour, and outcome (Engeström, 2001). The second-generation triangle is shown in Figure 2.

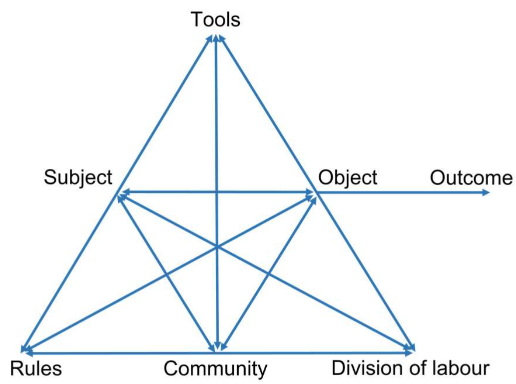

Figure 2: Second generation of activity theory. Adapted from (Engeström, 2001)

In the third generation of activity theory, more conceptual tools were developed to understand multiple perspectives, dialogue, and interacting networks of activity systems with more than one objects, as shown in Figure 3, (Engeström, 2001).

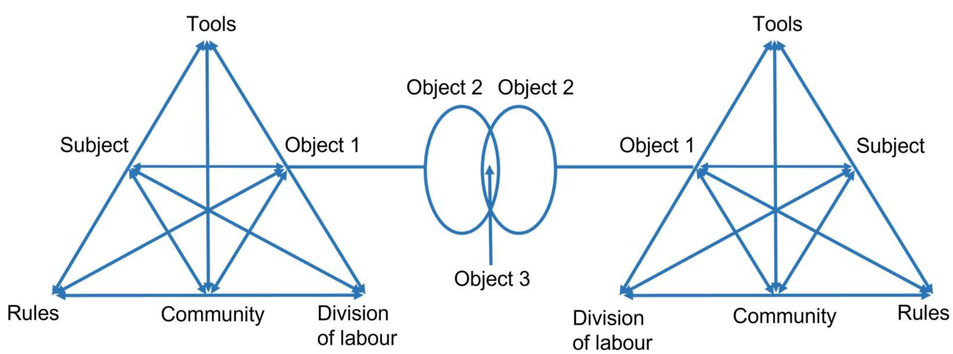

Figure 3: Third generation of activity theory. Adapted from (Engeström, 2001)

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Social learning theory

Social learning theory (SLT) was established by Albert Bandura and analyses the foundations of human learning through observing and imitating behaviours (Bandura, 1977). Learning phenomena through direct experience tend to occur on a vicarious basis by observing other people's behaviour and its consequences for them (Bandura, 1977). In particular, learning by observation helps people to acquire integrated patterns of behaviour without having to form them through trial and error (Bandura, 1977).

According to Bandura (1977), personal and environmental factors are not independent determinants. In particular, people produce environmental conditions through their actions and these environmental conditions affect their behaviour in a reciprocal fashion (Bandura, 1977). The experiences through behaviour partly determine what people become and can do, which, in turn, affects their subsequent behaviour (Bandura, 1977). In the social learning view of interactions and behaviour, the personal, behavioural, and environmental factors operate as interlocking determinants of each other, as depicted in Figure 4, (Bandura, 1977).

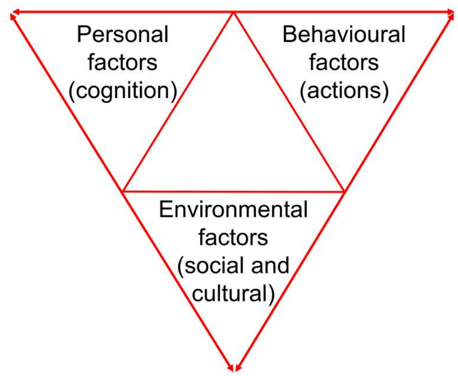

Figure 4: Bandura's triadic reciprocal determinism. Adapted from (Bandura, 1977)

Bandura (1977) also defined and analysed self-efficacy, which is a specific concept in social learning theory. According to Bandura (1977), "an efficacy expectation is the conviction that one can successfully execute the behaviour required to produce outcomes". As shown in Figure 5, outcome and efficacy expectations are different because individuals may believe that particular actions will produce specific outcomes but question their ability to perform those actions (Bandura, 1977). Bandura stated that "efficacy expectations determine how much effort people will expend, and how long they will persist in the face of obstacles and aversive experiences."

Figure 5: Efficacy and outcome expectations. Adapted from (Bandura, 1977)

Bandura (1986) also stated that 'the stronger the perceived self-efficacy, the more likely are persons to select challenging tasks, the longer they persist at them, and the more likely they are to perform them successfully'. Studies have shown that self-efficacy is important because it can determine performance, which operates partially independently of underlying skills (Bandura, 1986).

A great amount of social learning occurs among peers (Bandura, 1986). Peers may assist with some important efficacy functions and those who are most experienced and competent may provide models of efficacious styles of behaviour (Bandura, 1986). In addition, peers may provide information for comparison of efficacy appraisal and verification (Bandura, 1986). This is important because self-efficacy is a critical motivational contributor to success and development of competencies (Bandura, 1986).

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Framework for enhanced professional practice

Integration of activity theory and social learning theory

Activity theory has been used as a framework for designing constructivist learning environments (Jonassen & Rohrer-Murphy, 1999) and a framework for project work in learning environments (Hung & Wong, 2000). There has also been research that linked a capstone course with vicarious experience and development of self-efficacy (Dunlap, 2005). Self-efficacy is important for improving the motivation of struggling learners (Margolis & McCabe, 2004).

We propose the integration of activity theory and social learning theory as a theoretical framework for individual final-year research projects in engineering programs to recreate professional non formal ways of learning that prepare students for WIL placements. The motivation for the proposed framework stems from challenges that students may encounter in WIL placements due to lack of personal and professional attributes, teamwork experience, and self-efficacy. The objective of this framework is to inform final-year research project activities in engineering curriculum, reinforce self-efficacy and provide vicarious opportunities for development of personal and professional skills. The integration of activity theory and social learning theory is depicted in Figure 6.

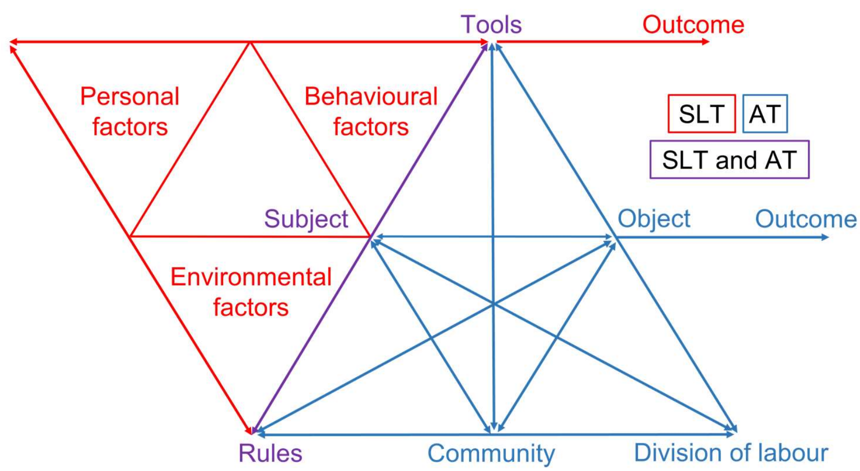

Figure 6: Integration of activity theory and social learning theory.

Case Study

We consider a case study at Queensland University of Technology, where the final-year research project is a 2-semester course and assessment tasks include written reports and oral presentations. There are individual and group projects, which include some components for individual work. The reports normally require a project definition and plan, a literature review, a detailed description of the research work, findings including visualisation tools such as plots, figures, and tables, and a reflection on progress and learning. Students may also be required to present a clear explanation of the research undertaken to an audience of supervisors and peers. Apart from the project requirements, students are also assessed in the quality of the written reports and presentation.

The literature review requires systematic search, relevant references, clear descriptions of the research gaps and explanations on how the selected literature will inform the research project. References and the format of the bibliography are also important. A concept map of the research topic and a Gantt Chart for the project timeline and milestones are normally required.

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The presentation slides need to be clear and have a logical flow and the oral presentation will be effective provided that clear and engaging language – including body language – is used. The presenters need to be able to answer questions from the audience in a clear and positive way.

In the proposed framework, we have the following representations for the artifacts and factors in the AT and SLT triangles in Figure 6, respectively.

- **Subject**: student undertaking a final-year research project
- **Community**: peers undertaking similar final-year projects, project supervisors
- **Object**: reports (including thesis) and presentation slides
- **Tools**: learning resources, library, successful completed theses and presentations as samples, Zoom, Microsoft Teams, Slack, software for sharing files, writing software (for example, Microsoft Office, LaTeX, Adobe Acrobat), office software, collaborative applications, computer software, EA Stage 1 competencies (or similar) document
- **Rules**: code of conduct, academic integrity, rules and expectations set by course coordinators, rules and expectations set by project supervisors, rules and expectations set by peers, meeting attendance, internal and external milestones
- **Division of labour**: individual tasks, collective tasks, decided by project supervisors and peers
- **Outcome in AT**: completed thesis, presentation, and work placement
- **Personal factors**: personality characteristics, personal expectations, learning needs and styles, previous learning experiences
- **Environmental factors**: physical and social environment, feedback, previous learning experiences
- **Behavioural factors**: cognition, social stimuli, skills, motivation
- **Outcome in SLT**: development of professional and personal skills, self-efficacy, better preparation for work placement, self-reflection

Students can be influenced by some peers and, in turn, be perceived as models by their peers (Bandura, 1986), (Dunlap, 2005). Through the proposed framework, engineering students undertaking an individual final-year research project will interact with their peers for some project components. Instead of trying to improve the thesis and presentation using trial and error, this can be done collectively by exchanging ideas and feedback with peers.

In the proposed framework, engineering students undertaking a final-year research project as a part of a 2-semester course will form small groups (4-6 students, aiming at diversity in culture, gender, and engineering discipline) in the first semester and collaborate in project components that are common in different projects, such as project plan and timeline, Gantt Chart, literature review search and bibliography, report writing and formatting, presentation slides, and practise their oral presentation together. Learning resources, such as sample reports and presentation slides will be provided for reading and discussion. Students will also discuss a reflection of their progress and learning as a group and as individuals and reflect on development of personal and professional skills. In the second semester of the final-year research project course, the number of students in the group will be increased to 10-12 students aiming again at diversity in culture, gender, and engineering discipline. The reason for the increase in the number of students is to enable students to interact with more peers and observe their behaviours. Students will have regular meetings with their peers and with their project supervisors as individuals and as a group. The roles of the project supervisors will interchange between mentor, facilitator and client with different objectives in each role.

The specific choice of peers to form groups will affect the students' learning of professional skills from observations and competencies and will shape their learning outcome. This, in turn, will affect their actions and shape the nature of the peer collaboration in learning in order to develop specific personal and professional skills. These skills include, among others, behavioural and cognitive skills, written and oral communication skills, project management. As an example, we provide a list of professional and personal attributes that may be developed through the proposed framework (Engineers Australia, 2019) in Table 1. This framework is applicable to other equivalent international initiatives, such as CDIO, ABET, etc.

Table 1. EA Stage 1 professional and personal attributes that may be developed through the proposed framework (Engineers Australia, 2019)

Elements of competency	Indicators of attainment
3.2. Effective oral and written communication in professional and lay domains.	a) Is proficient in listening, speaking, reading and writing English, including: - comprehending critically and fairly the viewpoints of others; - expressing information effectively and succinctly, issuing instruction, engaging in discussion, presenting arguments and justification, debating and negotiating - to technical and non-technical audiences and using textual, diagrammatic, pictorial and graphical media best suited to the context; - appreciating the impact of body language, personal behaviour and other non-verbal communication processes, as well as the fundamentals of human social behaviour and their cross-cultural differences. b) Prepares high quality engineering documents such as progress and project reports, reports of investigations and feasibility studies, proposals, specifications, design records, drawings, technical descriptions and presentations pertinent to the engineering discipline.
3.4. Professional use and management of information.	a) Is proficient in locating and utilising information - including accessing, systematically searching, analysing, evaluating and referencing relevant published works and data; is proficient in the use of indexes, bibliographic databases and other search facilities. b) Critically assesses the accuracy, reliability and authenticity of information. c) Is aware of common document identification, tracking and control procedures.
3.5. Orderly management of self, and professional conduct.	a) Demonstrates commitment to critical self-review and performance evaluation against appropriate criteria as a primary means of tracking personal development needs and achievements. b) Understands the importance of being a member of a professional and intellectual community, learning from its knowledge and standards, and contributing to their maintenance and advancement. c) Demonstrates commitment to life-long learning and professional development. d) Manages time and processes effectively, prioritises competing demands to achieve personal, career and organisational goals and objectives. f) Presents a professional image in all circumstances, including relations with clients, stakeholders, as well as with professional and technical colleagues across wide ranging disciplines.
3.6. Effective team membership and team leadership.	a) Understands the fundamentals of team dynamics and leadership. b) Functions as an effective member or leader of diverse engineering teams, including those with multi-level, multi-disciplinary and multi-cultural dimensions. c) Earns the trust and confidence of colleagues through competent and timely completion of tasks. d) Recognises the value of alternative and diverse viewpoints, scholarly advice and the importance of professional networking. f) Takes initiative and fulfils the leadership role whilst respecting the agreed roles of others.

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Conclusions and future work

In this paper, we provided a theoretical framework for final-year research projects in engineering programs using activity theory and social learning theory to inform the design and structure of activities in individual final-year engineering research projects with the aim of developing personal and professional competencies that will better equip students for their WIL placement.

The proposed framework has the potential to be applied internationally in similar engineering programs for professional practice. The proposed framework will be the foundation of a study in which the proposed design will be tested with students who have recently completed the engineering final-year research project and the professional placement. Contradictions when using this framework will be also studied. Future analysis will also explore the role of supporting technology to facilitate the implementation of this framework.

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Mapping and Enhancing Sustainability Literacy and Competencies within an Undergraduate Engineering Curriculum

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ABSTRACT

CONTEXT
There is growing pressure today to tackle complex sustainability challenges of climate change, resource limitations, extreme poverty, to name a few. As part of this drive, today's engineers are expected to deliver technological solutions that maximise social value while minimising environmental impact. Consequently, engineering graduates must be equipped with the knowledge, skills and attributes needed to work and live in ways that safeguards environmental, social and economic wellbeing, both in the present and for future generations.

PURPOSE OR GOAL
The objective of the work reported in this paper was two-fold: first, to map out all the sustainability components in the undergraduate mechanical/automotive engineering curricula at the University of the West of England, Bristol (UWE) at the time of the study; second, to use the outcomes of the mapping exercise, and best practice from the sustainability literature, to develop a curriculum that equips its graduates with the sustainability skills and competencies now required of them by employers and society at large.

APPROACH OR METHODOLOGY/METHODS
The work that we report in this study consisted of a mapping exercise of the undergraduate mechanical/automotive engineering curriculum, followed by curriculum redesign to ensure that the resulting curricula could deliver the required sustainability skills and competencies. Both the mapping exercise and curricula redesign were underpinned by a sustainability framework adapted from the Sustainability Literacy Test for Higher Education institutes by HESI (Higher Education Sustainability Initiative). A survey questionnaire based on the list of topics covered in the Sustainability Literacy Test was developed and sent to Module Leaders of all the 40 modules making up the Mechanical Engineering/Automotive Engineering undergraduate degree programme. Findings from the survey were used to identify sustainability literacy gaps in the curricula. Then, using this mapping together with the sustainability framework, the curricula were redesigned to ensure a throughline coverage of sustainability topics, starting from the first year to the final year of the degree programmes.

ACTUAL OR ANTICIPATED OUTCOMES
Topics on sustainability are now much more explicit, and accreditation requirements pertaining to sustainability are now more explicitly evidenced. Students are now engaging more with sustainability, as evidenced by the significant increase in the proportion of students tackling topics on sustainability in their final year dissertation. In addition, the number of students interested in pursuing a career in sustainability after graduation has increased over the past 3 years. The outcome of the study has been highly solicited and shared at faculty level within the university. Universities in the South West England and Wales region have also approached the department to learn how Project-Based Learning can be used to integrate sustainability in the engineering curriculum.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
Sustainability topics have now been given prominence in the undergraduate degree programme. Sustainability literacies and competencies are now covered alongside other relevant and important topics such as climate change, renewable energy, sustainable development and community engagement.

KEYWORDS
Curriculum mapping, sustainability literacies and competencies, academic accreditation, curriculum reform.

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Introduction

There is growing pressure today to tackle complex sustainability challenges of climate change, resource limitations, extreme poverty, to name a few. Engineers are faced with the challenge of providing solutions that maximise social value while minimising environmental impact. Bourn and Neal (2008) draws the link between global sustainability issues and engineering illustrating how those issues affect the engineering sector and how the work of engineers has potential to have strong impacts in that context. In fact, it is now an obligation for engineers to consider sustainability, the environment, health, safety and social wellbeing in their work duties (Engineering *Council, 2021)*. A recent study of engineering students from across the USA suggests that they have a strong sense of personal responsibility regarding sustainability issues (Wilson, 2019). This suggests that engineering students increasingly expect and appreciate coverage of sustainability topics in the curriculum.

In 2016, the Department of Engineering Design and Mathematics at the University of the West of England, Bristol (UWE Bristol) redesigned the curriculum of its entire portfolio of undergraduate engineering programmes to ensure that its graduates would be equipped with the skills they need to address the complex challenges facing the 21st. The redesign process was carried out in alignment with the university's education strategy to equip students with the skills they need to make a positive contribution to society, and to contribute to the development of a sustainable global society and knowledge economy (UWE Bristol, 2013).

Recommendations for creating sustainability literate graduates published by the Higher Education Academy (HEA) and the UK Quality Assurance Agency for Higher Education were also consulted. These recommendations emphasise the needs for graduates to: (1) understand what the concept of environmental stewardship means for their discipline and their professional and personal lives; (2) think about issues of social justice, ethics and wellbeing, and how these relate to ecological and economic factors; and (3) develop a future-facing outlook by learning to think about the consequences of actions, and how systems and societies can be adapted to ensure sustainable futures (QAA & HEA, 2014).

This paper discusses the work to incorporate sustainability education within the undergraduate Mechanical and Automotive Engineering programmes at UWE Bristol. This work includes the mapping exercise carried out in 2016 to identify all the sustainability components in the undergraduate mechanical/automotive engineering curricula at the time, the module-level reforms carried out in 2016-17 in response to the mapping exercise, and finally, the root and branch engineering curriculum reform carried out in 2018 in which sustainability education was designed into the curriculum as a central and integral component. The study therefore offers a phased approach to incorporating sustainability education into undergraduate engineering education characterised by introducing sustainability education into the engineering curriculum through incremental changes to course module elements, and gradually building up to a fully integrated programme-level approach. .

Implementing sustainability education: A review of recent and current approaches

UNESCO defines education for sustainable development (ESD) as the "the acquisition and practice of knowledge, values and skills that ensure balance between the economic, social and environmental aspects of development, and the observance of both individuals and society development and progress in life"(UNESCO, 2008, pp 8). ESD as a dynamic concept intends to empower learners with the necessary skills, attitudes and knowledge to address the global challenges we face, including protecting biodiversity, eliminating poverty, access to safe water and climate change (Shulla et al., 2020; UNESCO, 2019). In 2015, the global community launched 17 Sustainable Development Goals (SDGs) aimed at addressing issues related to poverty, hunger, health, education, energy, work, industry, inequalities, cities, consumption, climate, ocean life, ecosystems, peace, and partnership (UNESCO, 2020). ESD is regarded as both an integral component of SDG 4 on education and a key enabler of all the other SDGs (United Nations, 2018).

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According to UNESCO, the goals of ESD are to “empower learners to take informed decisions and responsible actions for environmental integrity, economic viability and a just society, for present and future generations, while respecting cultural diversity” (UNESCO, 2014, pp 12). This requires that learners be equipped with the competencies that allow them to engage constructively and responsibly with today’s world (UNESCO, 2017). However, competencies cannot be taught but must be developed by the learners themselves during action, and based on experience and reflection (UNESCO, 2017; Kolmos, 2021). Consequently, the UK Quality Assurance Agency for Higher Education and the Higher Education Academy, have advised that for ESD to be effective in HE, staff and students should work together collaboratively to develop the core competencies to be able to deal with sustainability issues in their practice (QAA & HEA, 2014). This therefore suggests that with respect to sustainability education, a student-centred, interdisciplinary, team-teaching designed to expose students to multiple perspectives on sustainability related issues is more effective than traditional teaching-centred, siloed approaches. (Hooey et al., 2017; Pompeii et al., 2019). Furthermore, Filho et al. (2020) and Graham (2018) comment on the importance of curriculum in engineering education to shift its’ attention from just imparting academic technical knowledge and towards a broader, complex problem-solving and interdisciplinary approach. Such approaches would thus empower learners with skills for complex problem identification, and to provide engineering-based solutions to societal and sustainable problems.

Like most education innovations, the introduction of sustainability education within the engineering curriculum is typically initiated by individual academics (early adopters) introducing elements of sustainability content within their own course modules. Typical strategies for introducing sustainability content usually include one or more topics within a course module, incorporating sustainability-related assignments and adding readings on sustainability to course module reading lists (Natkin & Kolbe, 2016). This ad hoc, module-level introduction of sustainability education typically leads to change within single and isolated course modules. Holgaard et al.(2010) refer to this strategy as an add-on strategy. It has the advantage that individual academics, as early adopters, can begin to lead change within their school or department, however, it usually leads to non-systemic change (Kolmos et al., 2016). Other strategies include introducing courses focussed on SD, such as ‘sustainability studies’ (Stough et al., 2018), through interweaving sustainability in the curriculum (Bakthavatchaalam et al., 2017), and creating an action-oriented learning, linking theory with practice and inter disciplinary projects (Aleixo et al. 2020).

A more coordinated strategy to implementing ESD within the curriculum is to do this at programme level. The focus can be on one or more course programmes offered by an academic unit, typically a department or a faculty. This strategy, which Holgaard et al. (2010) have termed the integration strategy, requires mapping and coordination across the various course modules to ensure integration and streamlining of the sustainability content across the entire course programme(s). Filho et al. (2020) and Brandli et al. (2015) comment that the barriers for implementing ESD include a lack of knowledge, appropriate technology, investment, policies and misconceptions of SD being an add-on, soft concept. Furthermore, Kolmos et al. (2016) comment on the importance of leadership and support from management, e.g. faculty deans, heads of department and programme leaders.

Brosens et al. (2021) have highlighted that traditionally universities have tended to review and update their curricula without the involvement of external stakeholders. However, based on their review of successful curriculum change programmes within engineering across the world, they conclude that programme redesign could benefit from evidence-driven, iterative approaches that actively engage stakeholders in the curriculum development process. (Brosens et al., 2021). This is consistent with the view by Graham (2012), that for successful systemic change in engineering education to be successful, it has to be based on a participatory vision of developing a world class education that incorporates input from a range of stakeholders, including students and academics.

Holgaard et al. (2010) use the term “rebuilding strategy” to refer to this institution-wide, collaborative approach to embedding sustainability education. Given the complexities

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associated with collaborative working across and beyond university structures, Hooey et al. (2017) suggest that the introduction of sustainability education should be underpinned by a common institutional sustainability culture that ensures a shared understanding of sustainability amongst all stakeholders.

The 2016 sustainability mapping exercise

The sustainability mapping was carried out using a survey questionnaire framed on topics covered in the Sustainability Literacy Test for Higher Education institutes by the Higher Education Sustainability Initiative (HESI). The sustainability literacy test is an online multiple choice question assessment intended to evaluate, the minimum level of knowledge in economic, social and environmental responsibility (United Nations, 2015). The United Nations assert that the test is applicable to all, higher education institutions all over the world, and it is relevant to all tertiary level students, including those undertaking degree courses at bachelor, masters and PhD level. The questionnaire was sent out to all the module leaders of the 40 modules making up the Mechanical and Automotive Engineering undergraduate degree programmes. The university ethics procedures were followed, and consent was acquired from participants. The response gathered gave an overview of ESD coverage in the curriculum. The curricula were subsequently redesigned based on the outcome of the study.

Outcome of the sustainability mapping exercise

The staff survey allowed for gaps to be identified in the curricula. The outcome of the survey was mapped out against the HESI's Sustainability Literacy framework (see Table 1). The survey revealed that only nine of the 55 surveyed topics were covered across all the 40 modules making up the Mechanical and Automotive Engineering undergraduate degree programmes. Discussions held with module leaders after the survey revealed that explicit reference to sustainability was not always made when teaching those topics. Therefore, students did not necessarily perceive that they were learning about sustainability.

The expectation for Higher Education institutions is not to cover all the topics in all programmes, especially as some topics may be relevant to specific fields more than others. Nonetheless, there were relevant and important topics that were not covered in the two undergraduate programmes. This included such topics as climate, biodiversity, the social sphere of sustainable development and community development and involvement.

As expected, coverage of sustainability topics was not uniform, but occurred on an ad hoc, unplanned basis across the programme in line with the individual interests of the academics in a manner consistent with the description by Natkin and Kolbe (2016). There was no coverage of sustainability topics in the first year of the engineering programme, and only three topics were covered in the second year. The remaining six topics were covered at third year and Masters level. Two sustainability topics of critical importance to modern day professional engineering practice – health and safety at work, and climate change and mitigation – were only covered at Masters level. Students graduating with a BEng, and not proceeding to MEng or MSc would therefore graduate without having covered these two critical topics.

Integrating sustainability into the curriculum

The outcome of the mapping exercise was used to inform the redesign of the curricula and ensure a through-line coverage of sustainability topics, starting from the first year to the final year of the degree programmes. A staged approach was used to integrate ESD in the curriculum.

The first stage, which lasted from 2016 – 2018, consisted in working with existing modules and module leaders, with no radical changes to the overall structure and learning outcomes of the module, in a manner similar to the add-on strategy (Holgaard et al., 2010). The main difference between our approach and the add-on strategy was that, like the integration strategy (Holgaard et al., 2010), our approach was collaborative between interested staff members, and we had a programme-level perspective across all modules being delivered.

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Amongst the modules that introduced ESD in stage one were the Design and Project Management modules at Level 1 and 2. We did this by incorporating the EWB-UK's Engineering for People Design Challenge as the assessment brief for the students. In this brief, students develop engineering solutions to real world problem faced by communities around the world. The social, environmental, and economic aspect of ESD were well integrated within the brief.

The next stage, Stage two, took place with a more integrated programme-level approach, as part of the department's major restructuring of its engineering programmes in 2018. A Project-Based Learning approach was adopted at department level, which saw the introduction of dedicated Project Weeks where students worked on the Engineering for People Design Challenge with an international outlook (at Level 1) and on homelessness project with a local focus on the Bristol community (at Level 2).

Stage three followed with an entirely programme based approach, which we called the Integrated Learning Framework. New modules were introduced, and existing traditional modules were restructured to provide through-line coverage of ESD, throughout all levels of the engineering curricula. These modules are: Engineering Practice 1 and 2 (at Level 1 and 2 of the undergraduate degree programme and 'Engineering for Society' (at Level 3 of the undergraduate degree programme and Masters Level)). They use a Project-Based Learning approach giving students the opportunity to work on real-world problems, touching on a wide range of sustainability and ethical issues. Table 2 shows the ESD coverage in the undergraduate Mechanical and Automotive Engineering programmes following the curriculum redesign.

Table 1: HESI's sustainability topics coverage by module and programme level at UWE (Bristol) Mechanical/Automotive Engineering in 2016

Sustainable Development	Module	Level/Year
Founding principles		
Basic definitions	Design and Electromechanical Systems	2
Pollution	Motorsport Performance, Advanced Powertrain Technologies	3,M
Energy and resource of the planet	Design and Electromechanical Systems, Motorsport Performance, Individual Project, Industrial Applications of Vision and Automation, Advanced Powertrain Technologies	2,3,M
Social Responsibility (ISO 26000)		
Organisational governance		
values, stakeholder engagement, diagnostic & strategy, accountability & reporting	Business Environment	3
Labour practices		
Health and safety at work	Industrial Applications of Vision and Automation	M
Environment		
Prevention of pollution	Motorsport Performance, Individual Project, Advanced Powertrain Technologies	3,M
Sustainable resource use	Design and Electromechanical Systems, Business Environment, Motorsport Performance, Industrial Applications of Vision and Automation, Advanced Powertrain Technologies	2,3,M
Climate change mitigation and adaptation	Advanced Powertrain Technologies	M
Consumer issues		
Sustainable consumption	Individual Project	3

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Table 2: ESD coverage following curriculum redesign of the Mechanical/Automotive Engineering programme at UWE (Bristol), 2021

Sustainable Development	Level (2016)	Level (2021)	Social Responsibility (ISO 26000)	Level (2016)	Level (2021)
Founding principles			*Labour practices*		
1. Basic definitions		**1**	1. Employer and employee relationships		**2,3,M**
2. Governance	2		2. Condition of work and social protection		**3,M**
3. Demography (age pyramid, urbanisation)			3. Social dialogue		**1,3,M**
Environment			4. Health and safety at work	M	**2,3,M**
1. Biodiversity		**1,3,M**	5. Human development and training in the workplace		**2,3,M**
2. Climate		**1,3,M**	*Environment*		
3. Pollution	3,M	**1,3,M**	1. Prevention of pollution	3,M	**1,3,M**
4. Energy and resource of the planet	2,3,M	**1,2,3, M**	2. Sustainable resource use	2,3,M	**1,2,3, M**
Social			3. Climate change mitigation and adaptation	M	**1,M**
1. Fundamental human rights		**1,3,M**	4. Protection of the environment biodiversity and restoration of habitats		**1,3,M**
2. Health and basic human needs		**1,3,M**	*Fair operation practices*		
3. Inequality and poverty		**1,3,M**	1. Anti-corruption		
4. Wellbeing and social progress		**1,3,M**	2. Responsible political involvement		**3,M**
5. Cultural diversity and heritage preservation		**1,3,M**	3. Fair competition		
Economy			4. Promoting social responsibility in the value chain		**1,3,M**
1. Economic growth and development		**1, 3,M**	5. Respect for property rights		
2. Global finance			*Consumer issues*		
3. Green economy		**1,3,M**	1. Fair marketing, factual and unbiased information, and fair contractual practices		**1,3,M**
4. Tax havens and corruption			2. Protecting consumers' health and safety		**1,2,3, M**
5. Underground economy			3. Sustainable consumption	3	**1,3,M**
6. Prosperity indicators			4. Consumer service, support, dispute resolution		
Social Responsibility (ISO 26000)			5 Consumer data protection and privacy		**1,3,M**
Organisational governance			6. Access to essential services		**1,3,M**
1. Values, stakeholder engagement, diagnostic & strategy, accountability & reporting	2,3	**1,2,3, M**	7. Education and awareness		**1,3,M**
Human rights			*Community development and involvement*		
1. Due diligence		**1,3,M**	1. Community involvement		**1,3,M**
3. Avoidance of complicity		**1,3,M**	2. Education and culture		**1,3,M**
4. Resolving grievances			3. Employment creation and skills development		**1,3,M**
5. Discrimination and vulnerable groups		**1,3,M**	4. Technology development and access		**1,3,M**
6. Civil and political rights		**1,3,M**	5. Wealth and income creation		**1,3,M**
7. Economic, social and cultural rights		**1,3,M**	6. Health		**1,3,M**
8. Fundamental rights at work			7. Social investment		**1,3,M**

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The integration of ESD throughout the curriculum was supported at institutional level. As highlighted in UWE Bristol's 2020 and 2030 strategy documents, ESD is at the forefront of the university teaching and operational agenda. A faculty wide Knowledge Exchange for Sustainability Education (KESE) was created to support staff by providing a platform of knowledge sharing. In terms of training and support for academic staff during the Integrated Learning Framework transition, Departmental Staff Away days were used to hold sustainability workshops for staff. In Stage one of the initial phase of the mapping exercise, a lack of common understanding amongst staff on what ESD is was noted, what it should include, and whether it is necessary for student engineers to learn about it. Over the years, alongside the staged approach, there has been more acceptance of ESD as an essential part of the engineering curriculum amongst staff and students. Another challenge and limitation of the approach was the allocation of teaching workload for ESD integration. In the initial phases, a small number of committed academics had to put a lot of time, effort and dedication in to push through with ESD integration. There is now wider support by module leaders and tutors, who all feel capable of delivering some aspects of ESD, which eases the workload.

Outcomes of integrating ESD into the curriculum

Following the staged approach to integrating ESD into the curriculum, a wide range of ESD topics are now covered in the Mechanical and Automotive Engineering undergraduate programmes. ESD topics are now covered coherently across all levels from Year 1 all the way to Year 3 and Masters level. A through-line of core sustainability topics are now systematically covered across compulsory modules right through the degree programmes, thereby ensuring that no student misses any of the core topics. The Mechanical and Automotive Engineering programmes offered by the Department of Engineering Design and Mathematics were assessed and accredited by the Institution of Mechanical Engineering (IMechE) in December 2020. In their academic accreditation visit report following the visit (IMechE, 2020), the Accreditation Panel commended how the Department had embedded ethics and sustainability throughout the programmes so as to offer good coverage of legal, sustainability and societal factors in a manner that was beneficial to all students on the programmes, and how they had aligned this with the UK Specification for Professional Engineers.

Student interest in sustainability has increased over the past five years as evidenced by the steady increase in students taking sustainability topics in final year projects and dissertations. Whilst this increase may be consistent with increasing awareness of sustainability by students world-wide, particularly by engineering students, in recent years, student informal feedback suggests that there is a growing appreciation for the inclusion of ESD in the curriculum. Furthermore, at the end of the five-year curriculum redesign process, students were surveyed through module feedback surveys, and it was found that the project-based learning approach was viewed very positively. Students commented that they enjoyed working on 'real-world projects' where they can make a difference locally or globally.

Our novel, staged integration of ESD into the engineering curriculum has also caught the interest of other universities, with several making enquiries, and some visiting us to learn how we went about the process. Disseminating our ESD practice has become an integral part of our remit, and colleagues within the department have presented invited talks on ESD integration at several universities, including the Universities of Bath and Swansea, and the French Ingenium network.

However, findings from this study indicate that students were more inclined towards sustainability topics that were relevant to their subject discipline. For instance, Aerospace Engineering students tended to prefer topics relevant to Aerospace Engineering. A survey of USA engineering students by Wilson (2019) also indicates a link between students' study discipline and their predilection for certain sustainability topics. The main recommendation from this study is that for sustainability education to be effective, the content coverage should be aligned, or better still, integrated, with the topics that form part of the students' disciplinary studies.

Concluding Remarks and Future Work

Whilst there is a multiplicity of approaches to integrating sustainability in higher education curricula, it is apparent that most higher education institutions are yet to fully integrate ESD into their curricula. For instance, a recent study of UK higher education institutions suggests that only a handful of institutions have implemented ESD into their curricula in a manner that ensures that ESD is an integral and systemic part of their curriculum (Fiselier et al., 2018).

At this time of Climate and Ecological Emergency, it is therefore pressing that engineering curricula throughout the world consider how best engineering can contribute to adaptation, resilience, and mitigation of environmental issues. This study, therefore, presents a phased strategic approach to integrating education for sustainable development into existing engineering curricula. We hope that other higher education engineering institutions will follow suit to produce engineering professionals capable of operating within a fast changing global environmental crisis. Documented best practice recommendations about this phased and programmatic approach to ESD is therefore something that other engineering educators can learn from, and in that regard, is an important contribution to the sustainability education literature.

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A thematic analysis of the intersection of engineering judgment and student writing practices

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ABSTRACT

CONTEXT
Engineering judgment is one of the defining characteristics of engineering practice and identity. Despite the prominence of engineering judgment in shaping engineering education and practice, the definition of engineering judgment as embodied communication processes and practice is under explored. Most studies of engineering judgment view judgment as something an individual does, however, engineering judgment also emerges from communication and work practices among team members. Moreover, engineering judgments are also communicated when work products, including a range of written documents, are disseminated to target audiences.

PURPOSE OR GOAL
The objective of this study is to explore the ways that undergraduate engineering students' engineering judgments are embodied and communicated in and through writing practice and processes. Specifically, our work addresses the question, "What is the interplay between engineering judgment and communication practices involved in completing a capstone systems engineering project?"

APPROACH OR METHODOLOGY/METHODS
This study employs the academic literacy and discourse identity frameworks. Semi-structured interviews were collected with 5 systems engineering undergraduate students at a US mid-Atlantic private engineering school. The interview protocol involved two 60-90 minute interviews with each participant: one after initial scoping of the project, and one after the project was completed. This paper analyzes data obtained from the first of the two interviews. The data will be analyzed using thematic analysis.

ACTUAL OR ANTICIPATED OUTCOMES
This research yields four themes that may help engineering educators understand how students' engineering judgments emerge from praxis and writing processes: framing and positioning, audience awareness, analysis, and synthesis Engineering judgments are both conveyed in writing through documents produced and also emerge from writing processes represented by these themes. These judgments are forged by complex interplay between students' engagement with their engineering knowledge base, the technical nature of the engineering work, and the communication requirements perceived by the students as they are confronted with various rhetorical scenarios and stakeholders.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
The findings of this project will inform pedagogical interventions aimed at developing students' engineering judgment and professional identity formation.

KEYWORDS
Engineering judgment, academic literacy, discourse identity

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1 Introduction

This paper explores the ways students convey engineering judgments in written communication processes and products. Engineering judgment is foundational to the practice of engineering where judgment is required to identify a societal or technical need that can be addressed through engineered artifice. Judgment is used to formulate and encode engineering problems, and to determine technical and economic feasibility. It is also involves learning from experience. This understanding is critical to effective engineering pedagogy due to engineering judgment's central role in engineering practice.

Concurrently, engineering judgment is not clearly defined. Some researchers and practitioners define engineering judgment as activity undertaken by individuals when faced with making difficult tradeoffs (Pantazidou & Nair, 1999; Shaw et al., 2006). Others define engineering judgment as the practice of making decisions under uncertainty, ambiguity, or incomplete information (Douglas et al., 2012; Wait et al., 2013). Still others define engineering judgment as embodied communication processes engaged by teams of engineers to perform engineering work (Weedon, 2019). This paper builds upon these views through exploration of the following research questions:

1. How do students construct engineering judgments through writing processes?
2. How does the construction of engineering judgment shape writing processes or products?

These questions distinguish our efforts from those reported in prior research. First, our investigation frames judgment that occurs by an individual and among individuals. Second, our approach implies that engineering judgment is both situated in and constituted by the communication processes used to construct and convey judgments. To explore our research questions, we interviewed five 4th year undergraduate systems engineering students at a middle point of their year-long senior project. In the US, where this research was conducted, the senior project is a common culminating experience intended to replicate the expectations and tradeoffs students might face in professional practice. The next section of this article describes the theoretical frameworks we have selected for framing this work. The following section describes our use of the instrumental case study method and thematic analysis method for this work. We then present our results and discuss some of the key findings.

2 Theoretical Framework

Our research employs the academic literacies framework of Lea and Street (2006) as well as closely related discourse identity framework of Berkenkotter et al. (1988). Lea and Street (2006) observe that academic literacies are "concerned with meaning making, identity, power, and authority," and that this meaning making occurs within institutions which value particular forms of knowledge. This perspective guides our investigation as the senior projects are designed to initiate students into professional practices of knowledge production within sub-fields of engineering. Pembridge and Paretti (2019) highlight this focus on the workplace orientation of senior capstone projects, indicating the centrality of these project experiences to students' transition to work. One aspect of this transition is the shift from students' academic experiences with meaning making in their classwork to practice-based meaning making situated in design, confronting them with new perspectives on authority. While most classrooms involve the professor as the clear authority, the senior project adds additional layers of complexity depending on whether students' projects are completed primarily for intimately involved external stakeholders and/or are responding primarily to the demands and criteria placed by the supervising professors. The students' perception of the "institutional nature of what counts as knowledge" (Lea and Street 2006) can shift considerably while completing the senior project, as the institutional lines blur based on the number and types of stakeholders involved in their work.

The academic literacies model also attends to the contexts in which student writing is applied, viewing literacy practices as not residing entirely in discipline and subject-based

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communities (Lea and Street 2006). The participants described multi-disciplinary contexts that required students to carefully select literacy practices in various stages of their projects to be responsive to their specific audiences and expectations. Thus, the academic literacies framework helps understand how participants used judgment to engage in a range of literacies and communication practices in their work.

3 Methods

3.1 Data

The data analyzed in this paper are drawn from five semi-structured interview with undergraduate systems engineering students during the first half of their final semester. The students studied at a U.S. mid-Atlantic private institution. These interviews were collected as part of a larger study whose goals and objectives are described in Francis et al. (2020). Relevant methodological details are as follows. At each interview, the participant was asked to bring an example of a past writing sample they believed represented good engineering writing as well as writing samples related to their senior research project that could show how they have made engineering judgment choices in writing. The questions used during the semi-structured interviews were designed to investigate students' responses to the broad ideas: "What is Engineering and Writing?" and "How are Engineering Judgments and Process Expressed in Writing?" The questions were intended to understand students' backgrounds with and dispositions towards writing, then build on this understanding to explore how students understand the role of writing in engineering practice.

Each interview was between 45 and 75 recorded minutes in length on zoom and was manually transcribed prior to coding in Atlas.ti 9 qualitative analysis software. While the participant and interviewer were able to share screens and audio connection, no video was coded during analysis. During parts of the interview, participants used the screen sharing feature to show the interviewer specific choices made in their writing, or to explain specific aspects of their work during the interview. After the manual transcription was obtained, all three members of the writing team conducted first-cycle coding of one interview transcript to clarify coding objectives and assess consistency of the segments coded as judgments. Two additional transcripts were coded by two members of the writing team to inform further development of the final codes. The interviewer coded all five interview transcripts using thematic coding methods.

3.2 Thematic Analysis

We orient this study as an instrumental case study following Stake (2000). The goal is to identify themes that could lead to avenues of research yielding potential generalizations about the intersection of judgment and writing practices. Descriptive coding was used to develop themes. Descriptive coding summarizes in a word or short phrase the basic topic of a passage of qualitative data (Saldana, 2016). A preliminary codebook of approximately 23 codes reflecting themes or processes related to writing practice and engineering judgment was created based on prior literature and a review of the audio recording and interviewer field notes. Each transcribed interview was then coded by the interviewer using descriptive codes and in vivo coding. Additional descriptive codes were generated through a combination of interviewer judgment, in vivo coding, and cross-comparison with the codes obtained by the other members of the writing team. the interview transcript was coded a second time employing the expanded codebook. Ultimately, 65 descriptive/in vivo codes were obtained. These codes were then evaluated to recognize potential patterns and organized into four high-level themes.

4 Thematic Analysis of Judgment Processes in Student Writing

In this section, we present the results of our thematic analysis. Four major themes have been identified after analysis of the interview transcripts: Framing and Positioning, Audience Awareness, Analysis, and Synthesis.

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4.1 Framing and Positioning

The first major theme, framing and positioning, is derived from several sub-codes used in analyzing the data, including 'assessing relevance or societal need' and 'framing and problem formulation'. Framing and positioning refers to actions related to framing or conceptually formulating the problem to be analyzed. The student makes judgments about what their reader needs to know in order to effectively communicate with them. Once the student decides what the reader needs to know, the student formulates and conceptualizes the scope and definition of the problem. This step is framed and potentially constrained by the student's understanding of their audience's needs. Therefore, framing and positioning involves an assessment of their conceptual problem's relevance or societal need. Students make judgments about the importance or motivation for a problem they are constructing, analyzing, or interpreting. The goal is to make judgments related to positioning the work that is to be completed in reference to the student(s) stakeholders' needs or expectations. The term 'stakeholders' should be viewed broadly: these could be clients directly involved in the construction and evaluation of their work or the students' conceptual representation of their external audience. Assessing relevance or societal need involves students deeply understanding their stakeholders' concerns while wrestling with how their work is responsive to these concerns.

Assessing relevance is closely related to other sub-themes employed in analyzing the interviews, including: 'thesis formulation', 'audience awareness', and 'framing and problem formulation'. From the students' point of view, these themes may overlap. Nonetheless, there are subtle distinctions. For example, the distinction between framing and problem formulation and assessing relevance or societal need is the internal vs. external orientation. With framing and problem formulation, attention shifts from explicit focus on stakeholder concerns to an internal (to the student or group) focus on deciding what the problem is. Assessing relevance could happen before problem formulation, as students survey the range of concerns present in the audiences they hope to engage with. Consider the following excerpt:

> *… one thing that I had noticed…was that the analysis was good for a lot of the papers that I had read, but they - to me it seemed like they weren't fully acknowledging that... A lot of people came to the conclusion that… Airbnb is raising rental prices and they show that by saying… look at… these neighborhoods and they're all… growing superfast in terms of rental prices and look how many Airbnb's are here. [T]hat's… where I thought they stopped. And my problem with that was there's…reasons why you might see that correlation, but I don't know if the causation exists...You could say Airbnb's tend to pop up where tourists want to say. [T]ourists probably want to stay in…nicer areas and those…areas probably have their rents growing fast...*

First, notice the student's emphasis on the audience. This student's full attention is on the conclusions of the authors whom they hope to engage. Second, the sentence beginning with *"[T]hat's…where I thought they stopped"* indicates that while this student is clearly questioning the conclusions made, this student is also crafting an opening for their own contribution. This interaction indicates a transition from an external focus on stakeholder concerns to an internal focus on defining or re-defining the problem. The next three sentences provide a prologue to this student's problem formulation by proposing potential alternative reasons to explain the observations reported by the members of the student's audience. Nonetheless, this segment stops just short of problem formulation because the student does not explicitly articulate their own thesis or conceptual problem for analysis.

4.2 Audience Awareness

The second theme, audience awareness, addresses how the students conceptualize their audience and how the students conceptualize their position within the intersecting communities the audience represents. Notably, audience awareness guides the students' participation in the discourse of their community of practice. This involves their ability to understand the types of knowledge and knowledge representations accepted by members of the community, appropriate methods of knowledge production, and their ability to convey the knowledge and methods of knowledge production in forms that will be readily recognized by

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the community of practice and its peripheral stakeholders. These peripheral stakeholders may not be members of the engineering community of practice, but their understanding and acceptance of the work products is a critical concern directing engineering work.

In sum, the interview transcripts include reflective attention to the students' understanding of an audiences' background knowledge and needs. Audience awareness clearly influences the aforementioned 'assessing relevance or societal need' and 'framing and problem formulation' sub-themes. The distinction here is that while those codes refer to the assessment and formulation of the content of what is to be communicated, audience awareness involves a focus on audience expectations around not only the content but also on how the information can be effectively communicated. Thus, the transcripts describe how the students made judgments concerning word choice, oral vs. written communication, or even document design based on what they thought their audience considered most appropriate or easiest to understand.

Another dimension of audience awareness involves potential authority claims around the students' work products. The students each expressed concern about their ability to engage with their audiences authoritatively based on their work products, especially how to best communicate the results of their work products so that they would be well received by the authority. One strategy described by the students is the use of prior work as a model Here is an example:

> *… these studies that were run were run pretty close to the proposal being due, and were..a last minute thing. Parts of it were – I looked at what we had, and read it, and then I looked at what other teams had done before. … there was also another writing sample that had been sent to me by our adviser from a separate competition but similar type of analysis. And I read those, and realized.. here's ten things that we need to address, and seven… we didn't. We need to go run these studies to figure that out. …I pushed it off to them, and they went and thought about it, and then brought it back.*

This student is describing an experience with an extra-curricular aeronautics club where they submitted a design to a flight competition. In the passage, the student is looking at examples from other student teams who had previously submitted designs to the competition. The student observes and reads these prior reports to familiarize themselves and their team with the rhetorical forms used for this situation. Since each of these submissions were judged by the same criteria, the forms observed in these reports presumably possess the rhetorical moves required to authoritatively convey their proposed design to the judges because the judges would likely be expecting similar form and style from the student's report. We also observe the student using their familiarity with these documents and the rhetorical strategies used to communicate authoritatively to their team about what work needed to be completed before their design could be completed.

In several of the interviews, the students described a struggle with a crisis of authority, e.g., (Berkenkotter, 1984), where their work products needed to be responsive to multiple, potentially conflicting audience members. One way this crisis could arise is if two or more important audience stakeholders expressed demands that the students found difficult to reconcile. For example, this occurred if the supervising faculty imposed a demand on a student group that obfuscated an objective expressed by their group's client. Another possible source of the crisis of authority is ambiguity. Some participants reported concerns that their clients could be unresponsive or unclear about project objectives. This could lead to frequent changes in project scope as student groups struggled to assimilate client feedback while simultaneously satisfying the supervising faculty's requirements. A third way this crisis could arise is when students question their expertise relative to practicing engineers or academic experts.

4.3 Analysis

The analysis theme reflects students' efforts at formulating and conducting analysis. One sub-theme is 'assessing available resources and capabilities' dealing with students' efforts to

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assess their own and their team's available resources, capabilities, and interests. Resources include tools such as computers or computing power, data availability, and access to suitable experts or professorial advice. Capabilities refer to the students' technical capacities. Students' interests provide intrinsic motivation to the work; thus, the interview data include student assessments of the types of problems available to their groups within the articulated interest areas of the group members. Other relevant sub-themes include 'constructing and conducting analysis' and 'making assumptions' or 'questioning assumptions'. These codes are derived from students' descriptions of tasks related to constructing their analyses using appropriate modeling techniques while making assumptions and tradeoffs within model form or parameterization. The students also describe their teams' internal discussions and strategies for organizing teamwork.

Constructing and conducting analysis refers to computational tasks immediately required in the course of producing the analyses subject to the project goals and objectives. Although one might consider this central to engineering work, it is worth noting that the students' interviews do not foreground the arcane technical details of their projects. Rather, where methods and techniques are mentioned, they are discussed at a relatively high level as if stating the technique alone is sufficient shorthand for an informed individual (e.g., a systems engineering professor from the same department). Instead, the students carefully describe representative scenarios or models, their assumptions, and tradeoffs required to keep the work manageable. Student descriptions of their analytical processes are quite lengthy in the interview transcripts. This relatively compact excerpt describes one student's approach to making assumptions and tradeoffs prior to computation:

> *… it went from I know that I want to stop people from trespassing in general on the metro system. … we looked up [how]…people in..the literature talk about the topic. And then they said [well there are different types]. You could stop it by a physical barrier, or you could stop it by having more police people around that area, or…there were other ways. Like you could put up signs and tell them not to trespass….So we had to decide, first of all, what kind of barrier we're looking at, or deterrent, [from trespassing]….[W]e found out there were different types of trespassers. So that makes it not equally – like, for example, signs would maybe deter common citizens from accidentally going on it, so accidents would be prevented by having signs.*

Note that this student's thesis has already been formulated. We see this in the phrase "I know that I want to stop people from trespassing…" Thesis formulation, described below, is distinct from constructing and conducting analysis because analytical choices depend on the type of questions or objectives that are chosen. Next, we see this student iterating between engaging the discourse (e.g., "how people in general in the literature talk about the topic") and making assumptions (e.g., "…we had to decide, first of all, what kind of barrier we're looking at…"). The judgments about the key assumptions and tradeoffs that must be made interact with the student's participation in the discourse. Indeed, the computational or technical aspects of engineering work that are commonly emphasized are situated within accepted discursive practices. More importantly, students generally use models present in the literature as points of departure for their own work. Thus, their modeling judgments are contingent on the types of examples they have seen modeled for the scenarios they encounter. Finally, the student's description of their assumptions indicates early stages of a mental model of the phenomenon the student's group is studying (e.g., "…signs would maybe deter common citizens from accidentally going on it, so accidents would be prevented by having signs.") This step is similar to Weedon's (2019) description of students' embodied cognition when seeking to make sense of measurements during group work. In the example, the student envisions the scenario that needs to be modeled while also creating a mental representation that can be modified to represent different types of trespassers or barriers. While the student is familiar with the barriers or signage from their experience riding trains, the student must struggle to convert this embodied experience to the mathematical and conceptual representations required for analysis. Thus, the embodied representations created by the student are prerequisite to the student's judgment of which scenario models are most critical to their ultimate communication task.

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4.4 Synthesis

Synthesis is a crucial judgment theme in the transcripts and is involved before, during, and after analysis. Before the students enter the analysis stage, synthesis involves the sub-theme "thesis formulation". Thesis formulation highlights the choices students make when selecting the main ideas to focus on and communicate through their work. This theme is related to the "discourse and authority", "audience awareness", and "framing and problem formulation" themes referred to in earlier sections because students must engage with the corpus of the discourse (i.e., knowledge base) and become familiar with the frames and ideas used by their audience. Once the students are familiar with these frames and ideas, they can create a niche that can be occupied by their thesis. For example, students reflect this point in their interviews by using phrases such as "one of the main tenets" and "bring out the point" indicating that they selectively emphasize or de-emphasize some ideas to the exclusion of others. In addition, thesis formulation is fundamentally creative. While in many other themes discussed in this paper the students refer to, and claim authority from, the ideas of others, thesis formulation proceeds from the students' own ideas. At the same time, it is not "problem formulation" because the students are not yet constructing problems for analysis. Thesis formulation precedes problem formulation because the problems selected depend on the thesis. Another way of thinking about this is to keep in mind that a thesis can be approached using multiple problem frames, implying multiple possible modeling or computational techniques that might be responsive to those frames. Therefore, thesis formulation—identification of a key question or idea that will be the subject of subsequent analysis and inform action related to a problem frame—is distinct from audience awareness, framing and positioning, and analysis. This excerpt that illustrates thesis formulation:

> *… [O]nce we realized that…if you introduced more electric vehicles it doesn't necessarily mean that your planet is getting greener as you're using… fossil fuels to make those cars. We were thinking what if we… created a policy to decommission these coal plants and instead put that money into renewable energy sources to then use.*

First, take note of the fact that this student prioritizes their team's own realizations (e.g., "…once we realized that…"). In thesis formulation, the students' own ideas are foregrounded. Second, notice that this student describes their niche by foregrounding a perceived gap or shortcoming in the knowledge base (e.g., "… if you introduced more electric vehicles it doesn't necessarily mean that your planet is getting greener…"). Finally, the students' focal idea emerges (i.e., "We were thinking what if we…created a policy to decommission these coal plants and instead put that money into renewable energy sources to then use?")

After the analysis stage, synthesis involves interpretation. This step takes place after some computational or technical work has been completed and the students are considering how to understand and advocate for their work. Once a student has results, before they can make additional judgments about how best to communicate with their audience, they must determine what their results say and how best to use those results in persuasive communication tasks (Winsor, 1996). While students often consider quantitative results to "speak for themselves," Winsor demonstrates how students must determine how best to use their results in their own rhetorical tasks. This excerpt demonstrates this dynamic:

> *… [O]ur research shows that until you get the grid, green electric vehicles are actually worse. I think our results show – we did the heavy electric vehicle push and then we said, OK, let's delay electric vehicles for so many years, increase grid renewability and then it showed a big decrease in greenhouse gas emissions. And you're thinking, OK, well, it's not really worth it until we get our grid clean, and so hashing out that.*

This student must determine what their work's most salient features are. They focus on showing "…that until you get the grid green electric vehicles are actually worse." Next, this student describes the most important reasons why this is the case and what can be done to change their findings (e.g., "…increase grid renewability and then it showed a big decrease in greenhouse gas emissions."). Of course, this judgment about selecting which causal factors should be emphasized takes place in the context of audience awareness. It is possible the student's audience awareness conditions their interpretive judgments, potentially leading to a re-evaluation of the work performed, the audience addressed, their understanding of the corpus, or the original formulation of the problem. Consequently, it is important to note that the interpretation and thesis formulation stages are iterative. A good way of thinking about this is viewing them as mutually interacting together in cycles as students and their teams create a thesis based on their understanding of the knowledge base. They then formulate problems and conduct analysis, interpret their results and potentially revisit their original thesis, problem formulation, analysis techniques, or a combination of these as a result of their judgment about what their work products say. Together, thesis formulation and interpretation are synthesis, because this process describes the cyclical and iterative processes through which knowledge and their appropriate representations are created.

5 Discussion and Conclusions

Our results support the idea reflected in Cristancho's (2017) investigations on biomedical decision-making that judgment emerges from the interaction of complex components of a decision context. Judgment is not an isolated step in 'problem solving' but emerges as the expert's conceptualization and understanding of the problem evolves. In the interviews, student descriptions of the formulation of their projects indicates that judgments emerge at different stages in their writing processes as their understanding of both the discourses and their audiences evolves. The four themes described—framing and positioning, audience awareness, analysis, and synthesis—interact and intersect as each theme supports the emergence of judgment.

Our observations are a useful point of departure for investigating the ways students make writing decisions as they interact with both the knowledge base and the set of interpretive practices engineers draw on when making decisions. Our results support the idea that writing practices can help to support how engineering students learn to apply and interpret that knowledge in specific contexts. For example, our observations of students using 'embodied' cognition to construct and conduct analysis echoes Gainsburg's (2015) observations that engineering judgment ties deep domain and mathematical knowledge about physical phenomena to physical interpretations. Student writing practices may help to deepen these connections by strengthening students' understanding of the phenomena they are engaging as they seek to convey their understanding persuasively to their audiences.

Finally, our research suggests that in engineering education, investigators and instructors seeking to strengthen students' engineering judgment capacities could use intentional design of writing assignments to help develop these reasoning capabilities. For example, Swenson et al.'s (2019) use of open-ended mathematical modeling problems to develop the ability to determine the reasonableness of the analysis or design could be augmented with carefully designed writing assignments that foreground the themes of framing and positioning, audience awareness, and synthesis alongside the analysis. Moreover, our work extends Claris and Riley's (2012) work where reflective and metacognitive practices aid in developing engineering judgment. At the reflective and meta-cognitive levels, students use multiple observations and experientially informed reasoning to make connections and achieve knowledge transfer across conceptual areas. Our work shows that students writing projects engage them in making these connections across concepts, courses, and sub-disciplines to foster this quasi-rational combination of analysis and intuition.

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Role of Course and Individual Characteristics in the Course-level Persistence Intentions of Online Undergraduate Engineering Students: A Path Analysis

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ABSTRACT

Online learning is increasing in both enrollment and importance within engineering education. Online courses also continue to confront comparatively higher course dropout levels than face-to-face courses. This research paper thus aims to better understand the factors that contribute to students' choices to remain in or drop out of their online undergraduate engineering courses. Path analysis was used to examine the impact of course perceptions and individual characteristics on students' course-level persistence intentions. Specifically, whether students' course perceptions influenced their persistence intentions directly or indirectly, through their expectancies of course success, was tested.

Data for this study were collected from three ABET-accredited online undergraduate engineering programs at a large public university in the Southwestern United States: electrical engineering, engineering management, and software engineering. A total of 138 students participated in the study during the fall 2019 (n=85) and spring 2020 (n=53) semesters. Participants responded to surveys twice weekly during their 7.5-week online course. The survey asked students about their course perceptions related to instructor practices, peer support, and course difficulty level, their expectancies in completing the course, and their course persistence intentions. This work is part of a larger National Science Foundation-funded research project dedicated to studying online student course-level persistence based on both students' self-report data and course learning management system (LMS) activity.

The survey sample was consistent with reports indicating that online learners tend to be more diverse than face-to-face learners. Findings from the path analysis revealed that students' perceptions of course LMS fit, perceived course difficulty, and expectancies of course success positively and significantly predicted persistence intentions, making them the most important influences. Expectancies of course success had a direct effect on persistence intentions. The findings underscore needs to elucidate further the mechanisms through which expectancies of success influence persistence.

KEYWORDS

Online learning, course perceptions, persistence

Introduction

Online education offers numerous advantages such as accessibility, flexibility, and scalability (Rovai, and Downey, 2010). For these reasons, it continues to gain widespread recognition and acceptance as evident from the rising number of student enrollments over the last decade (Seaman, Allen, and Seaman, 2018). Yet, despite the advantages online education offers, it has been known for its higher dropout rates compared to in-person instruction (Frydenberg, 2007; Heyman, 2010). While engineering education has been slower in comprehensively adopting the online format of education relative to other fields, the number of online engineering courses and degree programs has been growing (ABET, Inc., 2021), and research on online engineering education is specifically lacking. Therefore, student persistence in online engineering education remains an issue that needs to be addressed.

The work presented in this study is part of a larger National Science Foundation (NSF) funded research study aimed at building a theoretical model for student persistence in online undergraduate engineering courses (Brunhaver et al., 2019). The Model for Online Course-Level Persistence in Engineering (MOCPE) framework used in this project is shown in Figure 1, and it includes both course and individual characteristics (Lee et al., 2020). This study investigates a subset of the model to better understand the individual and course characteristics that contribute to students' choices to remain in or drop out of their online undergraduate engineering courses. Specifically, we use path analysis to examine how students' course perceptions and expectancies of course success impact their course-level persistence intentions. We also test whether students' course perceptions related to their instructor, peers, and learning management system (LMS) influence their persistence intentions directly or indirectly, through expectancies of course success.

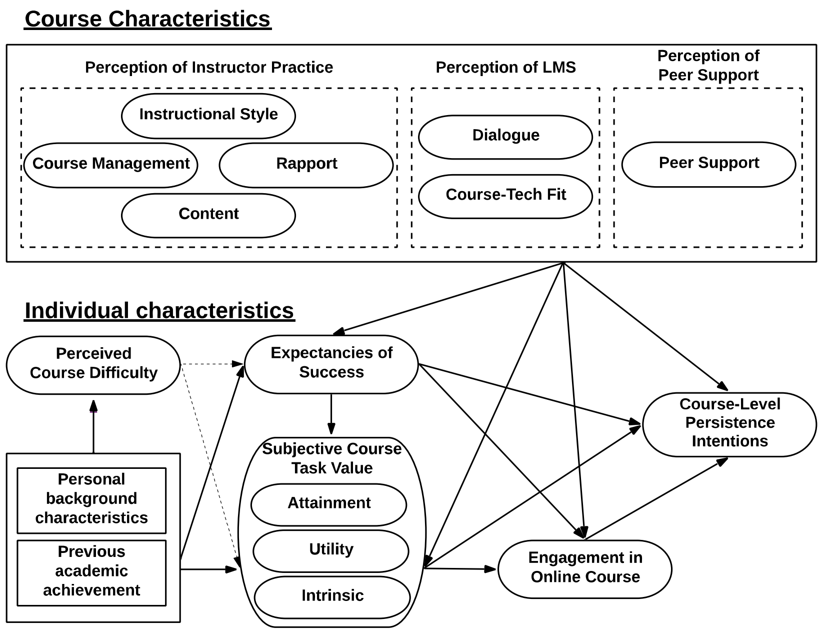

Figure 1: Model for Online Course-Level Persistence in Engineering (MOCPE) (Lee et al., 2020)

Course and Individual Characteristics in Online Courses

Due to their remote format, online courses have shown to increase boredom, isolation, and frustration among students (Young, 2006). The interpersonal interactions that take place between student-to-student and student-to-instructor in online courses can significantly mitigate these effects and enhance the quality of students' experience (Moore, 1993; York and Richardson, 2012). Interpersonal interactions help connect students to their teachers and classmates, enhancing numerous positive student outcomes (Luo, Zhang, and Qi, 2017; Muir, Douglas, and Trimble, 2020). For example, in one study, instructor online presence and connection with the instructor significantly improved student learning (Martin, Wang, and Sadaf, 2018). In another study, instructor presence and behavior in online courses was reported to influence student engagement (Muir et al., 2019).

Like instructor support, peer support has shown to benefit online students. Peer interactions in online courses are beneficial in exchanging knowledge and collaborating on projects, activities which in turn help build connections with other students and enhance sense of belonging (Luo, Zhang, and Qi, 2017; Muir, Douglas, and Trimble, 2020). Both instructor and peer support have also been linked to online student persistence decisions. Hart (2012) confirmed peer support as a top influencer on students' decisions to complete or withdraw from their online courses, while the absence of peer interactions negatively impacted students' persistence decisions in Robertson (2020). Notably, learner-to-learner and learner-to-instructor interactions were used in another study to identify students at risk of dropping in online courses; researchers identified the quality of online interactions with others to be a significantly better indicator than amount of interaction in student success and persistence (Shelton, Hung, and Lowenthal, 2017).

Researchers have also used students' individual characteristics to study their persistence decisions in online courses. In their review study of online course droppers, Lee and Choi (2011) reported that students with higher levels of self-motivation, internal locus of control, confidence in computer skills, and course self-efficacy were more likely to persist in and complete the courses. In another study, Yang et al. (2017) investigated the persistence factors of fully online students and identified mastery of specific skills and perceived utility of learning among the top two influences. Willging and Johnson (2009) reported four reasons why students leave online programs: personal reasons (financial difficulties, time management, family problems), job-related reasons (lack of employer support, difficulty in managing work and student responsibilities, changing job responsibilities), program-related reasons (difficult program, too many assignments, lack of interactions with students and instructor), and technology-related reasons (de-personalized learning environment, lack of support from the staff). Other work has found prior academic achievement and continuous academic enrollment to be helpful (Salvo et al., 2019).

Perceptions of the online course learning management system, course difficulty, and expectancies of course success have been a critical aspect in influencing students' persistence decision in online courses. For example, Bunn (2004) in a study on student persistence in distance education reported access to resources and coursework issues as barriers to distance learning. Difficulty in accessing course related materials was cited as reasons for students to drop out of online courses in several other studies (Hart, 2012; St Rose and Moore, 2019). Students are likely to not perform well or discontinue a course if they find the course difficult. Roberston (2020) reported that challenges and frustrations related to the discussion board in online courses as one of the factors influencing student's decision to drop out. Confidence in one's abilities of performing the course related tasks is likely to help them persist and successfully complete the course. Lee and Choi (2011) in a review study on online course dropouts argued that students with internal locus of control, higher levels of self-efficacy, satisfaction with courses, and self-motivation were more likely to complete the course.

In this paper we focus on the subset of the MOCPE model i.e., we examine the relationships between course perceptions, expectancies of course success, and course-level persistence intentions. Expectancies of course success among other variables influences a student's engagement and motivation to persist (Wigfield and Eccles, 2000), hence, expectancies of course success is hypothesized to mediate the relationship between course perceptions and course-level persistence intentions.

Methods

Participants

Participants for this study were enrolled in one of three ABET-accredited online undergraduate engineering programs (electrical engineering, engineering management, software engineering) at a large, public university in the Southwestern United States. A total of 138 participants were recruited (85 during fall 2019 and 53 during early spring 2020 before the pandemic). Participants were 23% women, 82% transfer students, 33% first-generation college students, and 28% U.S. military veterans. Their race/ethnicities included White (73%), Asian (3%), Hispanic/LatinX (7%), Black/African American (3%), American Indian or Alaska Native (1%), multiple races/ethnicities (12%), and Other (1%). Their ages ranged between 18 and 59 years old (M=31.2 years, SD=7.1 years). Most participants were employed (84%) and married or in a committed relationship (67%). About a third (36%) reported having dependent children. From the participants' demographic information, it is evident that the online learners tend to be diverse (Safford & Stinton, 2016).

Procedure

Invited students were eligible to participate if they were enrolled in at least one online course during the study. Each participant was surveyed twice weekly during their 7.5-week course using their preferred mode of communication (email and/or SMS message), as indicated in an initial screening survey. Participants were given a 48-hour window time to respond to each survey and a reminder to take each survey within 24 hours of survey administration. Participants received a $5 Amazon gift card for completing at least one of two weekly surveys they received and $15 for completing both. We used the survey data specific to week 4 (i.e., the midpoint of the course duration) as the data for the current study.

Survey Instrument

The survey instrument measures students' individual characteristics, course perceptions, and course-level persistence intentions (refer to Figure 1). The individual characteristic variables on the survey include expectancies of course success and subjective course task values (i.e., students' intrinsic, attainment, and utility-related motivations for taking the course). The course perception measures on the survey include perceptions of instructor practices, perceptions of peer support, perceptions of course LMS (LMS dialog and LMS fit), and perceptions of course difficulty. All scales were measured on a five-point Likert scale ranging from 1=strongly disagree to 5=strongly agree. Table 1 shows the number of items, example items, and Cronbach's alpha values for each scale used in the study. The score for each scale was calculated by averaging the set of items scores associated with the scale. No missing data was found in the survey responses related to the scales. For more information about this survey instrument, its associated scales, and items in each scale, the readers are directed to Lee et al. (2020).

Table 1. Overview of the scales of the instrument (Lee et al., 2020)

Scale (# of Items)	Definition	Example Items	Cronbach's α
Perception of instructor support (8)	Students' perceptions of the instructor's classroom practice and behavior in the online course environment	• The instructor incorporates a variety of different approaches to learning. • The instructor explains concepts in a way that makes them easy to understand.	0.95
Perception of peer support (6)	Students' perceptions of peer connectedness and support in the online course environment	• I have access to peer support in this course. • I can join study groups with other students in the course if I want to.	0.90
Perception of course LMS fit (4)	Students' perceptions about the fit between course and online learning platform	• I am satisfied with the format of the material provided. • I am satisfied with the technology used in this course.	0.87
Perception of course LMS dialog (4)	Students' perceptions about the opportunity for dialog with others in the online learning platform	• I feel comfortable using the course Canvas site to converse with others. • I feel comfortable using the course Canvas site to ask questions to others.	0.92

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Perceived course difficulty (5)	Students' perceived level of difficulty to complete the required tasks in their online course	• I find the tasks required in this course to be hard. • I find that this course is difficult.	0.94
Expectancies of course success (5)	The extent to which students feel confident in their ability to complete their online course	• I can meet the goals set out for me in this course. • I can satisfy the objectives for this course.	0.93
Course-level persistence Intentions (5)	The extent to which students intend to complete their online course	• I intend to complete this course. • I am fully committed to completing this course	0.88

Path Analysis

Path analysis was used to identify the individual and course characteristics that most influence students' persistence decisions in online undergraduate engineering courses. We also tested whether students' course perceptions influenced their persistence intentions directly or indirectly, through expectancies of course success. The path diagram for the model under study is described in Figure 2. In the model, we examine both the direct and indirect effects of perceptions of instructor support, perceptions of LMS dialog, perceptions of LMS fit, perceptions of peer support, and perceptions of course difficulty on students' course-level persistence intentions. To assess how well a model fits the data a chi-square (χ^2) estimate is used, a relatively low chi-square value (closer to zero) indicates a better model fit (Kline, 2005). The other indices used to assess the model fitness include comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root means square residual (SRMR). The values of these indices that indicate the level of acceptableness are CFI ≥ 0.90 (good) and CFI ≥ 0.95 (excellent), RMSEA ≤ 0.10 (good) and RMSEA ≤ 0.05 (excellent), and SRMR ≤ 0.08 (Sun, 2005). Table 2 presents the means, standard deviations, and correlations among all the variables considered in this study.

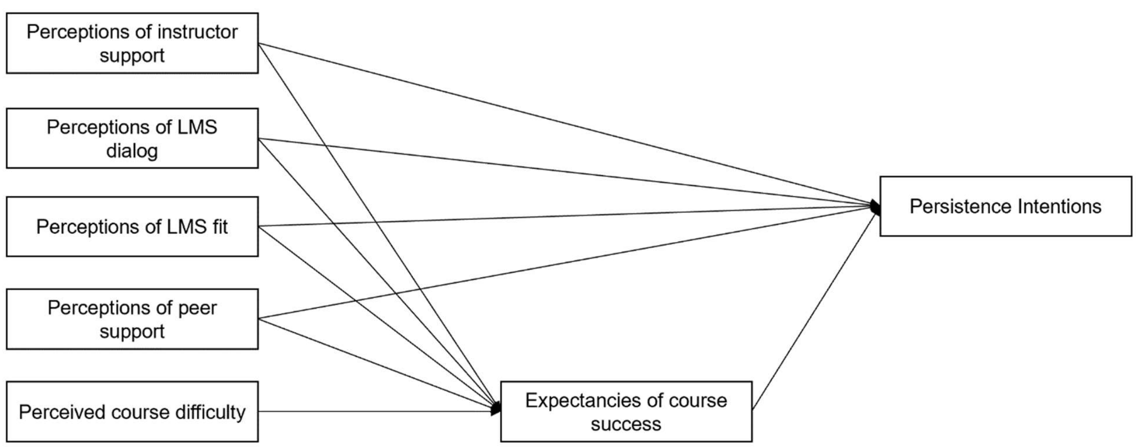

Figure 2: Block diagram of the hypothesized model

Table 2. Means, standard deviations, and correlations among variables.

Variable	1	2	3	4	5	6	Mean	SD
1. Instructor support	-						3.4	1.0
2. LMS dialog	0.31**	-					3.5	1.1
3. LMS fit	0.66**	0.53**	-				3.7	0.9
4. Peer support	0.47**	0.41**	0.44*	-			3.5	0.9
5. Course difficulty	-0.26**	-0.12	-0.23**	-0.19*	-		3.5	1.1
6. Course success	0.51**	0.35**	0.55**	0.44**	-0.40**	-	4.1	0.8
7. Persistence Intentions	0.43**	0.31**	0.42**	0.38**	-0.27**	0.62**	4.6	0.6

Note. *N*=138, *p<0.05, **p<0.01

Results

The model tested in this study fit the data well across the model fitness indices, all of which were within their levels of acceptableness as described previously ($\chi^2(1)$=0.107, *p*=0.744, *RMSEA*<0.05, *CFI*=1.00, *SRMR*=0.004). The final model with standardized estimates and standard errors in parentheses is shown in Figure 3 – bold highlighted numbers on the arrows indicate where effects were statistically significant (*p*<0.05). Findings from the path analysis revealed that students' perceptions of LMS fit (*p*=0.003) and perceived course difficulty (*p*=0.007) significantly predicted expectancies of course success (positively and negatively, respectively). Expectancies of course success (*p*=0.000) positively and significantly predicted students' course-level persistence intentions. Therefore, Expectancies of course success was the most important influences as it had a direct effect on persistence intentions. The indirect effects from the path perceptions of LMS fit to expectancies of course success, and perceived course difficulty to expectancies of course success on course-level persistence intentions were statistically significant (*β*=0.148, *p*=0.014 and *β*=-0.13, *p*=0.008).

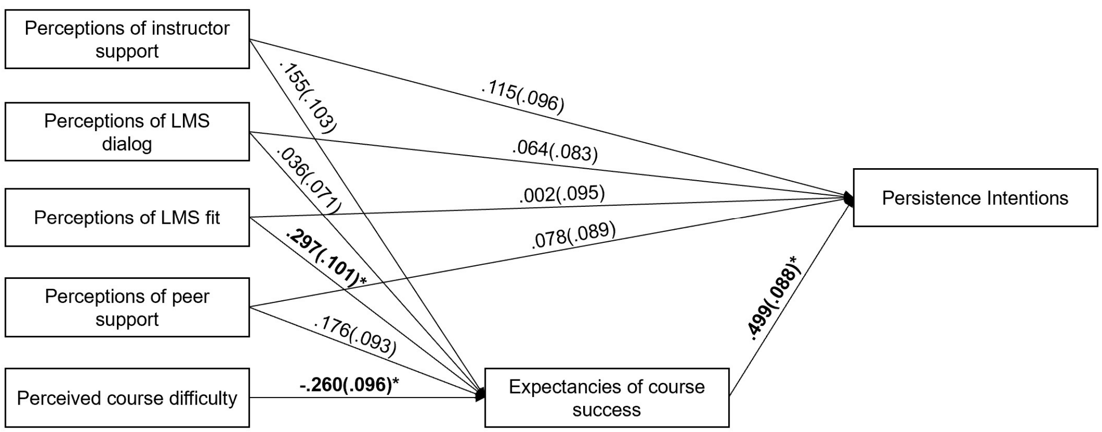

Figure 3: Model with standardized estimates and standard errors

Discussions and Implications

The findings from this study reveal that perceptions of LMS fit (a course characteristic) and perceived course difficulty (an individual characteristic) had statistically significant predictive relationships with expectancies of course success (an individual characteristic) which in turn influenced students' persistence decisions in online undergraduate engineering courses. Previous studies have shown that perceptions of LMS influences students' persistence decisions in online courses. For example, Kittur et al. (2021) found perceptions of LMS to be a significant predictor of students' course-level persistence decisions while investigating the importance of interpersonal interactions in online undergraduate engineering courses. St Rose and Moore (2019) reported that accessing resources through the course LMS among other factors impacted student's retention in online courses. Course difficulty can be associated with student's persistence decision. Designing online courses with a focus on traditional students in mind can make the courses difficult for non-traditional students (a large part of students enrolled in online courses are non-traditional) (Robertson, 2020).

Expectancies of course success might be influenced by student's prior experiences related to online courses. Lee and Choi (2011) found that in addition to having greater internal locus of control, self-motivation, and course satisfaction, students with higher levels of confidence in their computer skills reported lower likelihoods of dropping out from their online course. Salvo et al. (2019) also found prior academic achievement, continuous academic enrollment, and previous information technology training to be some of the factors responsible for students' successful completion of online courses.

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Institutions facing higher student dropouts in online undergraduate engineering courses must consider students' perceptions of LMS and perceived course difficulty as important aspects in online courses. Being aware of the students' beliefs related to the online courses can help faculty identify students at-risk of dropping out from the course. In addition, understanding students' expectancies of course success can help alert faculty members teaching online courses to students with reduced expectancies of being successful so that they can help these students persist. The students' perceptions on course LMS and their expectancies of course success can be measured by collecting data using the survey instrument presented in Lee et al., (2020), and the same can be monitored by collecting the data at different time points during the course to examine the changes in students' perceptions (if any).

Conclusions, Limitations, and Future Work

In this study, a path analysis was conducted to investigate the role of course and individual characteristics on students' course-level persistence intentions within online undergraduate engineering courses. The findings from this study emphasize the importance of understanding students' perceptions of LMS and perceived course difficulty in online undergraduate engineering courses and the need to delineate further the mechanisms through which expectancies of success influence persistence.

This study comes with some limitations like any other study. The sample considered in this study was not representative of the entire online undergraduate engineering education community as the participants recruited in this study belonged to only one institution. Moreover, the data collected for this study is not sufficient to provide reasons to the findings, specifically answers like how and why perceptions of LMS, and expectancies of course success influence students' persistence decisions.

Further investigation is needed to examine the mechanisms through which perceptions of LMS and expectancies of course success influences persistence intentions. Notably, a potential future research direction in this area could be to conduct a qualitative study interviewing students to understand their experiences taking online undergraduate engineering courses and making course-level persistence decisions in their own words.

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Changes in Non-Cognitive and Affective (NCA) Factors in Engineering and Computing Students: A Longitudinal Study of Mechanical Engineering Students

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ABSTRACT

CONTEXT

Numerous non-cognitive and affective (NCA) factors (e.g. Personality, Identity, Mindset, etc.) relate to student success in academics. Some factors or collection of factors relate positively to academic success while others do not. In addition, many NCA factors are malleable, creating an opportunity for educators to improve student academic performance with the use of targeted interventions. Understanding how factors change over time and the causes of those changes can provide insight to educators looking to improve individual academic performance in engineering and computing students.

PURPOSE OR GOAL

As a first step in determining to what extent NCA-based interventions can improve academic performance and the perceived quality of the undergraduate experience, we seek to know how NCA factors of a group of Mechanical Engineering students change over time. We posit that some NCA factors will not change (some constructs are not considered malleable) and some factors will change at identifiable points in the students' experience.

APPROACH OR METHODOLOGY/METHODS

A comprehensive and validated survey instrument measuring 28 NCA factors was given to engineering and computing students (n>2000) at a large state university in the United States for three consecutive academic years. A small group (n=47) took the survey in each of their first three years of university studies. Looking at these survey responses, we performed a repeated measures analysis of variance to determine longitudinal changes in NCA factors.

ACTUAL OR ANTICIPATED OUTCOMES

Analysis indicates that six of the NCA factors change significantly for the Mechanical Engineering students over time. These include *Engineering Identity*, *Motivation by Expectancy*, two measures of *Stress*, *Belongingness* and *Neuroticism*. There may be a slight increase in responses for the two measures of *Stress* and *Neuroticism* over time. However, for *Motivation by Expectancy*, *Belongingness* and *Engineering Identity*, there is evidence of a significant decrease in these factors over time. This may be of particular concern since decreases in these three factors correlate with decreased success.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

NCA factors can predict elements of student success in engineering and computing students. Some malleable NCA factors change over time and targeted interventions can be developed to change these student beliefs and attitudes to foster greater academic success. Results of this work are being used to plan the scope and timing of these interventions. Some beneficial NCA factors decrease during a student's experience, which is troubling and indicates that perhaps larger systemic changes need to be considered as well.

KEYWORDS

Non-Cognitive Factors, Academic Success, Longitudinal Study

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Introduction

The U.S. National Science Foundation (NSF) funded Studying Underlying Characteristics of Computing and Engineering Student Success (SUCCESS) survey was created and validated to assess 28 non-cognitive and affective (NCA) factors in engineering and computing science students. Many of these NCA factors have independently been shown to relate to student success in college. The SUCCESS survey has now assessed over 4,000 engineering students in the United States over the course of four years and has provided valuable insight into the NCA profiles that exist within computing and engineering students (Scheidt et al., 2018; Scheidt et al., 2021; Perkins et al., 2021). Typically, student potential and preparedness for undertaking engineering and computing studies are determined via high school grade point averages and standardized test scores; however, these have been shown to be poor predictors of student performance trajectories over time. One purpose of the SUCCESS project is to utilize the information gathered through survey administration to explore student performance through new lenses that challenge traditional assessment of student potential. Another goal of the SUCCESS project is to identify student populations that may be at risk by using their NCA profiles to guide initiatives in support of those students and have a positive impact on broadly defined measures of student performance. A major research question of the project is to determine to what extent NCA-based interventions improve academic performance and the perceived quality of the undergraduate experience in engineering and computer science. Prior to determining what interventions should be developed, we are using longitudinal data to see if student NCA profiles change without interventions. In other words, do student NCA profiles change simply from their academic and life experiences in college and if so, when during their experiences do the changes occur? This knowledge can not only guide the selection and design of interventions, but can also provide a sense of when during the course of a student's academic experience would be the best time for the intervention. In this work, we explore the results of a longitudinal study of Mechanical Engineering students who took the survey in each of their first three years at University.

Background

Although the SUCCESS survey measures 28 separate constructs, only six proved to be relevant to this work (See Results). A description of each of these six constructs follows. For descriptions of all constructs and the complete set of questions in the SUCCESS survey, please see Scheidt, Godwin et al (2018). The cited study also reviews all constructs and the validity of the survey questions in the instrument. Each construct is measured by a set of questions that students answer on a seven-point Likert scale.

Belongingness: The sense of a student belonging to an academic field is important to engineering and computing students. Marra et al (2012) reports that belonging is a major contributor to students' decision to leave engineering. This basic human need must be met for human fulfilment in an occupation (Maslow, 1943). This construct is measured through six instrument items with high scores indicating that students have a greater sense of belonging in their academic community. The sense of belonging can be influenced by the academic environment and is therefore considered malleable.

Identity – Interest: Identity in general is defined as "being recognized as a certain 'kind of person,' in a given context" (Gee, 2000). When a student's identity matches with their academic experience, this can lead to better persistence and retention in engineering (Godwin et al, 2016). The SUCCESS survey measures three different subscales of *Identity* with the *Interest* subscale important in this study. This subscale measures a student's enjoyment of and their desire to learn a subject (Godwin, 2015), with higher ratings corresponding to a greater sense of engineering or computing identity. One's identity is developed and changes over time and is influenced by an academic setting and is therefore considered malleable.

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Motivation – Expectancy: For the SUCESS survey, we measured motivation using a future time perspective, by examining how students develop long-range behaviours to achieve distant goals. The survey measures motivation with five different subscales and the *Expectancy* subscale is significant in this work. Five survey items measure *Motivation by Expectancy*, which is a student's belief that they will do well in their endeavours. In general, higher motivation is linked to academic persistence and better performance in engineering. This construct is malleable and higher motivation can be fostered in students by connecting coursework to future goals and by encouraging students to believe in their ability to succeed (Ponton et al, 2001).

Student Life Stress – Reactions: The SUCCESS survey measures five dimensions of student stress with *Reactions* and *Changes* significant in this current work. The *Reactions* dimension measures a student's direct reaction to stress including physical reactions (e.g., sweating, headaches) and mental state (irritability, anxiety, fear, etc.). Higher scores on this measure relate to greater stress. Stress can greatly influence student academic performance, both positively and negatively (Gadzella et al, 2012). There are several ways students can learn to moderate stress, including learning better time management skills or through improved mindfulness (Chiesa and Serretti, 2009).

Student Life Stress – Changes: Another dimension of *Student Life Stress* is the stress caused by changes such as disruption of goals, unpleasant experiences or many life changes occurring at the same time. This is measured using three items in the survey.

Neuroticism: This personality trait is one of the Big-Five (McCrae and John, 1992), which also includes *Conscientiousness*, *Extraversion*, *Openness to Experience* and *Agreeableness*. *Neuroticism* relates to anxiety, personal insecurity and possibly irritability or hostility. Three items are used to measure this dimension with higher scores correlating to a stronger neurotic personality trait. Neuroticism has been shown to negatively relate to academic satisfaction (Trapmann et al, 2007). Personality traits in general may change throughout life over long time-scales and in response to life events, but are not considered as malleable as the other traits listed above.

Methods

Data Collection

The survey was given via paper copy to students starting in the 2017-2018 Academic year to the majority of first year students in all engineering and computing majors at California Polytechnic State University (Cal Poly), a large undergraduate focussed public school on the west coast of the United States. Using the paper copy and having the students take the survey in their courses ensured a high response rate. In the subsequent years, the majority of all Mechanical Engineering students took the survey. From this dataset, we identified 47 students who had taken the survey in each of the first three years at the University. It should be noted that all surveys were taken prior to the COVID-19 pandemic and therefore this did not influence the results.

Participants

The demographic profile of participants who took the survey in each of their first three years is given in Table 1. This demographic profile is reflective of the Cal Poly Mechanical Engineering department's student body.

Table 1: Demographic Profile of Mechanical Engineering Participants*

Race/ethnicity	Number of participants	Percentage
White	24	52.2%
Asian	7	15.2%
Hispanic or Latinx	5	10.9%
Black or African-American	0	0.0%
Native American	1	2.2%
Multi-racial	6	13%
Declined to answer	3	6.5%
Gender		
Female	15	32.6%
Male	31	67.4%

* Demographic information was voluntary and provided by 45 of 47 students in the sample

Data Analysis

To determine whether there was a difference in responses for each student and construct over the span of their first three years in school, a repeated measures analysis of variance (ANOVA) was performed using the statistical software R. There was one test per construct, resulting in 28 repeated measures ANOVA tests. Each ANOVA tested for differences in a student's score for a given construct over a three-year period. To adjust for multiple tests, the Benjamini and Hochberg False Discovery Rate (FDR) method (Benjamini and Hochberg, 1995) was utilized to identify as many significant comparisons as possible while also controlling the false positive rate. With the FDR method, each resulting p-value was adjusted and then compared to a significance level of 0.05. This means that the probability of making at least one false discovery would be at most 5%. Of the 28 repeated measures ANOVA tests, six tests found significant differences. For these six, a pairwise comparison using the same FDR adjustment was then conducted to identify which years were different from one another.

The most common indictor of academic success is Grade Point Average (GPA), and this variable is used in this study. Next, we investigated the relationship between GPA and each of the significant factors with a correlation test (Spearman's method) to evaluate the association of GPA and each of the six significantly changing constructs for each year of school. For each school year, a student's GPA was calculated from their official transcript and this value was tested against each of the six NCA factors. This test was repeated for each of the three years of study under consideration (thus the GPA tested was the year's GPA rather than the cumulative GPA).

Results

The repeated measures ANOVA indicated that six of the factors showed a statistically significant change during the first three years at University: *Belongingness* (p-value=0.028)*, Identify - Interest* (p=0.028)*, Motivation - Expectancy* (p=0.028)*, Student Life Stress – Reactions* (p=0.028)*, Student Life Stress – Changes* (p=0.036) *and Neuroticism* (p=0.048). Figures 1-3 show the box plots of each factor over the three years. In Figure 1, we see that scores for both *Belongingness* and *Identity – Interest*, decrease over time. For both factors, the temporal differences are statistically significant between the first and second year and between the first and third year, but not between the second and third year (Table 2).

We also see similar temporal differences for three other factors (Table 2). Both *Student Life Stress – Reactions* and *Student Life Stress – Changes*, scores tend to increase over time (Figure 2) whereas for *Motivation – Expectancy*, scores tend to decrease over time (Figure 3). Again, for these factors the changes are significantly different between the first and second, and the first and third years, but not between the second and third years of studies.

Finally, in Figure 3, we see that students' mean scores in *Neuroticism* increase at first and then decrease over time, with the largest difference being between first and second year. Although, the repeated measures ANOVA produced a significant p-value (p=0.048), a separate paired t-tests for each combination of years of study found no statistically significant difference (Table 2). This finding suggests that the repeated measures ANOVA produced an anomalous significance, perhaps due to the broad distributions in the scores for each year.

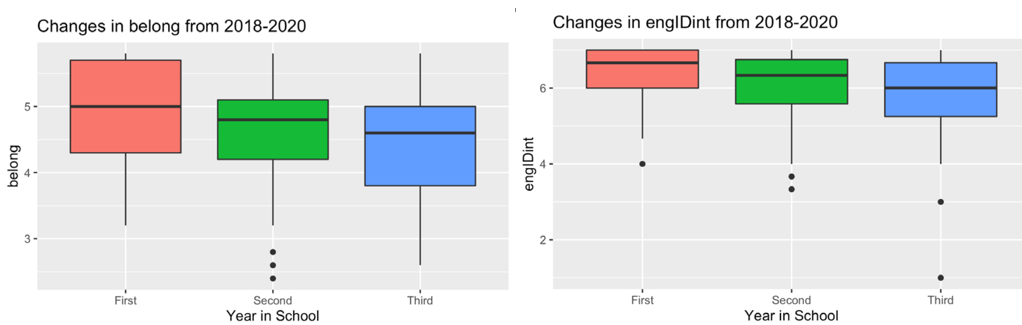

Figure 1: Box plot for changes in *Belongingness* (left) and *Identity – Interest* (right) for the first three years at University.

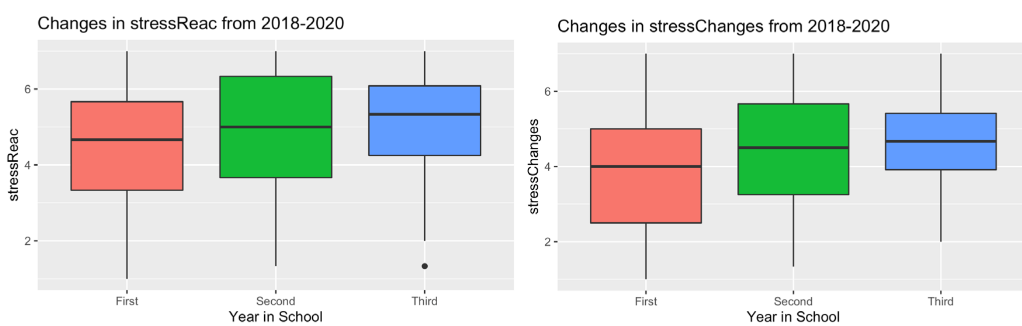

Figure 2: Box plots for changes in *Student Life Stress – Reactions* (left) and Student Life Stress – *Changes* (right) for the first three years at University.

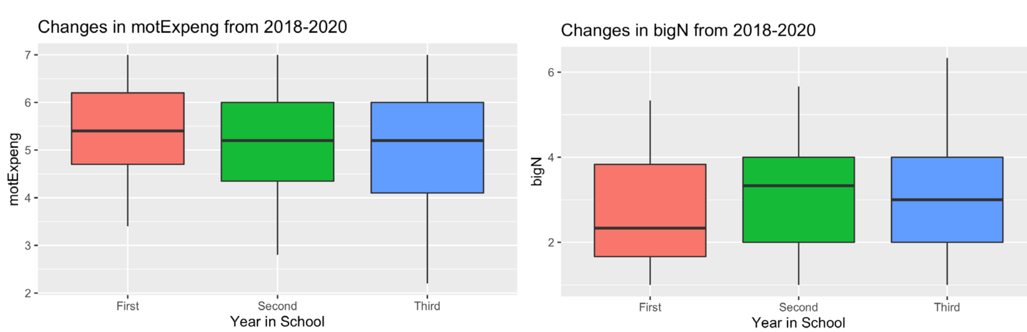

Figure 3: Box plots for changes in *Motivation – Expectancy* (left) and Neuroticism (right) for the first three years at University.

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Table 2: Pairwise Comparison Results for Significant Factors

Factor	School Year Comparison	Adjusted P-value
Belongingness	First – Second	0.033*
	First – Third	0.015*
	Second – Third	0.463
Identity – Interest	First – Second	0.017*
	First – Third	0.005*
	Second – Third	0.212
Student Life Stress – Reactions	First – Second	0.037*
	First – Third	0.024*
	Second – Third	0.719
Student Life Stress – Changes	First – Second	0.024*
	First – Third	0.024*
	Second – Third	0.614
Motivation – Expectancy	First – Second	0.043*
	First – Third	0.043*
	Second – Third	0.621
Neuroticism	First – Second	0.062
	First – Third	0.062
	Second – Third	0.610

* The mean difference is significant at the 0.05 level

The correlation tests between GPA and each of the five significantly changing factors (neuroticism is no longer considered based on results in Table 2) showed that three factors appear to have a significant association. As shown in Figure 4, there is a negative correlation, for all three school years, between GPA and *Student Life Stress – Changes* and *Student Life Stress – Reactions*. These negative associations indicate that the higher the score for either of these stress factors, the lower the GPA. On the other hand, for *Belongingness*, there is a significant positive association with GPA, but only during the third year at University. In other words, during students' third year of school, the higher a student's sense of *Belongingness*, the higher their GPA. It is important to note that correlation does not mean causation and that lower or higher NCA factor scores do not necessarily cause lower or higher GPAs. We also note that Figure 4 demonstrates the relatively broad distributions of GPA across factor scores for all three factors.

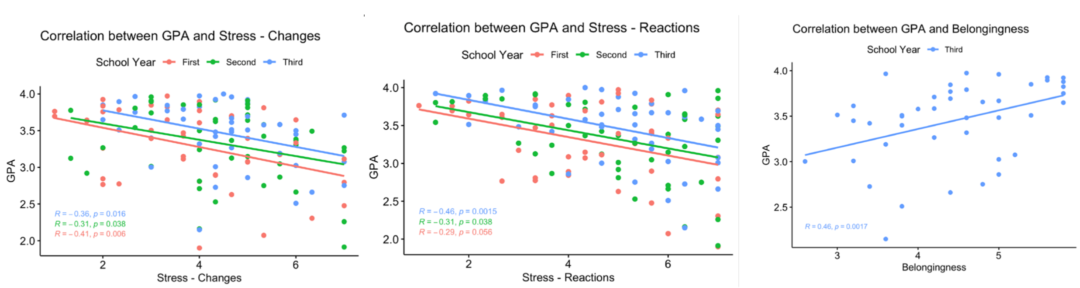

Figure 4: Scatterplots of GPA vs *Student Life Stress – Changes, Stress-Reactions and Belongingness*

Discussion

In general, we found that five of six factors (excluding Neuroticism) that changed significantly over time shared several traits in common. First, each factor trended in the direction that previous studies have found to be correlated with lower student success. While worrisome, students obviously are still capable of succeeding in the program and this finding suggests opportunities for helping students to not only succeed but to thrive. Second, all five factors were found to be significantly different between the first and second years and between the first and third years, but not between the second and third. This perhaps suggests that the major changes are occurring between the first two years of engineering studies and that targeted support to students should occur then. Sadly, it is well established that students usually leave engineering programs during this time, which adds further impetus to supporting students during this critical time period. Below we discuss the implications from the finding for each specific factor.

Belongingness: The decrease in students' sense of belongingness is important because a lack of belonging is one of the top reasons students leave engineering (Marra et al, 2012). In the science and engineering context, belongingness is also strongly correlated with student success (Holmegaard et al., 2014; Schar et al., 2017; Seymour and Hunter, 2019). We found that during students' third year of school, a higher sense of belongingness is correlated with higher GPAs, further emphasizing the importance of this factor to students' success. At Cal Poly, students do take introductory courses in Mechanical Engineering their first year; however, the majority of their academic work during this period is in basic math and sciences, which are not taught by engineering departments. The number of engineering classes increases in both the second and third year. This may explain some loss of belongingness as students may fail to identify with their major until they take more classes. If this is true, we would expect an increase in belongingness from the third to fourth year, which has not yet been evaluated. Engineering programs may consider hosting events that offer community-building experiences that may aid in increasing students' sense of belongingness with the goal of increased retention and academic performance.

Identify – Interest: Similar to *Belongingness*, students' engineering identity, more specifically their interest and enjoyment in learning about their major, decreased over the first three school years. These two findings are consistent since students whose identities don't align with their disciplinary roles may feel a decreased sense of belonging. It is possible that the decrease in *Belongingness* is also associated with the decrease in students' desire to learn more. Several recent studies have pointed to the importance of engineering identity to student success, especially for the retention of minoritized students (Ross, Huff & Godwin, 2021; Pierrakos et al., 2009). To counteract this decrease in identity, many interventions can be implemented. For example, instructors can be encouraged to provide more positive reinforcement and refer to students as engineering professionals rather than 'in-training' professionals. Additional actions include offering more projects that align with student interests and providing equal educational opportunities.

Significant Stress Factors: From the results, we found that over the first three years of study, Mechanical Engineering students' stress due to changes and their reactions to stress increased. Increased stressors could be because the curriculum for Mechanical Engineering students increases in difficulty during each year, with the third year typically considered the most difficult. With courses becoming more difficult, it becomes harder for students to manage all their work, thus affecting ability to manage time, which then impacts stress levels. It is also typical at Cal Poly for many first-year students to move out of the dormitories between the first and second years. This may also increase the level of stress students feel as they become more responsible for taking care of their personal needs (paying rent, acquiring and cooking food, managing transportation, etc.). This increase in stress and reactions to stress may have implications on student performance, as these two factors are negatively associated with GPA (see Figure 4). Discovering these trends about stress opens a window of opportunity for how to improve students' success. One possibility to help students in this area includes improving students' overall mindfulness, time management skills and providing increased levels of support for their courses.

Motivation – Expectancy: Past research has shown motivation to be a powerful factor in several aspects of student success (Guay et al., 2000; Matusovich et al., 2008). Our results

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show that students experience a decrease in motivation over the years, meaning that students are less likely to believe they will succeed in their future endeavors. Again, this decrease may be a result of the increasing difficulty in schoolwork each school year. It is possible that as the curriculum gets more difficult, students feel more challenged, thus feeling more discouraged in thinking they will do well in the future. As an intervention, faculty could encourage students to view their academic struggles as a means to grow, while also teaching students how to confront difficult assignments, so that they do not feel discouraged.

Conclusions and Future Work

NCA factors can predict elements of student success over time in engineering and computing students. It is possible to change malleable factors through targeted interventions that change student beliefs and attitudes toward their work, generating positive changes and perhaps helping students to thrive during their studies. This work reveals changes in NCA factors of students over their first three years of study without any intervention. We will be adding fourth year data shortly to extend our longitudinal dataset and complete a student's academic career. These preliminary results indicate that students' sense of Belongingness and Engineering Identity are prime candidates for intervention starting in the first year of studies. Work on those interventions has begun and will be piloted in the 2021-2022 academic year. For example, we are currently testing a values affirmation intervention (McQueen and Klein, 2006) and posit that an effective implementation will boost students' engineering identity, motivation by expectancy and belongingness. In addition, our results indicate that student stress levels may be having a negative impact on academic performance. We will also test interventions that help students better manage and minimize negative aspects of stress. Finally, the fact that certain important NCA factors are changing for students will lead to department-wide discussions about the need of systemic change to increase student success.

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Design Principles for Auto-mapping Professional Competencies

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ABSTRACT

CONTEXT

Engineers are required to maintain currency in their respective fields (through continuous professional development). In Australia, engineering students are expected to progress towards Engineers Australia's (EA) Stage 1 competencies throughout the course of their accredited engineering studies. Similarly, professional frameworks are well established internationally and recognised as key guide for the development of engineers in the workforce (Leslie, 2016). Throughout their professional careers, engineers are required to undergo formal, informal, and non-formal learning. The process of maintaining these records and mapping them to competency standards is rigorous and time consuming. This paper examines how this process is undertaken and investigate how this process can be automated to facilitate the alignment between education and industry needs.

PURPOSE OR GOAL

To provide the design principles of auto-mapping professional competencies, this research effort will apply the business process analytics methodology. This methodology will assist in identifying the inefficiencies of the current mapping process. By doing so, it will be possible to identify a new automated process that can facilitate the design of new software. This technology will assist both student and practicing engineers alike by providing correct mapping to competency frameworks and alleviating the time burden to do so. This system will also eradicate some of the administrative functions performed by professional bodies and their competency assessors.

APPROACH OR METHODOLOGY/METHODS

By applying the business process analytics approach to a series of case studies and an extensive literature review, the process of how mapping of skills and competencies to formal qualifications is presented. The paper identifies areas of inefficiencies and propose design principles and processes for an automated software solution.

ACTUAL OR ANTICIPATED OUTCOMES

The outcome of this research is a set of design principles that can be used to map competencies utilising an automated software solution. These design principles will inform the development of the system by providing a clear picture of what users are involved and the critical data that needs to be shared between them. The development of an automated solution to map different forms of learning to professional skills strengthen the connection between formal qualifications, continuous development, and professional competencies.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This study discusses the importance of mapping learning against skills in standard competency frameworks during formal engineering education and throughout professional life and sets the principles to conduct an automatic mapping to facilitate the development, achievement, and recognition of engineering standard competencies.

KEYWORDS

Continuous professional development, micro-credentials, professional skills, competencies, auto-mapping, life-long learning, learning technology.

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Introduction

Professionals, such as engineers, curate a portfolio of their learnings and experiences. A professional portfolio logs the skills and competencies of a professional from formal qualifications and extends with lifelong learning. By applying the business process analytics, an established methodology that seeks to understand business processes with a view of improving effectiveness and efficiencies, this paper will analyse the processes of how a professional currently maintains their records of competencies. These records, sometimes referred to as Continuous Professional Development (CPD) journal, are used for a myriad of reasons including, career goal setting and measuring, Curriculum Vitae and as evidence of maintaining currency to be produced for audit by an industry body.

Many professions require their practitioners to undergo regular audit, either as a regulatory requirement or as a requirement for society membership. As an example, Engineers Australia (EA) are one such industry body that has a rigorous auditing policy for their membership. This auditing process will also be analysed with the business process analytics approach. By doing so, this paper will be able to analyse and identify the full cycle of recording a professional's skills and competencies.

By applying the business process analytics approach to a series of case studies and an extensive literature review, the process to map skills and competencies to formal qualifications come to light. Current formal qualifications list learning outcomes in terms of knowledge, skills, and the application of knowledge and skills. However, formal academic programs are structured in units of study with a range of learning outcomes. The assessment is conducted overall for the whole unit, often not grading the achievement of each individual learning outcome. Students can pass the unit with 50% of marks, without indication of what 50% they have not mastered. Boud&Jorre de St Jorre reflect on that in a recent paper (Boud & Jorre de St Jorre, 2021).

Qualifications are meant to show employers and others what the holder is capable of and has achieved (Noonan et al., 2019). However, the graduation documentation does not provide enough clarity and transparency. The award testifies the completion of the formal qualification, the testamur lists the units of study with the overall student's grade for each, and the Australian Higher Education Graduation Statement (AHEGS) describes extracurricular activities.

Competency based frameworks and assessment provide a common language to translate learnings in formal education to industry expectations (Connors et al 2018). In Australia, for example, EA provides competency standards for different degrees and levels of experience in the engineering profession. Although research has been developed in the Australian context, the findings are general and applicable to other competency frameworks, recognised internationally (Leslie, 2016).

The mapping continues to be necessary after graduation, for Continuous Professional Development. This paper explores three case studies. The first relates to an engineering student during or just graduated their degree. The second case study explores the practicing professional undertaking life-long learning. The final case study relates to the auditing process of a professional.

Finally, by understanding how the process is currently being undertaken, this paper will provide design principles that can be used by a software development team to implement into an automated solution.

Mapping learning to competency frameworks – Case Studies

To ascertain how professionals currently map their learnings to competencies frameworks, this paper will use the case study method. This method is used to "*closely examine the data within a specific context*" (Zainal, 2017). The data which we need to ascertain is the process of how

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the mapping of competencies are currently being performed, as such, this paper will examine three separate case studies. The current mapping methods are analysed from Case study 1: Formal Education and Case study 2: Informal Learning. These two cases provide examples of how a professional currently map their skills and competencies. Finally, Case study 3: Peer Review and Audit is provided to inform the current process of auditing/peer reviewing a professional and their CPD journals. All three case studies have been adapted from the Skills Framework for the Information Age (SFIA) Self-Assessment Guidelines (SFIA-Foundation) and Writing Engineering Competency Claims (Engineers-Australia) to provide a 'high-level' and generic view of the processes performed.

Case 1: Formal Education

When a student undergoes a formal education, such as a bachelor's degree, the competencies that they learn are usually itemised for them. These programs are broken down into individualised units of study which in turn contain a mapping of competencies to standard frameworks. For example, in Australia, professional engineering degrees are accredited by EA and mapped against entry to profession competency standards (EA's Stage 1 competencies). In the effort to map and log these competencies into their CPD journals, the student must gather these itemised competencies and map them to their respective frameworks.

Within a four-year degree, there are numerous units of study (subjects), each with their own learning outcomes and list of competencies to map. The list of entries is large. When a student reaches the skills and competencies, the student then manually transfers these items into a journal, often in the form of a matrix or spreadsheet. The process undertaken to map these is as follows:

- ↳ Create a professional CPD (Continuous Professional Development) journal
- ↳ Find the unit of study and their attributed competencies
- ↳ Find the listing of the skills and competencies
- ↳ Individually copy and paste, or manually type in the skill or competency into the journal
- ↳ Date each entry and provide additional details surrounding the study including:
    - Where the unit was undertaken
    - The name of the unit
    - The learning outcomes for the unit
    - Duration of the activity (hours)
- ↳ Perform the above process for each of the skill and competencies for each of the frameworks targeted by the professional

Case 2: Informal Learning

Professional practitioners are required to undergo continuous professional development (CPD) for several reasons; to maintain currency of knowledge, maintain employability or as a requirement of membership of an industry society. For example, EA require their members to perform one hundred and fifty hours of professional development in a three-year cycle (*Continuing Professional Development | CPD | Engineers Australia*, n.d.). Such learning activities can include formal learning like Case 1, however, there are also many other types of learning that a professional undergoes. This can include reading journal articles, technical documentation, attending a conference and many more activities. Unlike Case 1, these do not come pre-mapped to any specific skill or competency. The onus is on the professional to figure out where to journal the activity. This may be simple for some frameworks; they read an article for an hour and can simply state that. However, some frameworks like the Skills Framework for the Information Age (SFIA) will require additional effort to map to. If a software engineer reads this paper, to which skill or skills of the many skills in that framework would they map the activity? To map these skills correctly requires additional training for the professional in how to recognise the skills being developed by the article and which skill(s) is the most appropriate to claim.

Below is the process of mapping this paper to the SFIA:

- ↳ Undergo learning activity
- ↳ Identify the pertinent skills as per SFIA within the article
- ↳ Create a new entry in the CPD journal
- ↳ Itemise the particulars of the paper
  - Authors
  - Journal
  - Date
  - Overall learning of the paper
- ↳ Itemise the skills being learned/strengthened

Case 3: Peer Review and Audit

Many industry bodies require their members to undergo regular audit and peer review. For example, EA require their charted engineers to undergo a minimum of 150 hours of professional development and these professionals are audited and peer reviewed to maintain industry standards. In general terms, this process is twofold. There is an administrative audit and a peer review. The peer review is conducted by fellow members of the industry body. The purpose of this is to seek peer acceptance of a professional's competence, attitude, and professionalism. The administrative audit, however, is a bureaucratic process. A professional is required to articulate and present a report detailing their profession, a statement of competence and a journal of their lifelong learning (CPD).

Although there are good reasons to keep peer reviews of a professional by the industry bodies, automation can assist in lighting the administrative burden of the audit. As such, the following (generic) process is observed:

- ↳ Professional to write a professional practice report which include the competencies claimed
- ↳ Reflective practice report
- ↳ Panel interview
- ↳ National assessor to confirm

Online Tools:

Many professional bodies and societies now have online solutions to assist their members with the task of recording their CPD activities. This involves the professional to log into the respective portal, and manually filling in the provided forms or spreadsheets. Except for some analytics and report creation, the process is still very similar to the above cases.

Methodology

Business process analytics can provide a unique perspective when we apply this methodology to the above three case studies. Business process analytics "*is a methodology for the analysis of a business with a view to understanding the processes and improving the efficiency and effectiveness of its operations*" (Business Process Analysis, 2012).

By applying the Business Process Analytics methodology, the efficacy of the respective processes come to light. The first step in this methodology is to develop a full understanding of the entire context of operation. The context here is a professional, once leaving school, undertakes a University Degree, enters the workforce, continues to learn via additional formal courses, informal learnings, and additional activities. The professional then must map these learning activities to the standards of their industry bodies and undergo regular audits to confirm the professional's competence is current and acceptable for their profession.

Analysing these processes, there are several inefficiencies that can be immediately identified. These include the following:

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1. Skills and competencies are not transferred when a formal qualification is awarded

   In Case 1, when the student successfully passes a unit of study or even the entire degree program, the skills and competencies that are already mapped for them are static. They are mapped and electronically stored, but they don't transfer to the student's record or journal. As these activities are already mapped according to the respective frameworks, a software solution could be implemented to transfer this information to the student and digitally stored.
2. The professional may not know how to map the skill or competence to their respective frameworks

   Some skill or competency frameworks can be quite complex, and it is not unreasonable to infer that this complexity provides a disincentive for the professional to be proactive in their journaling of their skills and competencies. This can be addressed by automating this process as mentioned above.
3. The process is quite repetitive in nature.

   When a professional undertakes regular professional development activities, they may spend just the same amount of time journaling their learning activities as they are learning.
4. How many frameworks does the professional need to comply to?

   As seen in Case 1, a learning activity can be accredited by more than one framework. Not to mention that the professional may also be engaged with additional industry societies that may also recognise the learning activity, but the activity hasn't been accredited by their framework. What data must the professional keep and what data can they ignore? A proactive professional who is engaged with multiple industry bodies must endure an exponential growth in complexity that they must navigate to maintain membership and accreditation.
5. Auditing a CPD journal is a lengthy process

   Auditing a journal is a manual and very time-consuming task. As indicated in Case 3, when a peer is conducting an audit, they not only offer a peer review as to the standards of their profession, but the process also requires a high level of administrative encumbrance. This burden is met by applying additional labour at the problem. This is a cost of time and money for all stakeholders involved.

The inefficiencies listed above may be perceived as a disincentive proactive journaling one's professional development. Some professionals may even be disengaged with CPD activities altogether, simply because of the administrative burden.

Data Management

Analysing the key findings above, data management is identified as the key factor that leads to inefficiency in the process. Each stakeholder has access to the data that they require, however, this data is not transferred efficiently. A university may have their programs mapped to a competency framework, but this information is not available on any transcript or in any digital form that is of use for this process. Even the competency frameworks themselves do not have their data available to effectively assist a professional. Some information is available as an online resource, and many have online tools to assist, however many professionals belong to multiple industry bodies, thus fragmenting their efforts to maintain a cohesive CPD journal and professional portfolio.

Current Attempts to Address These Issues

Some initiatives have emerged in recent times to address aspects of this issue. Such as micro-credentials and online repositories.

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Micro-credentials

According to Beverly Oliver a micro-credential is "*A certification of assessed learning that is additional, alternate, complementary to or a formal component of a formal qualification"* (Oliver, 2019). This provides a very powerful tool to allow for many different learning activities to be recognised by formal qualification frameworks. Oliver's credential taxonomy can be observed in practice at Deakin University (https://credentials.deakin.edu.au/). It is quite similar in nature to how EA recognises different learning activities, but Oliver's definition of micro-credentials has a strong emphasis on assessed learnings. It is the assessment that is fundamental to the micro-credential. Once a student passes the assessment, they are awarded the micro-credential, which in turn could be mapped to a formal qualification. The micro-credentialing paradigm provides an avenue for formal recognition of learnings, complementing formal qualifications. The need remains for a system that is primarily aligned with industry competency frameworks.

Online Repositories and Services

Online repositories of qualifications and credentials have been in service for several years now. One such service is (https://www.myequals.edu.au/). MyEquals is an online service that provides online access to certified official academic transcripts. This service, utilised by Australian and New Zealand educational institutions, maintains student's official transcripts, and provides these transcripts electronically utilising a myriad or security measures. This service allows students to log in and download official transcripts anytime. This is a useful service if one has lost their transcripts or requires forwarding one to potential employers. However, the mapping of the individual skills or competencies learned during those activities, is not addressed.

Another similar service is Accredible (https://www.accredible.com/). Unlike MyEquals, Accredible does not focus on formal qualifications but on badges. Accreddible states that a badge is "*a symbol or indicator of an accomplishment, skill, quality or interest*" (Digital Badges with Accredible, 2019). Accredible boasts an impressive list of both academic and industry clients. Their badges provide additional security features to protect against any attempts of fraudulent claims. Although their service does provide an ability to list skills and competencies that was required to earn a badge, the professional will still need to perform the before mentioned processes to map these to their CPD journals.

World Education Service

The World Education Service (WES) (https://www.wes.org/). is a service that provides validation of qualifications between jurisdictions. Should a professional travel to work internationally, WES provides a service that will validate their qualifications. This is usually done at the expense of the professional but offers to add a level of security and trust that the professional's claim of qualification is legitimate. WES has also adopted additional technologies to facilitate this process including blockchain technology. However, as the service offered by WES is strictly related to authenticating certifications and qualifications, the mapping issue prevails.

Design Principles for Auto-mapping Competencies

By identifying that data management is a major concern when attempting to map competencies, a software solution to automate the mapping process is proposed. As this will be an information system that involves users and artifacts(data), this paper chose to utilise design principles as highlighted by (Gregor et al., 2020). Their Design Principles in Research Practice and Information Systems have identified three categories of design principles, the third of which will be deployed here (Design principles about user activity and artifacts). This design principle asserts that a system should have features of X that perform functions of Y that allow the user to perform Z task(s). Within this context, a system will be required to be online (X), that will be automated (Y), and allow the user (or in this instance, not require the user to) map the competencies to their CPD journals.

The above example is provided as an abstract example, as the full context of mapping competencies involve more users and artefacts that just the professional and a competency. To facilitate an automated system, this paper has identified the need for five users (stakeholders in business terms) and two artefacts, described below:

Users (Stakeholders)

Professional

Within the context of this solution, the Professional is an individual who undertakes learning activities. As many frameworks also allow for formal, informal, and non-formal learnings as part of their CPD activities, the Professional also needs to have the ability to fulfil a Credential. This will help facilitate the mapping for Case 2. For example, if they participate in an informal learning activity, this activity is not pre-mapped, thus the Professional will need to utilise the same automapping solution.

Provider

A provider is an organisation or contractor of a learning activity, such as an educational institution or training provider. The provider is responsible for entering the required data into the Credential and issuing (forwarding) the Credential. This process itself can be automated through the providers Customer Management System (CMS). The provider may also provide learning activities that are mapped to multiple frameworks, like Case 1. Remembering that the Credential is templated by the Framework Entity, the Provider will need to utilise a single Credential from all frameworks required.

Framework Entity

The Framework Entity is the stakeholder that maintains a skill or competency framework. It is their responsibility to provide several 'templates' to be utilised by other users. The first template is the Credential itself. This Credential contains information on what framework it is from and a list of competencies that the credential can award. The second template is a template for the line entry in the professionals CPD journal, a Line Item. This template will enforce consistency and will ensure that all requirements of the professional to record, are recorded. As the framework entity constructs both credential and line item, the administrative burden of auditing is reduced.

Credential Host

The Credential Host provides a service to store, and provides access to, the Credential online. Very similar to the online repositories already available. Under this new process, the existing Credential Hosts will need to be augmented to facilitate the forwarding of the credential to the Portfolio Host. If there are more than one Credential Host, the Professional is required to nominate a 'primary' host. The required functions will be performed by the primary host. This includes providing the Credential particulars viewable online, should anyone follow the links from a Professionals portfolio.

Portfolio Host

The Portfolio Host is responsible for providing an online portal to the professional's portfolio as well as public viewership. When the Portfolio Host receives a Credential, the Credential is interrogated to ascertain which framework it belongs to. Once this is established, the Portfolio Host will request a Line-Item template (if this is the first line entry, otherwise the template will be used from a previous mapping request). Once this new Line Item is created, the data for that line is completed by matching the data in the Credential to the fields in the Line Item. If the Portfolio host receives multiple (a list of) Credentials, this process is repeated until all Credentials are exhausted.

Critical Data structures (Artefacts)

There are two critical data structures that will need to be implemented. As discussed, the Credential will be required to contain all the information about the learning activity. A concept of a Line Item is also required. This will contain all the information requirements, as mandated by the Framework Entity.

Credential

Within the context of this solution, a credential is a data structure that is created by the Framework Entity and used by a Provider and the Professional. Once the requirement of the Credential is completed, the provider or the Professional will forward the Credential to the Credential Host for storage and so forth.

The components of this data structure are critical for the automapping solution. It is the Credential that contains all the data that a Framework Entity requires for CPD journaling. And as indicated in Case 1, an activity can contain skills and competencies for multiple Frameworks. Thus, multiple Credentials will need to be fulfilled, One for each Framework.

Line Item

A Line Item is simply a single entry into a Professionals CPD journal. These commonly contain the date the activity was completed, what the learning outcomes were, how long the activity was etc. However, there may be certain particulars that a Framework Entity may require that is unique to their industry or professional body. Thus, the template for the Line Item is to be mandated by the Framework Entity. Upon adopting this solution, the framework Entity will be required to construct both Credential and Line Item and ensure that the data contained in the Credential 'fits' the fields in the Line item is also required.

To connect the above users and artefacts together into a single cohesive system, the following process is required:

↳ Professional completes a learning activity, either self-directed or as a student of a provider.
↳ The Framework Entity sends a Credential template that provides fields for the required information.
↳ If there is a provider, their customer management system will automatically complete the Credential requirements. If the activity is a self-directed activity that does not have an automapping feature, the professional will complete this requirement.
↳ The completed Credential is then forwarded to the Credential Host, to be permanently stored. If there is more than one Credential Host, a primary host is nominated by the professional.
↳ The Primary Credential Host then forwards the Credential to the Portfolio Host.
↳ The Portfolio Host then requests and receives a Line Item from the Framework Entity.
↳ The Portfolio Host then marries the data from the Credential to the required fields in the Line Item
↳ The completed Line Item is then journaled in the professionals CPD journal and is available for display

Conclusion

There has been a proliferation of courses and education offerings to seek to keep education up to date with the current industry needs and societal trends. Unfortunately, with this proliferation, education, training, and other learnings have become an enormous ecosystem each one competing with the other. This makes the context confusing to the professional. Such a fragmented environment is complex to navigate without a solution that guides with their choices for career building and professional development.

Analysing this issue through the lens of business process analytics, this paper has identified the current process of transferring, mapping, and storing data to be the main concern. The primary inefficiency is the manual nature in which these tasks are currently performed. By

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utilising current technologies, many of the tasks required to map and record learnings can be automated. By deploying the user activity and artefacts design principles, the required users and data have been identified and the process of how these interact with each other has been developed. The proposed design principles can inform the development of an automapping solution. An auto-mapping solution has the potential to facilitate the development, achievement and recognition of engineering standard competencies.

Future Works

As part of an ongoing research effort, the next step is to demonstrate the use of these design principles with practical real-world examples. This will be accomplished in consult with members of the Engineers Australia assessment team. This step will allow the research team to demonstrate the effectiveness of the design principles as well as provide empirical evidence for the engineering educators to interrogate.

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Creativity in Mechanical Design: Establishing Student Perceptions of Creative Designs and Impediments to Creative Solutions

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ABSTRACT

CONTEXT

Approaches to the measurement of creativity levels have been previously considered using methodologies such as the Creative Engineering Design Assessment method (CEDA) (Charyton, 2014) and further studies done by (Cropley & Cropley, 2000). Whilst statistical creativity measurement tools are available, a method for determining the perception and creativity levels of a particular cohort in their candidature is much needed (Belski, 2017). This study focuses on student's perceptions of what they perceive to be a creative design and the impediments to the presentation of creative solutions throughout their candidature.

PURPOSE OR GOAL

This study focused on two hypothesis. The first hypothesis focused on investigating if students' perceptions of what they consider to be a creative solution alters throughout their candidature. The second hypothesis focused on the impediments that students may have towards presenting creative solutions. Students have the potential to develop creative solutions to problems. However authors such as, (Kazerounian & Foley, 2007) identify, 'creativity blockers', whilst (Liu & Schonwetter, 2004) note 'blocks to creativity' which indicates that students prefer to present conventional rather than creative solutions.

APPROACH OR METHODOLOGY/METHODS

A longitudinal open-ended survey has been adopted as the methodology to examine the broad area of creativity in engineering students from the Schools of Aerospace, Mechanical and Mechatronic Engineering (AMME) and Biomedical Engineering at the University of Sydney. Students were surveyed whilst enrolled in design centred units of study under the conditions of Ethics Clearance Project Number 2018/630. Survey data was collected, analysed and categorised from five discreet student cohorts at different stages of their candidature. The data was used to test both hypothesis using a two-tailed proportion test (p-test) (Devore, 2017) (p. 391) method to compare adjacent cohorts incrementally.

ACTUAL OR ANTICIPATED OUTCOMES

The key observations made indicate that students' perceptions of examples of creative solutions or impediments they have to presenting creative solutions, do not alter significantly across their candidature.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The chief conclusions drawn from this study indicate that there are minor rejections of both hypothesis. These rejections are noted when comparing 2nd year vs 3rd year cohorts in students' perceptions of creativity and the impediments that they face when considering presenting creative solutions. Further qualitative research of these cohorts is required by undertaking standardised open-ended interviews, (Patton, 1980) (p. 206) to better understand the reasons for the rejection of both hypothesis.

KEYWORDS

Design, Creativity, Proportion Test

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BACKGROUND

Critical thinking and creativity skills are of paramount importance in engineering graduates. Current initiatives starting from a secondary education level include the N.S.W. State Government incentive, (Education, 2021). Programs at this level of education were driven by tertiary and industry bodies that are seeking to develop students into agency rich, critical thinkers that poses leadership skills. Industry expectations noted from studies conducted by organisations such as the (QS Intelligence Unit, 2019) of engineering graduate attributes, rate creativity at 82/100 in terms its importance. However, industry satisfaction of engineering graduates level of creativity was only rated at 64/100. Engineers Australia go further by, clearly reinforcing that engineering graduates have a, 'creativity, innovative and pro-active demeanour' as part of their professional and personal attributes (Engineers Australia, 2019). There is a need for a study to better understand creativity in terms of what students perceive to be creative coupled with the impediments to presenting creative solutions. How these two paradigms may change throughout their candidature is also critically important in curriculum development and in developing the creativity skills of the 21st century engineer. Previous studies using the method of literature review by (Mullet et al., 2016) focused on teachers and identified that, 'Teachers felt unprepared to foster or identify creativity'. A similar outcome that compared tutor to student perceptions of creativity was arrived at by (Rodgers & Jones, 2017) who utilised a semi-structured interview approach to identify the value of, 'understanding creativity more in order to improve teaching activities'. A more student focused study was undertaken using the CEDA (Charyton, 2014) approach using a mixed method was undertaken by (Carpenter, 2016) who focused on four primary creativity themes resulting in recommendations to, 'understand where differences in perception exist'.

METHODOLOGY

In order to carry out the analysis to test the two hypothesis being considered are:

1. *Do students' perceptions of what constitutes a creative solution alter throughout their candidature?*
2. *Do the impediments that students may have towards presenting creative solutions alter throughout the candidature?*

The approach adopted in this study focused on using a longitudinal (across a period of twelve months), open-ended survey that contained a mixture of questions that were either in a quantitative or qualitative answer format. This survey structure was adopted to gather responses in a mixed format that included a combination of closed-ended questions and open-ended questions on a number of creativity focused topics.

Students enrolled in units of study that had either an introductory or design focus offered at either the School of Aerospace, Mechanical and Mechatronic Engineering or the School of Biomedical Engineering at the Faculty of Engineering and IT, University of Sydney were given the opportunity to take part in the survey. The students who took part in the survey were distributed between: first year-first semester (these are students who had only been part of a cohort for a number of weeks), first year (these are students that had been part of the first year cohort for more than six months i.e. previous year, mid-year entry), second year, third year, and final year or postgraduate by course work cohorts. The participating students were enrolled in either: aeronautical/space, biomedical, mechanical or mechatronics as their main stream. In total over 1000 students had the opportunity to contribute to the survey, at the time of writing, 332 responses were recorded and analysed with the available data from 'not fully completed' responses still considered. All data was considered and no 'sampling' (Creswell, 2014) of the data took place.

The longitudinal survey approach was initially chosen for this study as it provided flexibility with the type of questions that could be asked across a variety of cohorts over a large period of time. The rapid turnaround of results compared to interviewing members of each cohort was also a driving factor in choosing this method. The survey method also provided valuable feedback for drafting a future interview structured qualitative study, which was its key goal.

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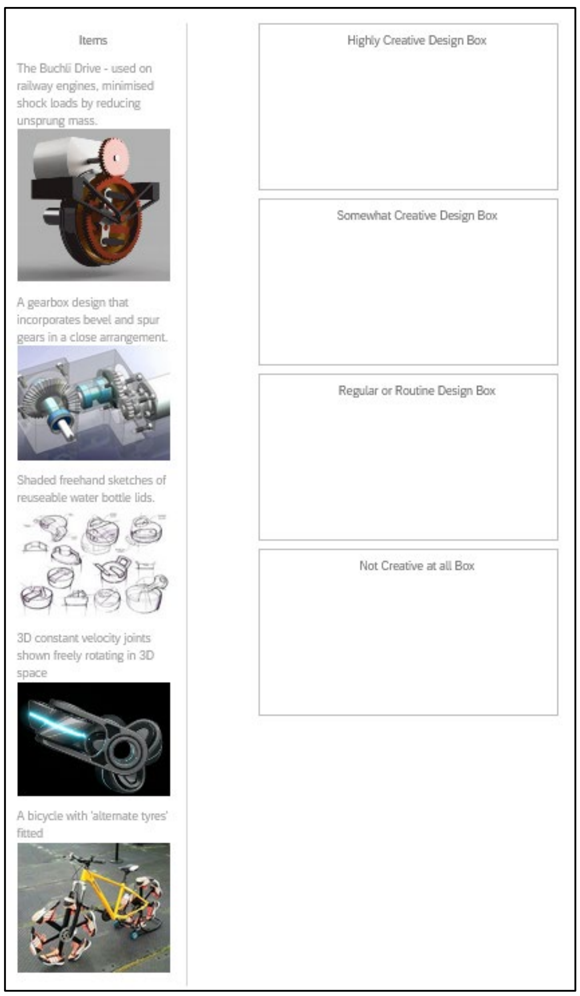
Qualtrics© was used as a platform for drafting and editing each survey question and also as a method of generating results in the form of data that was analysed using MS EXCEL©. The survey was initially tested on Tutors who were involved in the units of study being surveyed with an aim to identify points of confusion or logic errors in the flow of the script. The survey structure was defined by thirteen questions that could be categorised into six broad creativity themes that focused on: student candidature and demographics, identification and definition of creativity, method of creativity used, student extracurricular activities plus associations and barriers to creativity encountered. This study focused on analysing the themes of identification and barriers to creativity with the data stratified in terms of each student's year of candidature.

Survey Structure

Two key questions (Questions 3 and 11) which are the focus of this study are included below. Interested researchers are encouraged to contact the principal author to obtain access to all of the survey questions delivered via Qualtrics©. The typical survey question structure involved initially presenting the survey question followed by a statement to explain its axiology. No randomisation was utilised in determining the order of the questions.

Question 3 of 13: Move the following examples of design into the box which you think best fits their level of Creativity. The purpose of this question is to establish from the samples provided which YOU can relate to as being the most creative.



<drag and drop>

Question 3 of the survey used a combination of images and brief descriptive text to identify their function or purpose. The 'Buchli Drive' (1) (Buchli, 1919) incorporates elements of traditional mechanical design i.e. gears and linkages, combined in a compact and novel arrangement. The 'gearbox design' (2) image illustrates a conventional arrangement of gears driven by a face mounted electric motor. Although the 'Shaded Freehand Sketches' (3) image depicts an important phase of the design process, the sketches that are being drafted depict a conventional water bottle. The '3D constant velocity joints', (4) image illustrates two constant velocity joints that have non-orthogonal geometry transmitting synchronous motion in three dimensional space. The final image, 'bicycle with 'alternate' tyres fitted' (4) illustrates an almost comical solution to a design problem. One potential limitation of the images chosen for the survey include the mixed use of animated (1) and (4) and fixed (2), (3) and (5) images which may introduce selection bias. Further refinement of this part of the survey in terms of image analysis is warranted by implementing visual ethnography methods (Rose, 2016) (p. 26).

Question 11 of the survey focused on the barriers that students have in presenting creative solutions. Liu and Schonwetter (2004) define these barriers as, 'blocks to creativity' which are also emphasised by authors such as (Christiano & Ramirez, 1993). However, these impediments do not appear to have been investigated or tested previously by the use of the survey method. Having a better understanding of the barriers that imped students from demonstrating creativity in their assessments is critical for two reasons. Firstly, insights will be gained into the impediment areas that need to be better understood and dissolved and secondly, the study may indicate that student creativity development may not be needed as students may be creative, but just unwilling to demonstrate it in their assessments.

Question 11 of 13: Have you ever felt any barriers to presenting a Creative solution?
Select as many or as few options from the list below, we would like to know what barriers you have struck when you have tried to be Creative.

- *Fear of the Unknown - Do you avoid uncertain assessment feedback by not presenting Creative solutions in an assignment?*
- *Fear of Failure - Do you avoid potential failure in an assessment by removing Creative solutions from an assignment?*
- *Reluctance to Exert Influence - Do you feel uncomfortable exerting Creative solutions on others? e.g. in group work*
- *Frustration Avoidance - Do you find it easier to not persist with a Creative solution when faced with barriers?*
- *Resource Myopia - Do you feel that you may not have Creativity skills and/or the world around you is unsupportive of Creative solutions?*
- *Custom Bound - Do you feel that a traditional approach to a solution method would better than a Creative solution?*
- *Reluctance to Play - Do you feel that approaching a problem in a 'light-hearted' way is less productive than directly arriving at a Creative solution?*
- *Impoverished Emotional Life - Do you hold back on your emotions when arriving at a Creative solution?*
- *Over Certainty - Do you check and recheck your assumptions when you arrive at a Creative solution?*

METHOD

This study utilised the statistical proportional test (p-test) as two adjoining population proportions are being considered. A t-test was not considered to be appropriate as the data collected did not have a numerical value as in the measurement of a dimension or the value obtained from a Likert scale that a mean value could be extracted from. As a benchmark, the key population examined was the first-year, first- semester cohort vs the first year cohort. The first-year first-semester cohort was an important addition to the survey as they were offered the survey within two weeks of their commencement of candidature.

Hypothesis Testing:

In order to test if the data of each cohort has similar proportions to its adjoining, the difference between each respective proportion was tested.
The hypothesis test consisted of the following steps:

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$$Null\ Hypothesis \rightarrow H_0: P_2 - P_1 = 0$$

$$Alternative\ Hypothesis \rightarrow H_1: P_2 - P_1 \neq 0$$

Where P_1 refers to the proportion of students in (an example) the year 1 semester 1 (Y_1S_1) cohort and P_2 refers to the proportion of students in the year 1 cohort. The year 1 cohort was made up from students that may have been in the second semester of their first year.

Proportional Nomenclature:

$$\hat{p}_n = Proportion\ of\ Respective\ Data\ Set = \frac{X_n}{N_n}$$

$$= \frac{Number\ of\ Sucesses\ (COUNT)}{Number\ of\ people\ who\ submitted\ survey\ in\ their\ respective\ year}$$

$$Y_1S_1 \rightarrow \hat{p}_1 = \frac{X_1}{N_1}$$

$$Y_1 \rightarrow \hat{p}_2 = \frac{X_2}{N_2}$$

$$\hat{p}_{general} = \frac{X_1 + X_2}{N_1 + N_2} = Natural\ Estimator\ of\ \hat{p}$$

The analysis then compared the Y_1 cohort to the Y_{n+1} cohort i.e.

$$Y_1 \rightarrow \hat{p}_1 = \frac{X_1}{N_1}$$

$$Y_2 \rightarrow \hat{p}_2 = \frac{X_2}{N_2}$$

This analysis was repeated incrementally for Y_3 and Y_4 which was inclusive of higher years e.g. year 1 (Y_1) vs year 2 (Y_2), year 2 (Y_2) vs year 3 (Y_3) and year 3 (Y_3) vs years 4 (Y_4), 5 and postgraduates by coursework inclusive. A final, overall analysis of year 1 semester 1 (Y_1 S_1) vs years 4 (Y_4), 5 and Postgraduates by coursework was also carried out to investigate if an overall null hypothesis existed between cohorts at opposite ends of their candidature.

Confidence Interval:

Since the number of students completing the survey is low, the use of a 90% confidence interval, a 90% critical value (CV) was used (Barlett et al., 2001). Since each test is two tailed i.e. testing if the difference is or not equal to zero as dictated in the hypothesis test, the remaining 10% threshold is divided by 2 to consider each tail.

$$p_1 = p_2 = \frac{1 - 0.9}{2} = 0.05$$

Z Testing:

In the case of a two proportions test, the test statistic, Z represents a value in a distribution that is approximately standard normal (Devore, 2017) (p. 392).

$$Z = \frac{(\hat{p}_2 - \hat{p}_1) - (p_2 - p_1)}{\sqrt{\hat{p}_{general}\left(1 - \hat{p}_{general}\right) * (\frac{1}{n_1} + \frac{1}{n_2})}}$$

P Testing:

The p value was the obtained by inserting the value of Z in each case analysed by using the online p calculator tool. (Stangroom, 2021)

Hence in the cases (as there are two sides) where;

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$Z\ is - ve$, a value of $p > 0.05$ will retain the null hypothesis H_0.
$Z\ is - ve$, a value of $p < 0.05$ will reject the null hypothesis H_0.
$Z\ is + ve$, a value of $1 - p > 0.05$ will retain the null hypothesis H_0.
$Z\ is + ve$, a value of $1 - p < 0.05$ will reject the null hypothesis H_0.

The criteria form the decisions as to whether the null hypothesis H_0 is retained and therefore the two data sets have similar proportionality or the null hypothesis H_0 is rejected and the two data sets do not have similar proportionality. The analysis procedure was then performed for the cases analysed for each of the two hypothesis being considered.

RESULTS

When considering the first Hypothesis, i.e., '*Do students' perceptions of what constitutes a creative solution alter throughout their candidature?,* the results of the survey for 1st year 1st semester vs 1st year cohorts retained the null hypothesis H_0 in all cases analysed with one exception. The sole exception relates to the student perception of the creativity level of the, 'Gearbox Design' (2). In the, 'Not Creative at all Box' where the probability value (p-value) of $0.0054 < p_{x(\alpha/2)}$ 0.05 critical value (CV). This result is depicted in Figure 1.0 and implies that students have gained a greater awareness that a conventional gearbox design is not high in terms of creativity levels. One reason for this assumption is that the year 1 cohort has gained a greater appreciation of design and creativity within their first year of candidature than the semester 1 year 1 cohort. This argument is reinforced by no further statistical rejections in subsequent years noted in this category. For clarity of presentation in the bottom axis of each graph, Figure 1 the bottom axis '*Examples of Creativity*' is represented by the corresponding numbers rather than their names; 'Buchli Drive' (Buchli, 1919) (1), 'Gearbox Design' (2), 'Freehand Sketch' (3), '3D Constant Velocity Joint' (4) and 'Bicycle with Shoes' (5).

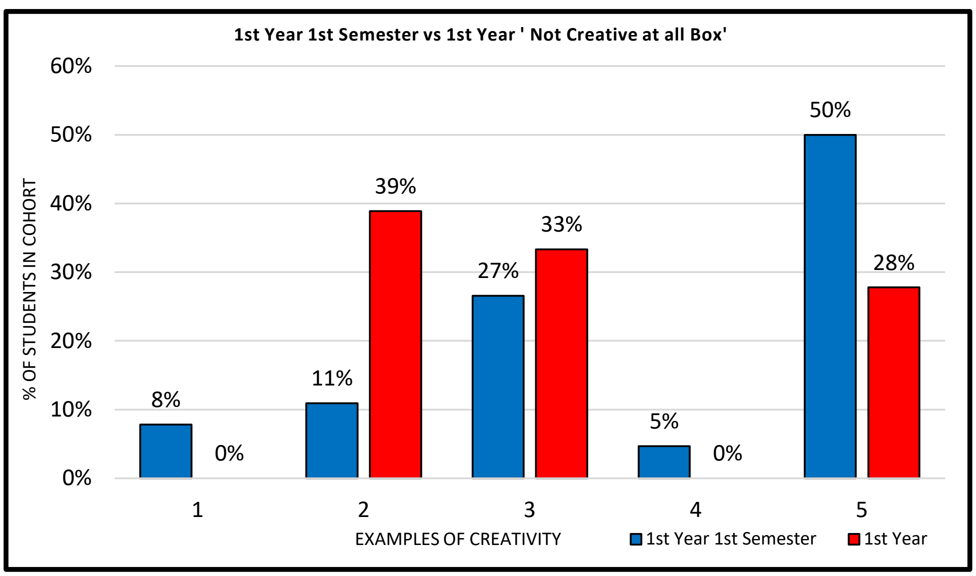

Figure 1.0 illustrates the rejection of the null hypothesis for the 'Gearbox Design' (2) when comparing 1st Year 1st Semester Students against 1st Year Students for the 'Not Creative at all Box'.

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The results of the survey for 1st year vs 2nd year cohorts retained the null hypothesis H_0 in all cases analysed with two exceptions. The exception of the perception of the creativity level of the, 'Bicycle with Shoes' (5). In both the, 'Highly Creative Box' and the 'Not Creative at all Box' where the probability value (p-value) of 0.0456 < $px_{(\alpha/2)}$ 0.05 critical value (CV) and 0.0343 < $px_{(\alpha/2)}$ 0.05 critical value (CV). The 'Bicycle with Shoes' example was intended to be a facetious 'example' of improvised creativity.

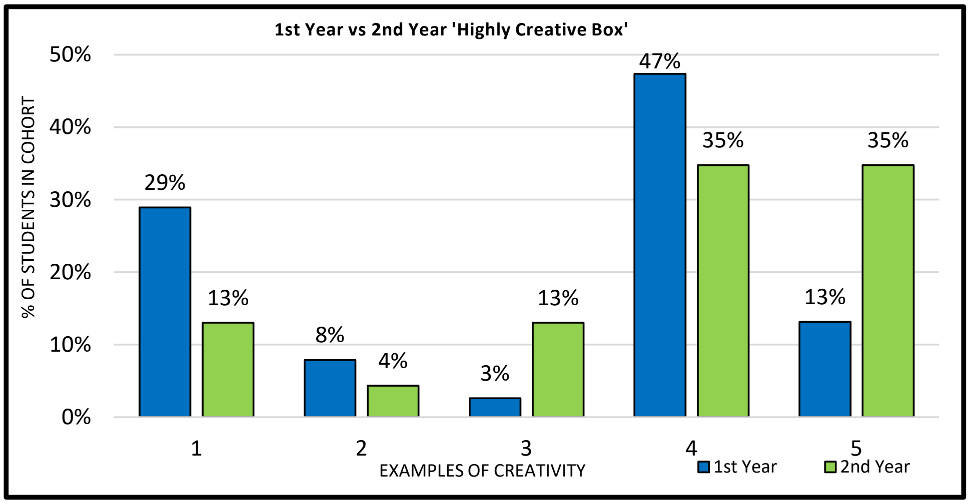

Figure 2.0 illustrates rejection of the null hypothesis for the 'Bicycle with Shoes' (5) when comparing 1st Year 1st Semester Students against 1st Year Students for the 'Highly Creative Box'.

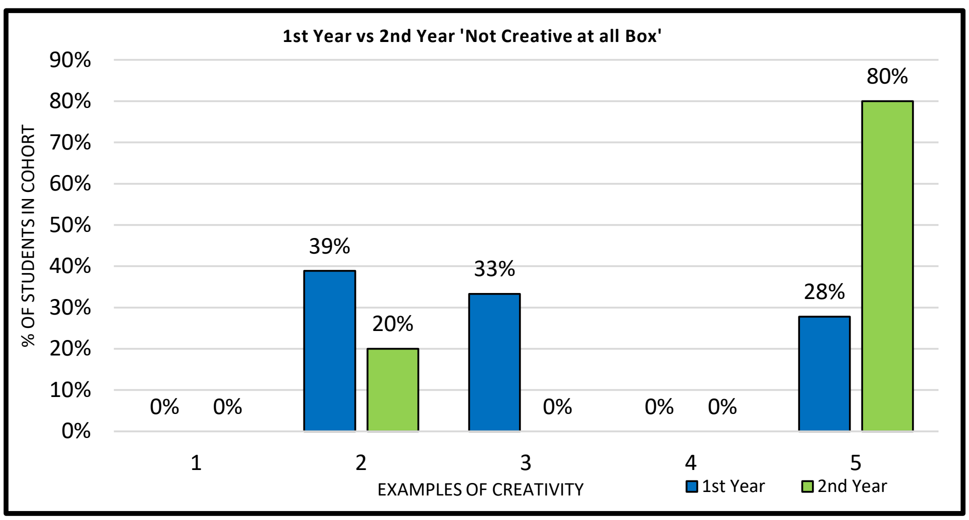

Figure 3.0 illustrates rejection of the null hypothesis for the 'Bicycle with Shoes' (5) when comparing 1st Year 1st Semester Students against 1st Year Students for the 'Not Creative at all Box'.

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The ‘Bicycle with Shoes’ example was intended to be a facetious ‘example’ of improvised creativity. As the exception is noted in both of the extremes of perception of student creativity, i.e. the ‘Highly Creative Box’ vs ‘Not Creative at all Box’. This potentially indicates that this image has been interpreted differently within each cohort i.e. some students see the image as a strong example of creativity and some saw it as not creative at all. However, the smaller data set in this and in more senior cohort studies, hampers a more definite analysis. No further statistical rejections in any subsequent years were noted in this category.

The results of the survey for the 2nd year vs 3rd year and 3rd year vs 4th year cohorts retained the null hypothesis H_0 in all cases which indicated a strong level of stability in student cohorts’ perceptions of creativity throughout these three years of candidature. This may be indicative of fewer units of study that contain or promote creativity being undertaken by students. Further examination to confirm this assumption could involve a degree stream based stratified thematic study of each cohort’s curriculum on a unit of study creativity content basis.

A final analysis to compare the results of the survey for 1st year 1st semester vs 4th, 5th and postgraduate cohorts combined was undertaken to provide an overall, ‘cradle to grave’ perspective. The result for this analysis task retained the null hypothesis H_0 in all cases analysed with two exceptions.

The first exception relates to the result for the creativity level of the, ‘Freehand Sketch’ (3). In the, ‘Highly Creative Box’ where the probability value (p-value) of $0.0124 < p_{x(\alpha/2)}$ 0.05 critical value (CV). The image depicted in the ‘Freehand Sketch’ (3) demonstrates a stage in the design process (Budynas & Nisbett, 2021) by illustrating the design of a water bottle. The exception to the null hypothesis could be connected with first year first semester students not being aware that freehand sketching plays an important part in the development of spatial skills (Sorby, 2009) and its place in the design process. In contrast, the combined 4th, 5th and postgraduate cohorts have been through the design process by completing a number of units of study that both teach and require freehand sketching skills.

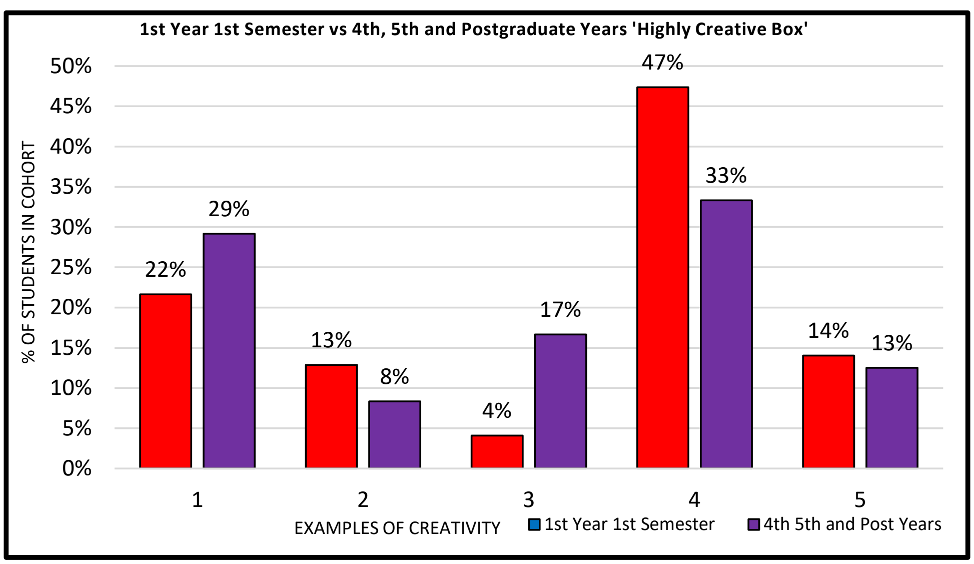

Figure 4.0 illustrates rejection of the null hypothesis for the ‘Freehand Sketch’ (3) when comparing 1st Year 1st Semester Students against 4th, 5th and Postgraduate Students for the ‘Highly Creative Box’.

The second exception relates to the result for the creativity level of the, ‘3D Constant Velocity Joint’. In the, ‘Regular or Routine Level of Creativity Box’ where the probability value (p-value) of 0.0029 < $p_{x(\alpha/2)}$ 0.05 critical value (CV). The image depicted in the ‘3D Constant Velocity Joint’ (4) illustrates a rendered non-orthogonal mechanism in motion. The 1st year 1st semester vs 4th, 5th and postgraduate cohorts identify the creativity level of the image differently. The 1st year 1st semester students potentially see the image as a highly creative example that is not routine or identifiable within the creativity domains they have so far been exposed to. The 4th, 5th and postgraduate year cohorts have been exposed to units of study and work experiences and consequently may see the image as representing a more routine example of creativity.

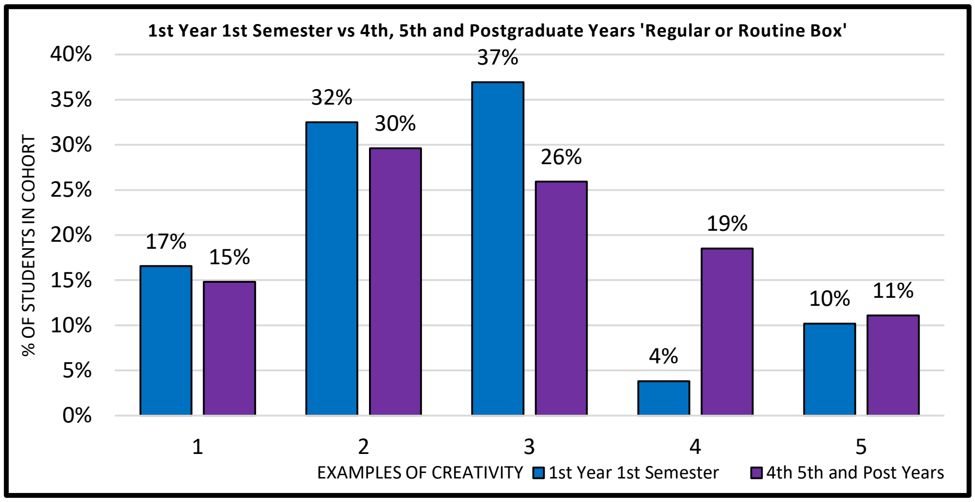

Figure 5.0 illustrates rejection of the null hypothesis for the ‘3D Constant Velocity Joint’ (4) when comparing 1st Year 1st Semester Students against 4th, 5th and Postgraduate Students for the ‘Regular or Routine Box’.

When the considering the second hypothesis, i.e., ‘*Do the impediments that students may have towards presenting creative solutions alter throughout the candidature?’* the results of the survey for all cohorts retained the null hypothesis H_0 in all cases analysed with one exception noted for the 2nd year vs 3rd year cohorts illustrated in Figure 6.0. In the Impediment ‘Reluctance to Play’ (7) the null hypothesis was rejected as the probability value (p-value) of 0.0448 < $p_{x(\alpha/2)}$ 0.05 critical value (CV). This result is only marginally outside of the critical value. An additional observation was that the barrier, ‘Fear of Failure’ (2), was noted as being an impediment in all except the 4th, 5th and postgraduate cohorts. This outcome is indicative of students being reluctant to take risks in introducing creativity within their assessment solutions. One potential reason for this result is that the ‘Fear of Failure’ (2) is closely linked to students, ‘fear of losing marks’ i.e. students are results driven and are not inclined to take the risk without strong resource support from the unit of study and the hosting institution.

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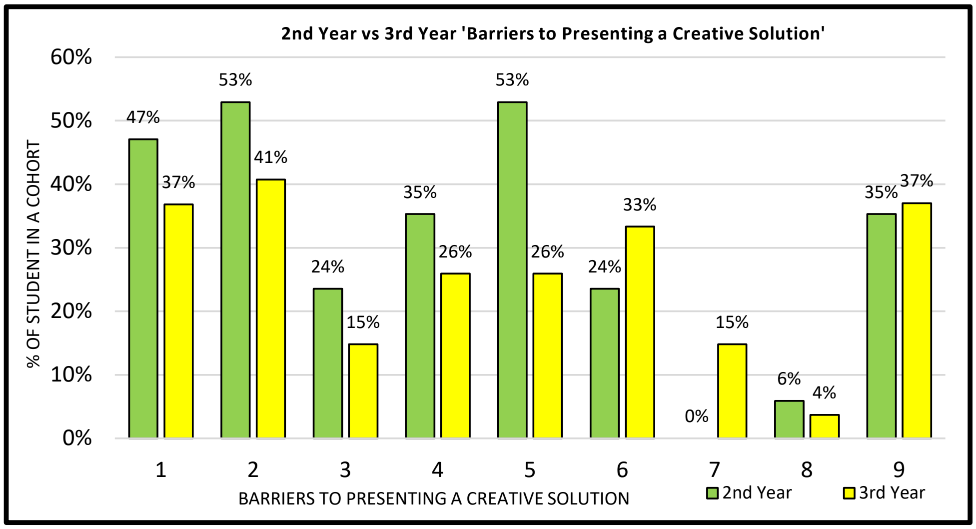

Figure 6.0 illustrates 2nd year vs 3rd year cohorts rejection of the null hypothesis in the Impediment 'Reluctance to Play' (7)

CONCLUSIONS

When considering the first hypothesis, the survey results highlight some irregularities. In the case of the interpretation of the perceived creativity level of the 'gearbox design', between the 1st year 1st semester vs 1st year cohorts is indicative of 1st year students having a greater knowledge of mechanical systems than 1st year 1st semester students this is expected as a cohort progresses through its candidature. In the case of the creativity level perceived of the 'Bicycle with Shoes' between 1st year vs 2nd year cohorts, the interpretation of a creativity level has acted as variable and indicative of the need for images within the survey that were better focused on one theme. In the third case, 'Freehand Sketch' between 1st year 1st semester students vs 4th, 5th and postgraduate year cohorts, the role that the image plays in the design process has been appreciated by the more senior cohort. This is a positive indicator of the important awareness that spatial skills plays in the teaching of the design process. In the final case of the first hypothesis, the '3D Constant Velocity Joint' between 1st year 1st semester students vs 4th, 5th and postgraduate year cohorts the results are indicative of a level of maturity in the appreciation of mechanical design as students' progress through their candidature. When considering the second hypothesis, the barrier, ''Reluctance to Play' in the 2nd year vs 3rd year cohorts, the rejection of the hypothesis is indicative that the more senior cohort is more likely to devote time to consider divergent ideation methods rather than converging on one solution. This not desirable from an educational perspective.

Although the survey presented requires some level of refinement and benchmarking against external cohorts to strengthen its external validity (*Statsdirect*, 2021), it has served the purpose of highlighting points from which to conduct further qualitative research. The use of phenomenography (Case & Light, 2011) as a methodology combined with the method of standardised open-ended interviews would serve to better understand the phenomenon. The proposed research has important implications for teaching staff and students in the teaching of creativity within the context of the design process and the future structure of design focused assessments.

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Demographic Mediation of the Relationship Between Engagement and Performance in a Blended Dynamics Engineering Course

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ABSTRACT

CONTEXT
This paper examines an engineering dynamics course at Purdue University that was specifically designed to create an active, blended, and collaborative environment. In addition to in-person classes and support, students have access to blended content such as solution videos, mechanics visualizations, a course discussion forum, and interactive simulations.

PURPOSE
Many studies have shown that students' engagement in an online discussion forum enhances their learning performance (Davies & Graff, 2005; Hrastinski, 2008). However, our previous research showed that students' engagement in the online forum of our dynamics course differed significantly across students' demographics. We showed that women, white, or Asian American students were more likely to be involved in online discussions than men, international, or Hispanic students (Duan et al., 2018). In this paper, we take the previous analysis further by examining whether the observed differences in online student engagement mediate or moderate student performance.

APPROACH
To answer our research question, we will first investigate the mediation effect by creating two models. A first model with race/international status as the mediating variable and gender identity as a control variable, and a second model with gender identity as the mediating variable and race/international status as a control. Second, we will investigate the moderation effect of demographic factors by creating a regression model including interaction terms to show the relationship of each demographic's discussion forum engagement to overall performance. The goal of investigating these interaction terms is to determine if a moderating relationship exists where demographic factors impact online engagement, which in turn impact course performance.

CONCLUSIONS
We find that gender identity is the only significant demographic factor that moderates the effect of a student's engagement on their performance. Based on the findings of our previous work, students of various racial and ethnic identities do engage differently in the discussion forum. However, this analysis was unable to detect any significant difference in student engagement based on demographics. Our paper contributes to understanding the mechanisms through which students' engagement can translate into academic performance by focusing on their demographic background. The moderating role of students' demographic background calls for a more targeted design of instructional tools in blended and collaborative environments to better support students from various demographic backgrounds.

KEYWORDS
Mediation Analysis, Dynamics Course, Demographics

Introduction

Freeform is an Active, Blended, Collaborative (ABC) that started in the School of Mechanical Engineering at Purdue University in 2008 in order to incorporate Active, Blended, and Collaborative elements into a typical dynamics course. The ABC approach was later expanded to include more courses in the mechanics sequence and has since been expanded to additional schools (DeBoer et al., 2016). A Freeform course includes hybrid textbooks paired with an interactive online learning environment and course discussion forums (Rhoads et al., 2014). Previous studies have looked at student data collected from multiple semesters and have examined both student (Stites et al., 2019) and instructor (DeBoer et al., 2016) behaviours within the course. Among student behaviours, prior research has concluded that the “ABC” approach contributes to a higher passing rate (Rhoads et al., 2014). Further, these studies have found some differences in course engagement based on demographics when engagement is measured through a binary variable of participation or non-participation in the discussion forum (Duan et al., 2018). Differences have also been found in engagement (where engagement was defined as participation in the various course resources) based on preference for how students engage with course resources (Stites et al., 2019). These studies concluded that women were more engaged with the online discussion forum than men. Likewise, Asian Americans engaged the most while underrepresented minoritized students (specifically Hispanic, Latino, and African American students within this study) engaged the least when compared to their representation in class overall (Duan et al., 2018).

Literature Review

Many studies suggest that engaging in a collaborative online learning environment has the potential to enhance students’ learning (Berger & Wild, 2016; Hiltz, 2019; Williams et al., 2006). By engaging with their classmates, students could learn from and assist one another in the learning process and therefore improve their academic performance (Yuan & Powell, 2013). However, previous research has also shown that online learning environments do not benefit all students in the same way. In fact, Ke and Kwak (2013) show how students’ ethnicities correlate to their participation in an online learning forum. Underrepresented minority groups who participated less in the course forum also reported lower levels of satisfaction with the web-based and distance-learning class, which the authors concluded was due to the important role discussion forums served in these courses as a place for students to interact with one another and the professors. Ke and Kwak’s work also showed how international students were less comfortable engaging in public online spaces, and thus engaged less in online discussion forums (Ke & Kwak, 2013). These differences in students’ engagement based on their demographic factors might result in differences in academic performances in the context of a blended course. In this paper, we will study whether differences in students’ engagement across demographic factors mediates or moderates students’ course performance. The context of this study is the innovative Active, Blended, and Collaborative (ABC) dynamics learning environment called Freeform.

Methods

Our dataset includes transcript-level data of all students enrolled in dynamics (2000-present), gradebook-level data for dynamics performance for nearly all of the offerings of the course (2012-present), data from various surveys (2015-present), performance on concept inventory and fundamentals exams (2015-present), discussion forum engagement data (most semesters 2015-present), and student-level data obtained from university data sources (demographics, admissions data; 2000-present). For this study, we subset this data to include only: (i) students who consented to participate in the study, and (ii) students enrolled

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in semesters for which we collected discussion forum data. We further confined the dataset for this study to include only Spring semesters because students, according to the standard plan of study, enroll in dynamics in the Spring of the second year. The dataset includes Spring data from 2015, 2017, 2018, 2019, 2020. All students from these semesters are included in the dataset regardless of their level of participation in the discussion forum.

This study uses forum activity, demographic information, and course grades as variables to determine the mediating effect of demographic variables for engagement with the discussion forum on performance. Demographic information will include gender identity and race/international status. Our institution categorizes international students' race/ethnicity as 'international' without gathering/storing additional information on their racial identity. Additionally, to protect student identities and create comparable groups within the dataset, student racial and ethnic identities had to further be simplified to White, Asian American, Underrepresented Minoritized Students (URM), and International Students. Underrepresented Minoritized Students (URM) included Hispanic, Latino, African American, and those who were categorized in the "Other" category as had been done in previous analyses of this data (Duan et al., 2018). These simplifications allow for a larger overview of mediation and moderation effects on how students participate and perform in the course. To perform these analyses,the groups being compared must be of significant enough size. The fact that these URM groups are so small (none are over 100 and some are as small as 19) reflects a lack of diversity represented in these courses. This problematic grouping into the larger category of URM does potentially obscure important data on how students experience their racial and ethnic identities within the classroom. We derived participant sex from institutional data, which only allows individuals to specify 'male' or 'female'. We understand that this practice is problematic and does not allow individuals to express the full diversity of gender identities.

Engagement with the discussion forum will be defined through pagerank, a social network analysis method explained below. Pagerank is an ordinal measurement.Thus, pagerank is best used in comparison of students to one another and gives less information on its own (Stevens, 1946). The authors used GEPHI 0.9.2 to calculate each student's pagerank, which shows their level of engagement compared to others in their same semester (Lee et al., 2021). Students are ranked based on the number of posts they make and the relative importance of their posts (examined through number of responses they receive and the relative importance of the respondents). In other words, posts that come from more active respondents who generate more comments are ranked higher. For instance, one student may only post questions such as "What day is the final exam?" that may only generate one comment. In contrast, another student may post deeper questions that lead to a larger discussion (several comments). While just analysing the number of posts may favour the first student, pagerank looks at interaction generated by the posts to better characterize engagement. As will later be shown in Figure 2, a majority of students who did post only still have a very low pagerank. Likely these students posted only once and their posts received no or few comments. Whereas, students who are outliers likely were not only posting frequently, but creating posts that other students commented on frequently. One limitation to this analysis is that it does fail to account for the relevance of posts (e.g. a post on a topic unrelated to the course that receives high engagement). However, since this analysis is not looking at individual posts but the overall engagement with posts created by individual students, we assumed that the effect of irrelevant posts is negligible.

Performance is characterized by final course grade on a 4.0 scale where a 4.0 corresponds to an A (90%-100%). Control variables will include GPA prior to the course and performance in the prerequisite course (statics).

None of the demographic variables in the data were missing for any of the student analysed in this study. Co-occurring missingness was examined and no patterns existed in missingness among the variables examined. Multiple imputation using R's MICE package was completed before analysing the data (van Buuren & Groothuis-Oudshoorn, 2011).

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This paper hypothesizes that a significant mediating effect exists for demographics (gender identity, race, and international status) on engagement which in turn affects performance as shown in Figure 1. Prior work has established a relationship between demographics and engagement in the online discussion forum (Duan et al., 2018) reflected in Figure 1 as relationship A. Literature has established a relationship between engagement in an online discussion forum and performance (Davies & Graff, 2005; Hrastinski, 2008) reflected as relationship C in the figure. Since engagement correlates to performance and demographics relate to engagement, this paper proposes a pathway AB through which demographics act as a mediating variable for engagement thus impacting overall performance.

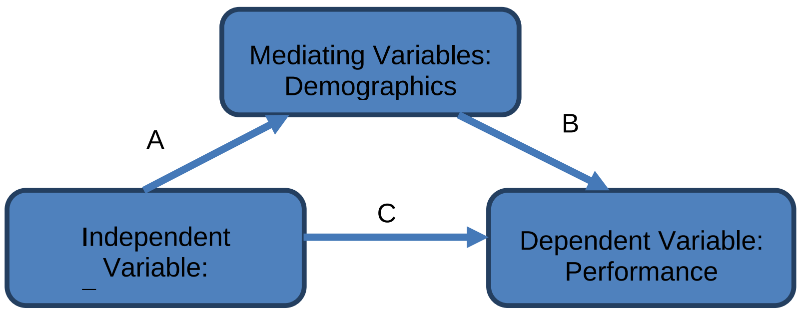

Figure 1: Conceptual Model – Mediating Effect

To investigate the hypothesized mediation effect, we used *mediate* in R's *mediation* package (Tingley et al., 2014) as well as bootstrapping to test if a significant mediating relationship exists. This analysis uses relationship A and C to test if relationship B exists and is significant. To investigate the hypothesized moderation effect, we created three models; Model 1 without demographic factors, Model 2 with demographic factors and Model 3 with interaction terms.

Descriptive Statistics

Table 1. Summary Statistics

	Mean	Standard Deviation	Min-Max	
Final Grade	2.6	0.9	0.0-4.0	
PreReq* Grade	3.1	0.8	0.7-4.0	
GPA	3.4	0.4	0.0-4.0	
Pagerank	0.0011	0.0031	0.0000-0.0384	
	Men	**Women**		
Gender	1518	352		
	White	**URM**	**Asian American**	**International**
Race/Ethnicity	1146	201	154	369

*PreReq = Prerequisite course (statics)

From the summary statistics, it is important to note that pagerank does not have a normal distribution. Most students never posted on the discussion forum and thus have a pagerank of zero meaning that the variable is zero-inflated. The median values of pagerank are the same for each demographic category (median = 0) as a majority of students in all

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demographic categories did not engage with the discussion forum. Figure 2 shows a violin plot of pagerank with zeros removed revealing that students of different races/international statuses did vary in pagerank. For white students, the overall range but the number of students slowly decreases for higher levels of engagement. Compared to White students, International students have a greater percentage of students at higher values up to pagerank of 0.01 and have higher outlying values than the white student. Additionally, the range of pagerank values for Asian American students is lower than other groups meaning that fewer outliers exist. Prior analyses gave a very different view finding that Asian American students were more likely to participate in the discussion forum when measured through the binary of whether they participated at all in the forum or not. Within this analysis, their data shows a bimodal distribution, but unlike other groups they have no students above a pagerank of 0.01. Thus, building on the prior analysis, this paper shows that while Asian American students were more likely in have at least one post, they engaged in the discussion forum differently than White, URM, and International students.

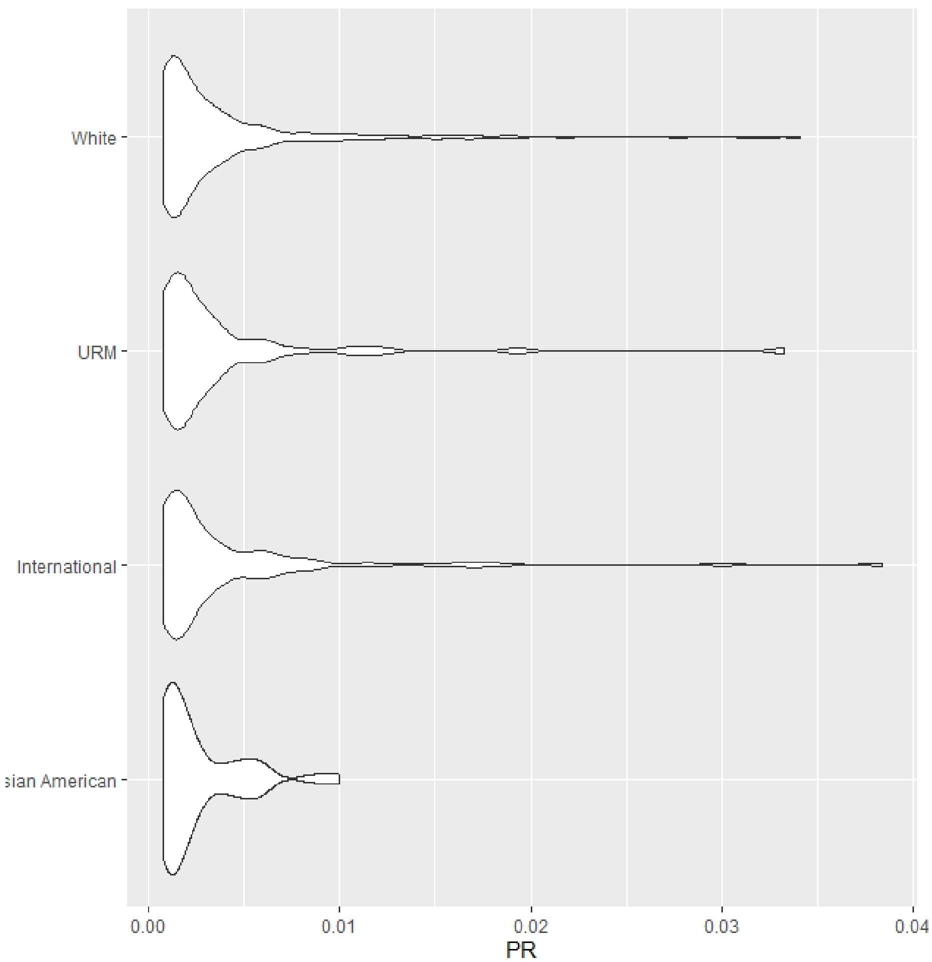

Figure 2. A violin plot of pagerank (with zeros removed) for race/international status

Bivariate analyses were completed for each of the variables. Table 2 shows Spearman correlation tables for numerical variables as several variables violate the assumptions required to do Pearson correlations including normality of variables. Table 3 shows the Kruskal Wallis test for categorical variables used to compare groups within demographics as it is a non-parametric method that does not require equal group sizes and can compare more than 2 groups at once (McKight & Najab, 2010). A significant Kruskal Wallis test indicates that at least one group is significantly different.

Table 2: Spearman Correlation

	Final Grade	Pre-Req Grade	Prior GPA	Pagerank
Final Grade	1			
Pre-Req Grade	0.6603	1		
Prior GPA	0.7061	0.7369	1	
Pagerank	0.1723	0.1456	0.1534	1

Table 3. Kruskal Wallis tests statistics. P-values are in parentheses

	Final Grade	Pre-Req Grade	Prior GPA	Pagerank
Gender Identity	X^2= 13.429 (p < .001)	X^2= 16.999 (p < .001)	X^2= 0.7906 (0.374)	X^2= 5.800 (0.016)
Race/Ethnicity	X^2= 6.895 (0.075)	X^2= 11.225 (0.011)	X^2= 17.240 (p < .001)	X^2= 3.106 (0.376)

Results and Analysis

For both mediation models, no significant mediating effect was found (relationship B in Figure 1). Testing for relationship A, an ordinal and logit regression models for race/international status and gender identity respectively showed no significant relationship between demographics and pagerank. Therefore, no mediation effect was found. Nevertheless, it is important to point out that these models may not accurately deal with the zero-inflated pagerank variable due to a majority of the students choosing not to participate in the online discussion forum.

Table 4. Three Regression Models

	Model 1: Controls	Model 2: Demographics Added	Model 3: Moderation Analysis
Pagerank (PR)	12.036 (p = .009)	12.056 (p = .009)	14.228 (p = .019)
PreReq Grade	0.349 (p < .001)	0.330 (p < .001)	0.328 (p < .001)
GPA	1.022 (p < .001)	1.053 (p < .001)	1.054 (p < .001)
Women		-0.107 (p =.004)	-0.130 (p = .001)
Race/International			

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Status			
URM		-0.014 (p = .767)	0.012 (p = .806)
Asian American		-0.088 (p = .096)	-0.080 (p = .164)
International		-0.127 (p = .001)	-0.116 (p = .003)
Interaction Terms			
PR: Women			22.094 (p = .099)
PR: URM			-27.443 (p =.086)
PR: Asian American			-9.215 (p =.767)
PR: International			-10.233 (p = .349)
AIC	**3500**	**3488**	**3491.4**

For the moderation effect, Model 3 shows how the addition of interaction terms caused the overall effect of engagement on performance to increase from 12.056 to 14.228 while all the other terms between the two models (Demographics and Interaction models) remained similar. As a reminder, this coefficient would be multiplied by the pagerank value for the student (mean = 0.0011). All interaction terms in Model 3 show how the relationship between engagement and performance changes for different demographics. For example, women students would have a 22.094 + 14.228 coefficient for pagerank. For a 0.001 increase in pagerank (similar to the mean value of pagerank), women would on average correlate to a 0.036 increase in performance (final course grade on a 4.0 scale). For the student who achieved the highest pagerank (pagerank = 0.0384), this would result in a 1.382 increase in performance. However, the model also shows that white men (the reference category of our model) has a higher pagerank coefficient (pagerank coefficient= 14.228) than the average student (pagerank coefficient =12.056). In other words, compared with the average student, a 0.001 increase in pagerank would on average correlate to a 0.002 higher final course grade for white men. While interaction terms were not found to be significant to conclude the existence of a moderation effect, this change between the three models does show however a relationship between demographics, online engagement, and performance in the course.

Conclusions and Limitations

This paper showed the existence of a relationship between students' demographic factors, their online engagement in a discussion forum and their course performance. The interaction terms were not significant for moderation and mediation. The differences in coefficients between models as discussed above do show that white men compared with the average student have higher pagerank coefficients in the analysis. This suggests some connection between students' demographic factors, their online engagement in a discussion forum and their course performance. The main limitation of our analysis is the operationalization of variables also presents issues specifically for engagement. Engagement could be operationalized by examining additional offline variables, such as course attendance, which was not gathered in this dataset but has previously been correlated with course grades (Ulmer, 2020) or by examining online variables such as clicks within the online course environment (not fully recorded in this dataset). This paper focuses on online engagement specifically in the discussion forum as it is a key blended (online) component that also allows for collaboration amongst students (Duan et al., 2018), which was also recorded within the dataset.

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An Investigation of Children's, Parents' and Teachers' Perceptions of Engineers and Engineering

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ABSTRACT

CONTEXT

Historic and recent trends indicate that there is a decline in the number of Australian students pursuing engineering careers, with this field also suffering from a lack of gender and ethnic diversity. One explanation revolves around perceptions of engineers and engineering, which are "extremely powerful and influential in human thought and behaviour" (Given, 2008).

PURPOSE OR GOAL

The aim is to develop a richer, more holistic understanding of children's, parents' and teachers' perceptions of engineers and engineering, to better inform the engagement of students in STEM subjects and ultimately, a career in engineering. This paper reports on the pilot investigation of perceptions. Findings from the main study will inform an intervention, to ascertain whether perceptions can be changed.

APPROACH OR METHODOLOGY/METHODS

Underpinned by the Social Cognitive Theory, this research will follow a sequential explanatory mixed methods approach, where a large-scale, cross-sectional study will be implemented, in which data will be collected via self-completion questionnaires followed by semi-structured interviews.

ACTUAL OR ANTICIPATED OUTCOMES

This paper reports on the results from the pilot study, in which a sample of 42 children's and parents' perceptions reported a significant level of familiarity with engineering, perhaps due to sampling bias of parents that happened to have STEM backgrounds. Most of the parents encouraged participation in STEM subjects and communicate mostly accurate information about the Engineering profession to their children, potentially impacting children's self-interests, abilities and positive perceptions of engineers and engineering. Despite these reasons, misconceptions around the Engineering profession still existed.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The pilot study demonstrates that further studies with children, parents and teachers from more diverse backgrounds and demographics of schools need to be performed, as the collected sample is currently biased towards STEM literate parents and children.

KEYWORDS

Perceptions, Diversity, Engineers, Primary School, Parents

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Introduction: Situating the Research

The Australian Engineering Landscape – Study and Employment

Engineers contribute value through creatively applying the principles of science, technology and mathematics to solve global problems, meet societal needs and enhance quality of life.

Alarmingly, commencements in Australian domestic undergraduate and postgraduate engineering courses have declined (slight increase in undergraduate commencements during recent years), also exhibiting a highly skewed sex ratio, with 18% of females commencing engineering studies (Kaspura, 2020). In addition to the lack of gender diversity, Australia's heavy reliance on permanent and temporary skilled migration programs to ameliorate such effects, has generated a lack of ethnic diversity (ibid). Countries which contribute the highest number of engineering graduates per year include China, India, Russia, The United States and Iran (Mackay, 2016).

Barriers to the uptake of school STEM (Science, Technology, Engineering, Mathematics) subjects, which underpin entry into tertiary engineering courses, have been highlighted extensively throughout the literature, with dominating themes such as negative imagery, perception of difficulty, low socioeconomic status, unclear career pathway, uninspiring teaching methods and a lack of encouragement from parents and teachers (Ge & Li, 2017). In the past, literature suggests a highly gendered perception of STEM capabilities between males and females, pointing to potential reasons such as gender stereotypes and stereotype threat, life goal preferences, workplace climate and learning styles (Bible & Hill, 2007; Shih et al., 1999; Spencer et al., 1999; Van Loo & Rydell, 2013). This has negatively influenced female participation in school STEM subjects, a gateway into tertiary engineering courses.

The STEM community is making progress in many areas, such as the implementation of this knowledge towards intervention programs, to improve participation in STEM study and employment. However, a lack of lasting engagement, especially in engineering, remains prevalent within Australia. One factor, absent in the current landscape of work conducted within this area, revolves around individuals' perceptions of engineering specifically.

What are Perceptions?

Given (2008, p. 607) characterises perception as "apprehending reality and experience through the senses, thus enabling discernment of figure, form, language, behaviour, and action." She proposes that perception is analogous to a set of lenses through which an individual views the world. "These lenses evolve from perspectives of location, subjectivity, particularity, history, embodiment, contradiction, and the web of teachings imparted to the individual." (ibid). Often, this interpretation of the world can be substantially different from objective reality and becomes one's truth. Hence "perceptions are extremely powerful and influential in human thought and behaviour" (ibid).

Children's Career Aspirations

Preschool aged children (as early as age 3) can cluster information to develop rudimentary perceptions of categories of work (Lutz & Keil, 2002). This is evident in their early encounters of the question "what do you want to be when you grow up?" Seldom do we hear children specifying an interest in becoming an engineer, let alone a particular engineering discipline. Such career decisions are often determined before children reach middle school, rendering the primary years highly critical in terms of shaping perceptions towards particular subjects and careers (Wyss, Heulskamp & Siebert, 2012). These perceptions do not develop in a psychological vacuum, but are cultivated under the guidance of various contextual factors, such as parental, institutional and societal influences (Wang & Degol, 2017). We next examine children's, parents' and teachers' perceptions of engineers and engineering within the literature.

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Perceptions of Engineers and Engineering

The perception of the general public, engineering students and novice engineers is that solitary technical work dominates engineering practice, one of the most deeply embedded misconceptions. There are similar perceptions among children, parents and teachers:

Perceptions about Engineers as Individuals

- Engineers are male, ‘geeks’ and ‘nerds’, exhibiting physical traits such as glasses, lab coats or pale skin (Hirsch et al., 2014; Leeker et al., 2017; Rivale et al., 2011).
- Engineers are exceptional at science, technology and mathematics but lack many social skills, particularly in communication, teamwork, organisation and leadership (Bazylak et al., 2016, 2017).

Perception about Engineering as a Profession

- Study in engineering is based solely on facts and is irrelevant to the real world (Fredericks et al., 2004; Mena et al., 2009; Myers, 2010).
- The engineering occupation primarily involves physical labour e.g. working in construction and automotive industries, driving trains, operating machines and computers, carried out by solo males (Capobianco et al., 2011, 2017; Chou & Chen, 2017; Newley et al., 2017; Reeping & Reid, 2014; Symons et al., 2015).
- The engineering occupation is generally associated with electrical, mechanical and civil engineering disciplines (Mena et al., 2009; Trenor et al., 2009).
- The engineering occupation does not provide opportunities to make social impacts (Graziano et al., 2011).
- The engineering workplace climate tolerates a poor work-life balance and workplace discrimination (Calnan & Valiquette, 2010; Settles et al., 2012).

Engineering is not usually perceived as a team activity, which may alienate people from considering it as a career choice. However, research indicates that many engineers estimate the actual time spent on solitary technical work (designing, coding, calculating, modelling) is around 10% of working time, with the rest spent on important social interactions of technical nature required to achieve and operationalise solutions (Trevelyan, 2014).

Research suggests that many young students who possess traits highly desirable in engineering such as creativity, curiosity and strong social skills, often do not know enough about the profession. Similarly, parents and teachers, who are their main sources of information, do not know enough about engineering to provide accurate career guidance. It is to be noted that this literature review about perceptions, which shift quickly, may be outdated. Recent work around children’s, parents’ and teachers’ perceptions of engineers and engineering are very limited, substantiating the need for such a study, described below.

Research Aims, Contributions and Implications

The aim of this study is to investigate children’s, parents’ and teachers’ perceptions about engineers and engineering. The overarching research question that will address this aim is: **How do upper primary children (Years 4-6/Ages 9-12), their parents and their teachers perceive engineers and engineering as a discipline and as an occupation, in an Australian (Victorian) context?** Three tiers of research will be conducted (1. Pilot Study, 2. Main Study, 3. Intervention). This paper reports on the pilot investigation of perceptions. Findings from the main study will inform an intervention, to ascertain whether perceptions can be broadened or influenced.

The outcomes of the research may inform approaches to diversity and attraction of more people who are suited to the job, based on the true representation and perception of what engineers do, rather than false or misleading perceptions, helping both potential students and the profession to have the right people. Trevelyan’s (2014) definition of engineering will be used as a reference point: “Expert performance in engineering practice, in its essence,

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requires a combination of technical and financial foresight and planning as well as the technical collaboration performances required to convert plans into reality." It is of benefit to both prospective engineering students and the profession to match up students' interests and strengths to a true representation of what engineers do in their daily activities.

This work can be used to improve engineering-focused educational activities including:

- Careful selection and design of outreach activities
- Recommendations into marketing and communications
- Creating a network of university student mentors, who are more informed about perceptions and can work more successfully in their interactions with schools
- Introducing accurate portrayals of engineering into primary school curriculum

Preliminary and Proposed Research

Theoretical Framework

Social Cognitive Theory (SCT) is used extensively throughout many areas of human functioning, for example in motivation, learning, achievement and career choice, and will inform the theoretical lens for this study (Bandura, 1986). SCT posits that personal factors, the social environment and behaviour influence each other (ibid). Parents, teachers, peers and the media, form the social environment, providing examples of behaviour for children to observe and imitate. Coupled with personal factors, such as behavioural capability, attentiveness, motivation, ability to retain and reproduce information, internal/intrinsic reinforcement, personal expectations and self-efficacy, this influences how children acquire and maintain behaviour, in particular, certain perceptions about engineers and engineering.

Methodology/Method

This research follows a 'sequential explanatory mixed method' design, in which a large-scale, cross-sectional study is currently being implemented with upper primary children (chosen due to the gap in literature and their ability to read, write and understand) and their social environment of parents and teachers. This paper reports on the pilot study, which validates survey and interview questions for the main study, from which an intervention will be introduced to ascertain whether perceptions can be changed. Online data collection via self-completion questionnaires (Qualtrics), followed by semi-structured interviews (Zoom), gains a broader view of the research landscape, with both breadth and depth. An established instrument, licensed from the Institution of Engineering and Technology (IET), has been modified to reflect findings from the literature and Australian context. The structure of the questionnaire includes a combination of 7-point Likert scale, open-ended, ranking, multiple and single selection options. Factual material showcasing a variety of engineering careers is displayed mid-survey, with follow up questions to investigate the effect on participants' perceptions of engineering. Participants are recruited from Government, independent and Catholic schools across Victoria, primarily (but not limited to) via a top-down approach, starting from school leadership to teachers, who distribute the questionnaire to parents via email and school newsletters. Participants who wish to participate in a follow-up interview are contacted via an email address voluntarily provided in their questionnaire. Participants complete the questionnaire and interviews separately. Additionally, the potential interplay between children, parents and teachers is studied via linking of surveys and interviews. This research has been approved by Monash University Human Research Ethics Committee (MUHREC, Project ID 27301), Melbourne Archdiocese Catholic Schools (MACS, Project ID 1089) and the Department of Education and Training (DET, Project ID 2021_004390).

Pilot participants comprise of 21 children (approximately equal gender distribution and mostly in Year 4) and 21 parents (71.4% female) from 6 co-educational schools (4 Catholic, 1 Government and 1 Independent) across the Victorian metropolitan regions. Parents education levels are as follows: 52.4% - Bachelor, 23.8% - Master, 14.3% - Doctorate, 4.8% -

TAFE, 4.8% - secondary school). Their primary occupation was in STEM (81% of parents were engineers, had spouses, family members and other connections who were engineers).

Results and Discussion

Children’s and Parents’ Knowledge about Engineers as Individuals

Whilst negative imagery is still frequently highlighted in the literature, as a cause for the lack of participation in engineering study and employment, as illustrated in Figure 1, no parents and a minority of boys and girls surveyed supported such claims in our sample. Children cited “creative”, “problem solver” and “have social skills”, as the top 3 attributes of engineers. Similarly, parents mentioned “problem solver”, followed by “good at mathematics” and “logical”, as key descriptors. This could be the result of sampling bias in a small sample, or it could indicate a difference in the views of the culture. Interestingly, only 33.3% of fathers and mothers supported the notion that engineers “have social skills”. This result correlates favourably with the findings of Bazylak et al. (2016, 2017), in which engineers are portrayed to lack many social skills, particularly in communication, teamwork, organisation and leadership. Although these perceptions were mostly unmodified by gender, surprisingly, no girls described engineers as male, despite engineering being a male-dominated industry.

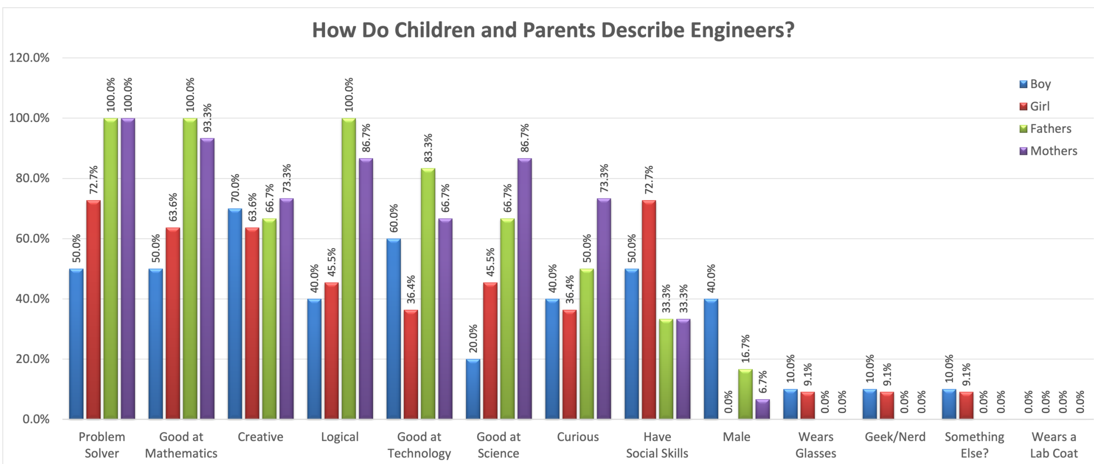

Figure 1: Children’s and Parents’ Descriptions of Engineers as Individuals

Children’s and Parents’ Knowledge about Engineering as a Profession

Figure 2 indicates pilot results for children’s and parents’ understanding about engineering work. Interestingly, children and parents perceived “build/construct things”, “design things”, “work in groups” and “test things” as the top 4 characteristics of engineering work, with mostly insignificant variations in gender. Unsurprisingly, 30% of boys and 90.9% of girls associated engineering with fixing things, particularly cars and computers, corroborating previous findings in the literature. A greater proportion of parents (66.7% of fathers and 80% of mothers) compared to children (40% of boys and 45.5% of girls) considered engineers to “invent new things”. “Drive trains” was the least popular selection, supported by only 9.1% of girls and unexpectedly, 16.7% and 13.3% of fathers and mothers, correspondingly, perhaps due to differences in language as train drivers tend to be referred to ‘train drivers’ rather than ‘engineers’ in Australia. Some of these results are contrary to the early literature around diversity in engineering being unapparent, especially by children, 61.9% of children were aware of the more ‘traditional’ branches of engineering, correlating the disciplines of aerospace, agricultural, civil, chemical, electrical and mechanical as the crux of engineering. Parents also demonstrated a more progressive understanding, familiar with biomedical, environmental, industrial, information technology, marine and mining engineering.

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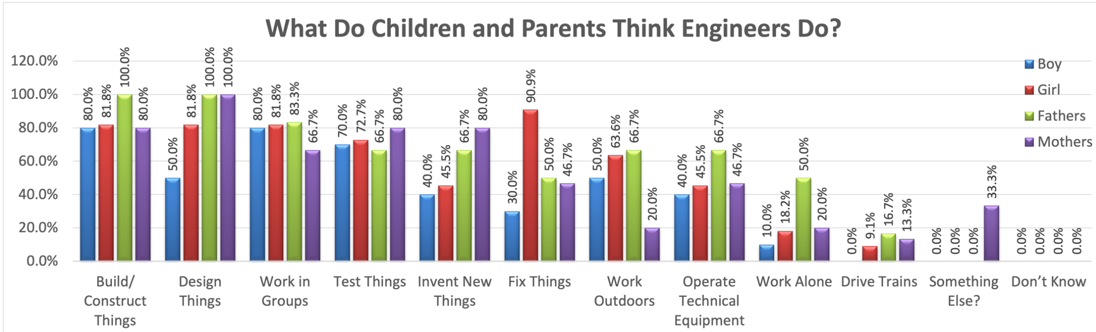

Figure 2: Children's and Parents' Understanding about Engineering as a Profession

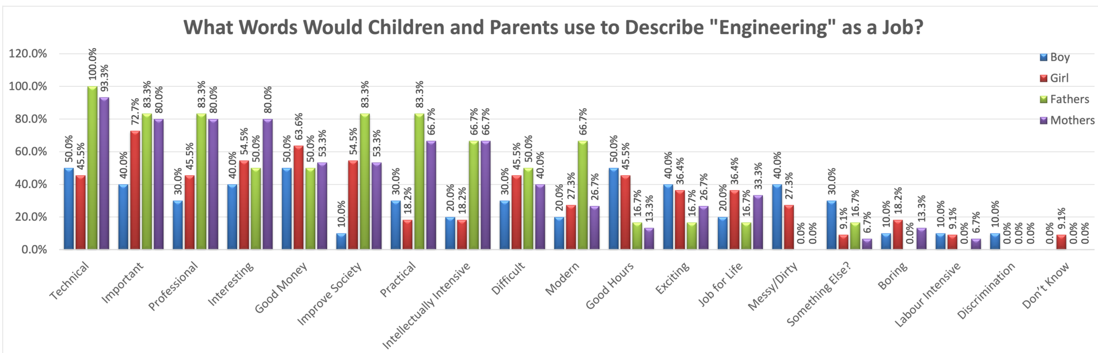

Figure 3: Children's and Parents' Descriptions of Engineering as a Profession

Figure 3 shows children's and parents' descriptions of engineering work, with "important" and "technical" as dominant descriptors. Remarkably, 72.7% of girls regarded engineering to be "important" in comparison with only 40% of boys. Children perceived engineering to generate "good money" to a greater extent than parents, citing this as their top preference, in conjunction with "good hours", "exciting" and "messy/dirty". Conversely, parents embraced more sophisticated views, deeming engineering to be "professional", "practical", "intellectually intensive" and "improve society". These results are in accordance with those of Fredericks et al. (2004), in which participants conveyed engineering to be a practical, highly interesting and financially rewarding career. Notably, mothers believed engineering to be most interesting, with 80% in favour, in comparison with only 50%, 54.5% and 40% of fathers, girls and boys.

Engineering is perceived as a predominately 'thing-oriented' career, involving mastery of technical skills, having no tangible relation to society with unapparent opportunities to make social impacts (Fredericks et al., 2004; Mena et al., 2009; Myers, 2010). Women embrace person-oriented cultures, with an inborn disposition for 'caring' or 'humanities' roles (Bible & Hill, 2007; Johnson et al., 2013; Shih et al., 1999; Spencer et al., 1999; Van Loo & Rydell, 2013). Unexpectedly, more girls than boys considered engineering to "improve society" (54.5% vs. 10%), in contrast with more fathers than mothers (83.3% vs. 53.3%). Engineering being seen as "modern" resonated most with fathers at 66.6%. Surprisingly, 26.7%, 20% and 27.3% of mothers, boys and girls, respectively, viewed engineering as "modern", despite being instrumental in the technological development that has helped shape modern society (Centre for Economics and Business Research, 2016).

Children's Favourite School Subjects

The Australian education system does not introduce engineering at primary and secondary levels. However, science, technologies (design and technologies, digital technologies) and mathematics, which underlie engineering principles, are currently offered. Enjoyment peaked in these subjects, however, with a lower proportion of girls in agreement (figure not shown). Positive and negative descriptors such as "fun to learn", "interesting", "imaginative", “challenging” and “boring” makes an interesting juxtaposition of children’s justifications. Expectedly, most children failed to articulate the importance and relevance of STEM subjects to everyday life, an exception being: *“What I enjoy about all of these subjects are that these are the principal tools and skills that we need to design and create our future and our understanding of how this universe works. Also these are the keys on solving mysteries and using the knowledge of our current understanding to advance human civilisation.”* This corroborates findings from the literature, in which complex scientific and mathematical calculations are seen as having no tangible relation to society (Myers, 2010). Enjoyment of STEM subjects by the majority is promising for boosting technical confidence and strengthening children’s interest in and positive attitudes towards engineering careers.

Integration of Engineering into Primary School Curriculum

Parents showed great interest in the infusion of engineering into primary school curriculum, with 78.3% in support, articulating an opportunity to introduce children to engineering and its relevance to society from an early age. Barriers around difficulty can be broken down, embedding positive attitudes around STEM subjects in children’s psyche, which may be passports to stimulating, diverse and lucrative engineering careers. It *“provides a unique opportunity and taps into a mindset that is currently left lingering or well underdeveloped at the primary school level”.* These views differ from parents in Hsu et al. (2011) and Bagiati’s (2011) research, in which parents indicated disinterest in integrating engineering into K-12 curriculum, justifying their responses due to the young age of their children and its appropriateness at the tertiary level.

Engineering Intervention Strategies

As indicated in Figure 4, children mentioned “visits to school from real engineers”, “more practical activities in school – games, making things etc.”, “school trips – to see what engineers really do”, “more visits to schools from young engineers” and “open days – to see what happens behind the scenes” as the top 5 ways to support positive perceptions about engineering careers, with a higher proportion of girls in favour.

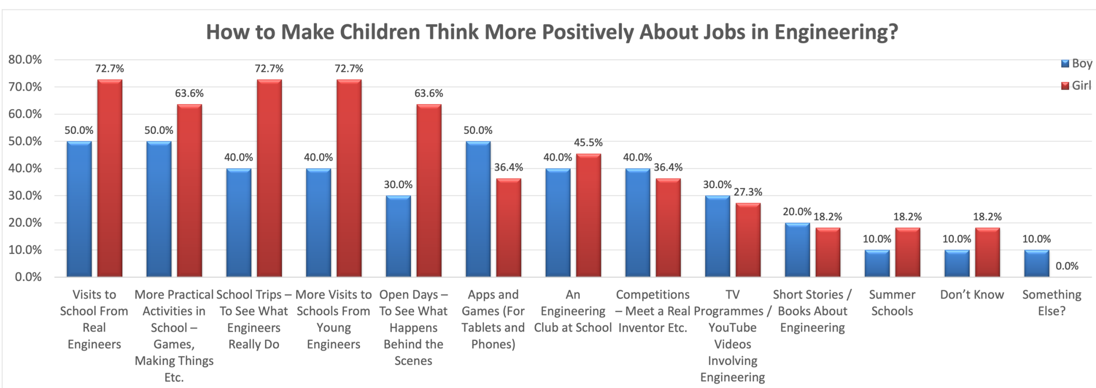

Figure 4: Engineering Intervention Strategies

Results are in accordance with those of parents (figure not shown), who furthermore expressed their advocacy for female engineer role models, as seen via this illustrative quote: *“I strongly advocate more female engineer role models as there are not many in women in core engineering area. There is a decline even further at senior leadership level. Girls have to be encouraged right from a young age to follow a career path in engineering and industry engagement is also essential to show the pathway to an engineering career.”* Common among these activities is the infusion of real-world experiences into engineering education, which can encourage richness, showcasing the breadth and creativity within the sector, in addition to its relevance. Real-world experiences, ‘elementary engineering’ and marketing

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material as methods to communicate accurate information about engineering, may be valuable to support children and families to make well-informed career decisions.

Conclusion

Parents have been widely recognised as critical early socialisers of their children's academic interests and a source of occupational knowledge (Jacobs & Harvey, 2005; Strutz, 2012; Wankat, 2007; Zhao & Akiba, 2009). Children have been found to exhibit a greater understanding of their parents' occupations compared to other occupations (Seligman et al., 1991) and the phenomenon of occupational inheritance is evident in engineering - children (particularly girls) with parents or family who are engineers often follow in their footsteps (Mannon & Schreuders, 2007). Our pilot study revealed children and parents having some accurate perceptions of engineers and engineering, which contrasts against findings from the outdated literature. Our findings were similar to those reported by The Institution of Engineering and Technology (2019). *"Since 2015, perceptions of engineering and technology have improved, with both children and parents less likely to describe engineering jobs as 'messy and dirty'. Children in 2019 are more likely to describe engineering as 'modern, professional and interesting', while parents are more likely to say that it 'makes a difference'. It's a move in the right direction, but there is still work to be done."* The proportion of parents and children who supported these views were relatively small and parents from our pilot study demonstrated more accurate perceptions, summarised below:

Table 1: Perceptions of Engineering – IET (Blue) vs. Pilot Study (Red)

Description	Parents	Fathers	Mothers	Boys	Boys	Girls	Girls
Modern	21%	66.7%	26.7%	23%	20%	21%	27.3%
Professional	54%	83.3%	80%	35%	30%	37%	45.5%
Interesting	43%	50%	80%	50%	40%	35%	54.5%
Creative	37%	66.7%	73.3%	43%	70%	38%	63.6%
Messy/Dirty	15%	0%	0%	27%	40%	34%	27.3%

Understandably so, due to their higher education and primary occupation being in STEM. Despite these reasons, data from the pilot study show that misconceptions still exist:

- Engineers lack social skills (33.3% of fathers and 33.3% of mothers)
- Engineers do not invent new things (60% of boys and 54.5% of girls)
- Engineering is not important (60% of boys)
- Engineering does not improve society (46.7% of mothers and 90% of boys)
- Engineering is not modern (73.3% of mothers, 80% of boys and 72.7% of girls)

The main study is currently being administered with children, parents and teachers from more diverse types and demographics of schools to gain more widespread insight into this multifaceted problem. Accompanied by results from semi-structured interviews (which were not available at the time of writing), this research will help to gain a more holistic insight of the perceptions held by these groups, so that we may help devise strategies to reinforce a more representative perception of engineers and engineering.

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Recentering local knowledge and developing collaborative relationships: Reflections on the design of a localized engineering program for former "street-youth" in western Kenya using an asset-based framework

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CONTEXT

Kenya is experiencing a crisis-level expansion in the number of "Street Youth" (S.Y., children who work/sleep on the streets), with estimates of over 50,000 (SFRTF, 2020). Traditionally, programs serving S.Y. have taken a need-based approach (Onwong'a, 2015a). Research shows that S.Y. have a greater risk of depression, learning disabilities, self-harming behaviours, and suicide (Moolla et al., 2008). However, S.Y. also show higher levels of mental health assets, such as resilience, self-esteem, and social cohesion (McCay et al., 2010). In Eldoret, western Kenya's fastest-growing city, practitioners and S.Y. have anecdotally reported how they can use their inherent resourcefulness and skills towards achieving their employment and livelihood aspirations.

PURPOSE OR GOAL

Engineering can offer a contextualized and asset-enhancing education for S.Y. to build 21st-century skills and a meaningful career pathway (Radhakrishnan & DeBoer, 2016). Our prior research at an alternative school for S.Y. in western Kenya has shown that co-designing an engineering course with students and teachers catalyses learner engagement, meaning, and agency and leads to sophisticated products (DeBoer et al., in press). In this paper, we critically reflect on the past 6 years of co-designing the curriculum, learning ecosystem, and pathways using Ebersöhn and Eloff's (2006) framework of asset-based trends in sustainable programs for vulnerable children. We ask, *how does the Localized Engineering in Displacement (LED) approach map to the asset trends in programs for vulnerable children?*

APPROACH OR METHODOLOGY/METHODS

Using Ebersöhn and Eloff's seven key trends defining the characteristics of asset-based programs as a framework we analyzed documents of the LED program's design and implementation since 2015. Our dataset includes journal and conference research articles, funding proposals, field notes, meeting notes, posters, and presentations.

ACTUAL OR ANTICIPATED OUTCOMES

We have identified two critical actions essential for integrating an asset-based approach in the LED program: (i) recentering local knowledge and (ii) developing collaborative relationships. Recentering local knowledge was accomplished by intentionally integrating locally embedded knowledge and practices. The collaborative relationships were critical to the program's success in valuing assets of the relevant stakeholders.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This study illustrates how the LED program integrates asset-based trends by empowering learners to be at the core of the design and developing long-term, collaborative relationships. Reflecting on our co-design process can yield guidance for continuous improvement and transferable outcomes for comparable communities. Based on our findings, we argue that engineering education can recognize and elevate S.Y. learners' assets and transform informal S.Y. programs as change-makers in the local community.

KEYWORDS

Localized engineering, asset-based framework, curriculum

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Introduction

It is estimated that there are over 50,000 "Street Youth" (S.Y., children who work/sleep on the streets) in Kenya (SFRTF, 2020). S.Y. face a variety of hardships: academic, socioemotional, and physical/psychological and it is hard for them to get the support they need in traditional schools due to transience and taboos (Embleton et al., 2012). They have a greater risk of feelings of hopelessness, depression, learning disabilities, self-harming behaviours, and suicide (Moolla et al., 2008). S.Y. also demonstrate higher levels of mental health assets, such as resilience, self-esteem, and social cohesion (McCay et al., 2010). However, programs serving S.Y. have traditionally been modelled using the need-based approach of solving problems of food, shelter, health, and education, rather than focusing on their assets (Onwong'a, 2015b). Studies on S.Y. have resulted in recommendations for educational, economic, and psychological support as sustainable solutions (Glauser, 2015; Scanlon et al., 1998; Aptekar, 1994; Ennew, 2003). S.Y. rescue, rehabilitation, and reintegration centers all around the world emphasize and place education at the center of their operations (Ennew & Swart-kruger, 2003). To achieve this objective, the educational context must consider available resources and existing social, political, and cultural structures (Choi & Hannafin, 1995).

The asset-based approach

The asset-based approach has gained significant attention in community development since the seminal work by John McKnight and Jody Kretzemen (McKnight & Kretzmann, 1993). Kretzmen and McKnight discuss the asset-based model as an alternative to the traditional needs-based approach for community development. The needs-based model reinforces feelings of deficiencies and powerlessness amongst community members. It also propagates and situates marginalized communities and members as problematic to the overall development, which harms their external presentation and self-image. For example, in 2015, PBS NewsHour reported on the status of education in the U.S.,with a piece titled "More students living in poverty strain the education system" (PBS NewsHour, 2015). The report concluded that schools in high poverty areas had to spend most of the resources to meet students' basic needs, e.g., food, comfort, and cleanliness while ignoring the community's assets entirely. Marginalized communities in the U.S. and around the world are often approached via a deficit model. In education a deficit model particularly portrays marginalized students as "lacking in some way, defective, deficient, needing to be fixed, not as good as…, and needing to develop skills valued by mainstream society" (Gerstein, 2016).

As an alternative, Gerstein proposes an asset or strengths-based thinking seeing students as "having unique strengths, being competent and capable in settings that are important to the learners, having their own personal powers, having much to offer to other learners and their school communities, sources of educating others about their communities and cultures, and thriving in a challenging climate." The asset-based model focuses on the capacities, skills, and resources of individuals and the community and builds on these assets further for development. Various scholars (Celedón-Pattichis et al., 2018; Lindsey et al., 2010; MacSwan, 2020) have commended and acknowledged the assets-based approach as key to achieving equity and access to education and development in low-and-middle-income countries. However, educational programs designed for low-and-middle-income countries targeting marginalized populations remain predominantly needs-based.

The LED program

Engineering is uniquely positioned to offer an asset enhancing and contextualized education for S.Y. to build 21st-century skills and a meaningful career pathway (Radhakrishnan & DeBoer, 2016). The Tumaini Innovation Centre, an alternative school in western Kenya has demonstrated a unique model of rehabilitating and empowering S.Y. through residential support and engineering-based skill development programs. The centre's model builds on

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the assets of the S.Y. to equip them with employable skills and self-efficacy (Bandura, 1977). Collaborating with the learners, and the teachers at the centre we have co-created a "localized engineering" curriculum that re-centres the marginalized S.Y. as learners, community leaders, and engaged citizens for community development. In the program, the students identify community's engineering needs, go through our digital resources and hands-on activities, and develop their solution. Our LED approach integrates: a curriculum, a learning ecosystem, and learning pathways (DeBoer et al., in press).

Our prior research has shown that co-designing an engineering course catalyses learner engagement, meaning-making, agency and leads to sophisticated engineering products. The active, hands-on learning is motivating for S.Y. and meets their educational goals. Additionally, our work also shows that students see their teachers as role models who play a critical role in the success of each student (Radhakrishnan et al., 2018). Our aim is to empower the teachers and build the local capacity to lead and innovate through our "localized engineering" approach. Towards this goal, we have also co-designed an engineering teacher development model. The teacher development program enables untrained engineering teachers at the school to efficiently facilitate the engineering curriculum using strategies of reflective practice and action research (Radhakrishnan et al., 2021). In the final phase of the development, the teachers, as matured engineering teachers have become mentors and now train new teachers to sustain the engineering curriculum. Therefore, our research and evaluation efforts demonstrate that the engineering program has impacted the learners, the teachers, and the community.

The LED program through an asset-based lens

Given the problems associated with a needs-based model, and our own perceptions on the benefits of an asset-based model, we probe the asset-based model relative to our LED program. We have selected our partnership in western Kenya as the context for this study because (1) this is the first location where our program design and implementation began in 2015, and we modelled our translations to other contexts based on the work at the center; (2) we have rich and diverse sources of data from our partnership with the center. In this work-in-progress study, we critically reflect on our efforts over the past six years of co-designing the learning curriculum, the learning ecosystem, and learning pathways for S.Y. We do this using the framework of asset-based trends in sustainable programs for vulnerable children developed by Ebersöhn and Eloff (2006). We ask, *how does the LED approach map to the asset-based trends in programs for vulnerable children?* The purpose of this reflection is to understand how asset-based trends were or were not integrated with the program and how they evolved. Through this reflection of the program development and our experiences, we draw recommendations for engineering education scholars who design programs and research with marginalized communities worldwide.

Approach

Ebersöhn and Eloff (2006) presented successful and sustainable education practices and programs for vulnerable children from the Southern African Development Community (SADC). The authors define vulnerability as the physical, psychological, and sociological circumstances that limit an individual from having their basic needs and achieving their potential, and adopt the groups of children as identified by Smart (2003a), whereby children/ youth living on streets is included. The authors determined common denominators across programs as indicators of sustainability and grouped the common factors to form an asset-based framework. he asset-based framework focuses on the capacities, skills, and social resources of people and their communities (Mathie & Cunningham, 2005). This alternative to the deficit-based models, prioritized thinking about the potential and about the ways the existing potential can be directed towards available opportunities (Ebersohn &

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Mbetse, 2003). The approach suggests outside resources can be effectively leveraged by mobilizing an individual or community's resources without ignoring the challenges they face.

The asset-based approach concentrates first on the agenda building and the problem-solving capacities of the local members and communities. Our localized engineering program was developed because of the collaboration with the Tumaini Center since 2015, based on the learners' request for a comprehensive skill-development education that could prepare them for the 21st-century workforce. The curriculum, a product of the long-term relationship with the community, aimed to build the problem-solving capacity of the learners, teachers, and the local community members. Ebersöhn and Eloff (2006) identified seven key trends to be the common characteristics of asset-based programs that we use as a framework of analysis. The seven trends include: (i) community-based participation, (ii) building and strengthening internal capacities, (iii) community-resource mobilization, (iv) Networking and establishing links, (v) advocacy, (vi) use locally embedded (indigenous) beliefs, structures, knowledge, and practices; (vii) information sharing.

Data Sources and Analysis

We benefit a variety of extant documents on the design and implementation of the LED approach since 2015, which we use as data sources for critical reflection against this established asset-based framework. For this paper, we selected five grant applications submitted during five years to different donor programs. We identified these five grant applications as a starting because (1) given their timeline, they can represent a chronological shift in our writings and (2) they are illustrative due to their diversity in terms of the funding amount, donor types, proposal types, and collaborations (see table 1). Other data sources include journal and conference articles, additional funding proposals, field notes, meeting notes, posters, and presentations for ongoing more extensive study.

Table 1: Data sources used in this study

Grant	Submitted Year	Proposal Type	Collaborators
Grant #1	2015	Practice	Community partner, Interdisciplinary schools within the university
Grant #2	2015 & 2016 (2016 submission was an extension request for the awarded 2015 grant)	Practice	Community partner
Grant #3	2017	Research	Community partner
Grant #4	2017	Research	Community partner
Grant #5	2020	Research to Practice	Community partner, Local University

Data analysis

We analyzed the content of the documents using the seven trends laid out by Ebersöhn and Eloff. We performed a deductive chronological analysis of the five data sources. Author 1 coded each grant first according to the seven trends and conducted a discussion session with Author 2. The coding process involved reading through the codes and assigning a code, which is the seven trends from the framework. Then within each trend, the data was re-read to identify patterns, similarities, and they were grouped under assertions. These assertions were then analyzed to identify larger thematic pattern. During the discussions, author 2 reviewed author 1's coding and provided comments and additional reflections based on their experiences. Upon reaching an agreement, authors 1 and 2 considered the emergent reflections on each trend and drafted them. After completing the emergent reflections, author 1 reviewed the data under each trend and identified the two critical themes. Author 2 reviewed the themes and provided feedback and consensus.

Results and Discussion

Based on the emergent reflections of each trend, we find two significant themes demonstrating how our "Localized Engineering in Displacement" program at the center for street youth in Kenya has evolved and mapped on to the asset-based trends. They are: (i) Recentering and prioritizing local knowledge, and (ii) Developing collaborative relationships.

Recentering local knowledge

For a program supporting vulnerable communities to succeed, the community, the organization, and the vulnerable population themselves must feel that the program matters. For S.Y., this meant seeing whether the curriculum and engagement in engineering activities are relevant. Does the content address issues they are faced with as individuals and in the community? One of the successful ways of making the content relevant is by recognizing and integrating local knowledge into a community-based learning model (Ignas, 2004). Our documents show that the local knowledge held by the youth and the center was valued from the start. However, the level of integration and importance increased over time.

In 2015, we wrote the first grant as a collaborative proposal with multiple partners. It shows that we view the center as a resource to build and translate useful technologies to address community issues and provide a livelihood for the S.Y. While we recognize the center as resourceful, we approach it as a beneficiary, offering our expertise and services *for* their growth. This is evident from the language, such as "utilize the center" and "equip the center."

> We propose to utilize the center as a living laboratory for research, education, and engagement and a jump off point for Kenyans to translate technology to practice through Kenyan owned and run startups and existing businesses. Tumaini center, the street children, and their innate entrepreneurial skills are a key element of the proposed approach. We propose to equip the center to provide a space for application of innovative practices related to Purdue University research and technology. (Grant #1, 2015)

In the same proposal, we further distinguish that we hold the expertise in engineering teaching, learning and research that will be provided to the center. We do not explicitly state the valuable knowledge possessed by the local communities and how that will be integrated.

> As such the first set of engineering modules will build on our unique expertise in engineering education research and introductory engineering teaching. We propose to develop content for students to interact with introductory engineering knowledge, skills, and attitudes (similar to our university's introductory engineering class). (Grant #1, 2015)

After submitting this grant, author 2 visited the center in Kenya for the first time and spent a few days interacting with the youth, the administration, and the international consortium on the ground that was supporting the center's activities. She conducted informal interviews with two youth, who pioneered the effort of voicing their needs and setting up the center. After this visit, grant #2 and its extension the following year was drafted. In this grant, there are subtle changes in the language and perspectives, recognizing the assets and strengths of the street youth. We acknowledge the youth as being resilient and having strengths that could help them be successful. They are more explicitly described as agents in the ecosystem of the partnership.

> Our goal is to break down educational barriers faced by street youth and other vulnerable youth in a changing society, leverage their inherent resourcefulness, resilience, and independence, and equip them with the knowledge and skills they need to not only get off the streets but to have successful and productive careers in their community. (Grant #2, 2015)

Grant #2 and its extension were the grants that were awarded amongst the five. As can be seen from the extracted quote, the approach has changed from just providing them with

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resources to breaking down the barriers to growth and excellence of the youth. In 2017, two research-focused proposals were developed at the beginning and end of the year, respectively. By this time, both authors 1 and 2 had visited the center a few times for short visits and continued to identify new ways of engagement while sustaining ongoing programs. In both grants, we see an increase in our acknowledgment that the center's model is revolutionary and that local knowledge and "ways of doing" are indispensable.

> Since 2014, the Tumaini Center has operated as an alternative school, and anecdotal success suggests that it provides the socio-emotional supports S.Y. have not found elsewhere. The ethos of the school shifts the focus from a "vulnerable" deficit construction to a resource/opportunity model (Grant #3, 2017)

In 2020, we co-developed a research translation grant with the center and a faculty at the local university. By this time, both authors 1 and 2 had made multiple visits to the center, had led three summer study abroad programs with students from two American universities to the center in Kenya, and author 1 had relocated to Kenya to be stationed there for a year. From the quote below, it is evident that the assets and capacities of the youth and the center were acknowledged and considered to develop activities and programs at the center.

> Historical evidence suggests that Street Youth demonstrates higher levels of resilience and self-esteem while still having a greater risk of emotional and behavioral problems…… Our learners are considered equal decision-makers; they play a critical role in shaping the nature of the program while building their socio-emotional competencies. The program includes a curriculum that integrates technical content, professional skills, and engineering design; all focused-on needs identified by the local students themselves. (Grant #5, 2020).

Over time, we see an increase in the level of our acknowledgment of the assets and capacities of the youth, the center, and the community. We also see progress in leveraging these assets and capacities directly into the program development and refinement. Based on the timeline of activities, we believe one of the key reasons for this change in the level of asset-based development is the consistent travel, interaction, and relationship building with community members. During earlier stages of the project, most development and coordinating activities happened via email and Skype. However, with in-person presence, there was an increase in our understanding of the context and the role of the community. *This is an important reflection that needs to be explored further, in light of the current pandemic situation and the adjustment institutions must make to sustain existing and start new international collaborations while staying true to asset-based models.*

Developing collaborative relationships

Ebersöhn and Eloff recommend that relationships be prioritized over reason and rationality when working with vulnerable communities to enable community-based participation. Since the beginning of our engagement, relationship has been the priority. In 2015, the collaborative relationship was being built on the successful North American universities consortium model in Kenya supporting health programs. Situating ourselves in a collaborative community that valued the relationships and had demonstrated success in global development was crucial to our partnership and engagement.

> The confluence of the AMPATH consortium model, Purdue University involvement with Tumaini center, and Engineering department at the university offers a unique opportunity to develop and ultimately scale a fundamentally new type of partnership with developing nations to the benefit of everyone. (Grant #1, 2015)

References to this successful collaboration of multiple partners continue to be referenced in most of our writings. In the 2020 grant, we have also emphasized the collaborative relationship as a critical strength to our program.

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> A unique strength of the Tumaini Center is its close collaboration with the global health care program model, an academic collaborative between [local university] in Kenya and several North American universities, working on all aspects of global health delivery and economic development for the last 20 years. This provides us with a vast network of expert trainers and mentors in areas like medicine, business, engineering, agriculture, environmental science, information technology, and energy as well as innovative job opportunities for graduating youth. (Grant #5, 2020)

An essential way of maintaining this collaborative relationship has been the continuous involvement of the community partner's members and affiliates in the program design and development. The level of involvement has changed over time. In the beginning, the members were seen as local experts who can continue to provide relevant local information and participation in testing and feedback, and we designed the curriculum and the technology tool for learning.

> The Tumaini center administration, teachers, and students will provide contextualized direction, testing, and feedback to the project outcomes. Working through the center's local affiliates and the P.I.'s local collaborators, we will explore the scalability to other local markets. (Grant #2, 2015)

As we moved from program implementation to research, we continued to involve the members in certain stages of the research processes.

> We include the teachers and director as well in data collection to triangulate observations from students. Teachers and director also help to facilitate group data collection. (Grant #3, 2017)

However, from both these extracted quotes, we see that the members were only engaged in segments, where we saw their role to be most fitting. By 2020, there is a drastic change to this perspective, where we engage the members as part of the design and development team from the beginning. First, we recognize and see the center having the potential to bring change in policy and practice due to the collaborative relationship we developed together, and those developed by the center with its local affiliates.

> The keystone to the program is our collaboration with local learning space that is invested in long term implementation of the development solutions and have the potential to translate research and influence both policy and practice. (Grant #5, 2020)

Second, we demonstrate how we have been able to scale our partnership and showcase the goals of translating research through evidence.

> The Purdue university and Tumaini center have a history of scaling our partnership in research translation. During the most recent school year, the students were able to develop a variety of engineering products (e.g., solar-powered refrigerator, charcoal briquettes press, farm mechanized vehicles). The semester ended with the students hosting community members for an exposition where they displayed their products, described how they were constructed, and the challenge they solve for the community. (Grant #5, 2020)

Third, the members recognize their role as important and are proud of their developing identities as engineers. For example, we have discussed in the grant proposal our collaboration and ways by which we mainly target female SY to be educated at the center.

> Each of the departments relates to an authentic engineering context, community issues, and social impact, and such relevant problems have been shown to be more engaging for female students. Our Co-PI and staff at Moi have conducted a needs assessment with the teachers on PSS and gender-responsiveness training, and with this project be supported in gender-responsive pedagogy training. The successful women teachers who are role models already at Tumaini will lead demonstrations. In a recent research study with the engineering teachers

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> at Tumaini, we found that the female teachers take a great pride in being engineering faculty, given the negative societal perceptions and stereotypes of engineering and women. The teachers have communicated that a key goal for them in the coming years to serve as role-models and mentor more female SY to take up engineering. We also ensure that male and female student at Tumaini directly and frequently connect to female engineering role models and near peers from Moi university. (Grant #5, 2020)

Collaborative relationships are vital to sustaining programs for vulnerable youth and a key asset-based trend that could define success. We have been privileged to use the existing successful collaborations in the community to build ours. We also recognize and recommend the higher inclusion of community partners and their affiliates in the program's design, development, and research goals from early on to realize their potential and encourage community-based participation.

Conclusion

Two key actions serve as critical process steps that we see as instrumental in integrating the asset-based approach into the design and implementation of the localized engineering approach. They are: (i) re-centring local knowledge, and (ii) developing collaborative relationships. We have presented the localized engineering approach as one of the asset-based educational programs supporting the S.Y. in education. Initially, we identified the asset-based trends in sustainable educational practices for vulnerable children as discussed by Ebersohn and Eloff. We then reflected on the parallels that exist between the asset-based approach and our localized engineering program. We see that the localized engineering program integrates asset-based trends by focusing on empowering learners to be at the core and developing long-term, collaborative relationships with the Tumaini center administration, teachers, learners, and the local community. By evaluating the engineering program using an asset-based framework, we argue that engineering education has the potential to recognize and elevate S.Y. learner's assets and empower the informal spaces working with them as change-makers in the local community.

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European engineering students' perception of learning and teaching activities

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ABSTRACT

STEM universities in Europe apply different pedagogical and didactic methods, which are reflected in the learning activities that are organised for the students. These activities provide students with different experiences in terms of handling their learning and in terms of achievement. There is great variation in terms of both semester structure and how teaching is carried out. A significant commonality is that besides technical domain skills and competencies, there are expectations (or demands) placed on students regarding acquisition of interdisciplinary skills and transversal competences.

The goal of this study is to illuminate students' perception of the various learning activities and teaching practices provided at STEM universities in Europe and to illuminate different perspectives of students' learning experiences. The goal is also to influence educators to implement increased use of student-centred learning approaches

The study was conducted through a survey disseminated through a European STEM students' network. Of the 349 respondents, 133 were determined as valid for extracting the conclusions. The survey included an open question where students were asked to describe a situation where they 'had significant learning accomplishment'. The survey also contained multiple-choice questions that aimed to create the profile of each respondent, based on their study structure and background. The answers were categorised according to contemporary learning theory. The profiles of the students were used to compare their experiences and draw conclusions based on students' perceptions of their learning experiences.

Based on the theoretical framework, the findings show that students' responses point to experiences of interaction processes (with peers or teachers) to a higher degree than experiences with acquisition processes (with content or with motivation). Recommendations point towards implementing a higher degree of student centred learning coupled with intensive teacher support. In addition, the development of students' reflective skills may improve their learning practices and thus increase their acquisition of skills and competencies.

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Introduction

Engineering educations all over the world are currently experiencing new expectations and demands regarding the graduates' skills and competencies. In addition to the technical domain skills and competencies, there is an increased demand for interdisciplinary skills and transversal competencies (Passow, 2012; Beagon et al., 2021), not to mention the Industry 4.0 concept requiring, for example, digitisation competencies (Nørgaard & Guerra, 2018). In addition, the UN's 17 SDG goals provide a framework for sustainability in the entire field of technology, having a major impact on engineering education. From a competency level, however, there is an overlap of competencies needed for sustainability and Industry 4.0. Guerra and Nørgaard (2019) identify crosscutting competencies such as problem solving, communication, creativity, leadership, collaboration, lifelong learning, etc., which are crucial for future engineers.

Higher education institutions in Europe apply different pedagogical and didactic methods, which are reflected in the learning activities that are organised for the students. These activities provide students different experiences in terms of handling their learning and in terms of achievement. There is great variation in terms of both semester structure and how teaching is carried out, which indicates that the Bologna Process with the aim of unifying higher education in the European Union has clearly different degrees of implementation (Sursock, 2015; Gaebel & Zhang, 2018).

The goal of this study is to illuminate the following question: What are students' perceptions of the various learning activities and teaching practices provided at STEM universities in Europe? Moreover, through a theoretical lens, the goals is to illuminate different perspectives of students' learning experiences. The paper first presents the theoretical framework used to interpret the collected data, then we present the methodology used, and finally we go through the results and discuss them.

Theory on 'how we learn'

Today, the question of learning, both theoretically and practically, is placed high on the societal agenda. There are different understandings of learning among today's learning theorists but despite the differences, there are also significant common features that express something central about the understanding of learning today. There is an underlying understanding that the old notion, that learning can have the characteristic of being 'a filling up', what Paulo Freire (2009) in, *Pedagogy of the Oppressed*, named, the Banking Model, has been abandoned. Learning takes place in the interaction between new impulses and activities and the previously established knowledge, ability and experience (Kolb, 1984). Another common feature is that learning is not only an individual matter, but also a social and societal concern. That is, the setting in which learning takes place is not only an external framework, an environment, but always an integrated element in the learning process and in the resulting learning. In addition, individual learning is no longer considered a purely cognitive concern, but emotions and motivation, like social and societal concerns, are always part of the learning process itself and shaping its outcome.

One of the contributors to contemporary learning theories is Knud Illeris (2007) with his book, *How We Learn*, in which he explains his understanding of learning. Illeris believes that all learning involves two very different processes, both of which must be active in order for us to learn anything. As illustrated in Figure 1, one process 'is the **interaction** between the individual and the environment, which takes place throughout our waking time and which we can be more or less aware of . . . the other process, the **acquisition** takes place through the impulses and activities that the interaction entails' (Illeris, 2007, p. 22). The conditions that determine the interaction process are fundamentally of an interpersonal and societal nature (the external social and material world), whereas the conditions that determine the process of acquisition, on the other hand, are fundamentally of a biological nature. The two processes

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thus relate to the outside world and inside the individual, respectively. The process of interaction is also referred to as the learning interaction dimension and it relates to an inter-personal and a societal level. The process of acquisition thus takes place exclusively at the individual level, but this process will always include both a '*content*' dimension and a '*driving-force'* dimension (Illeris, 2007, p. 23). The content is what is learned. There is always mention of *someone* having to learn *something*, and it is the acquisition of this *something* that is the element of learning. However, in order for acquisition to take place, there must be a driving force and it can be driven by desire and interests or by necessity or coercion, which will affect both the learning process and the learning outcome.

The basic structure of learning is thus comprised of two processes and three dimensions as shown in Figure 1.

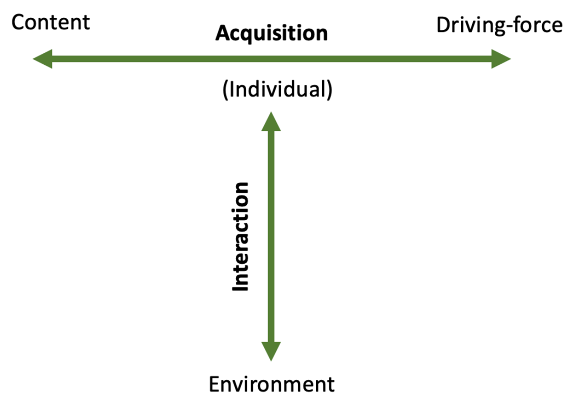

Figure 1: The fundamental processes of learning [adapted] (Illeris, 2007, p. 23)

In accordance with the aforementioned goals, this theoretical frame addresses learning as activities. Such activities are describable in everyday terms by students who normally have no theoretical knowledge of learning and its psychological mechanisms. This theoretical frame is also suitable for data obtained in ways that preclude further inquiry among respondents.

This theoretical frame will be applied to our data, and while going through the students' descriptions of their learning accomplishments, we will qualify Illeris' concepts. First, we will introduce our data collection methods.

Methods for collecting data and analysing students' perception on 'Best Learning Practice'

The data was collected as part of a research project on future engineering education, the A-Step 2030 (Lehtinen et al., 2020).The study was conducted through an online survey using the software, SurveyXact. It was approved by Aalborg University and disseminated through the Board of European Students of Technology (BEST) network. Of the 349 respondents, 133 were determined valid for the analysis. The validity was determined on the basis of respondents' answers to the open-ended questions. Unfortunately, a large number of students chose not to answer the open questions of the survey, but simply filled in answers where boxes could be ticked off. The analysis will mainly apply a qualitative approach using quotes that illustrate students' perception of learning. However, in order to exemplify the number of students relating to each concept of the theoretical frame, a quantitative approach is used to show the diversity in percentage.

The respondents were STEM students, studying at European universities, including 26% non-European citizens; respondents were 56% female, 41% male and 3% non-binary. They are affiliated with a range of universities in Europe and there are differences as to how far they are in their studies.

The survey contained two main open questions where students were asked to describe a situation where they 'had significant learning accomplishment' and a situation where they 'had a low learning accomplishment'. The survey also contained multiple-choice questions that aimed to create a profile of each respondent, based on their studies' structure and learning activities.

This study however, will solely analyse the individual descriptions of students' perceptions of a situation where they experienced significant learning accomplishments. They were asked:

> *Example of Best Learning Practice. Please describe in max. 300 words a situation where you had significant learning accomplishment. This may have been a situation where you were highly inspired and engaged, and experienced a key learning moment. Please outline the type and duration of the learning experience and include how it was initiated, supported and assessed.*

These descriptions were analysed using the software, Nvivo, and with inspiration from learning theories proposed by Illeris (2007). His understanding of learning and its two fundamental 'processes' and three 'dimensions' are described in the previous section. Illeris' understanding of 'how we learn' and his concepts are used as the theoretical frame for analysing students' perceptions of their 'Best Learning Practice'.

First, the descriptions were categorised using a deductive coding process as to whether respondents described processes related to 'acquisition' or the 'interaction' of learning. Then a second analysis where the descriptions categorised as 'acquisition' was analysed again, and again using a deductive coding, as to whether they relate to Illeris' predefined dimensions of 'content' or 'driving-force (incentive)'. The third and final analysis was using an inductive coding approach creating new categories (concepts) based on students' descriptions in relation to understanding students' perceptions of learning and teaching activities. The three analytical steps are illustrated in Figure 2.

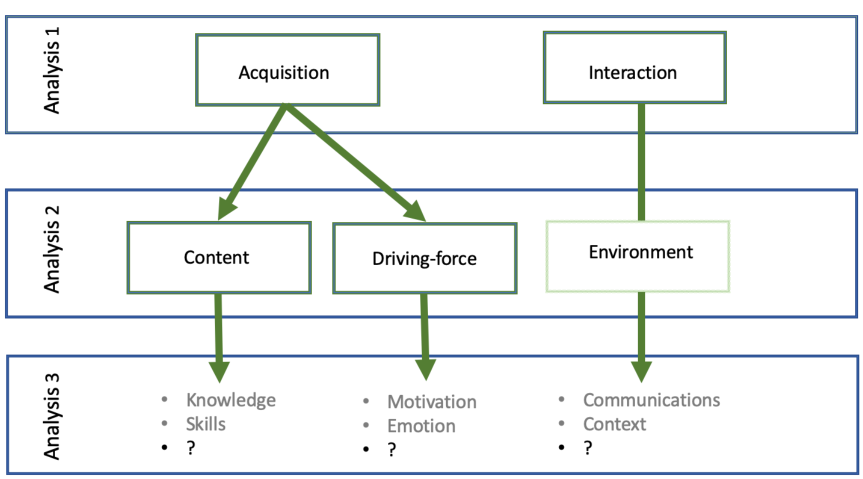

Figure 2: The analytical approach

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Analysis of students' perception of 'Best Learning Practice'

The first step in the analysis of data was a deductive approach that categorised the students' descriptions into Illeris' two fundamental processes, acquisition and interaction. There is a clear difference in what practices the students described as being the main attribute to a significant learning experience. No less than 68% of the students described their learning experiences as a process related to interaction, and the remaining 32% described their learning with a process related to acquisition. Perhaps it is not surprising that students to a greater extent described their learning with attributes related to an interpersonal and societal nature than that of a biological nature. As anticipated, describing your context and world appears to be more straightforward than describing your inner processes. In any case, what primarily characterises the descriptions of the two processes is the distinction between the individual-oriented, where the student describes a motivation or an individual process for learning, and the interaction-oriented, where the student describes an environment or a relationship and interaction with peer students or with teachers.

The second step in the analysis is aimed entirely at the process of acquisition, thus the individual level. Again, a deductive process was applied and Illeris' two dimensions 'content' and 'driving-force' is used as the frame for categorising students' descriptions. The distinction here is whether the student described her/his 'best learning practice' with emphasis on 'what is learned (e.g., the element of learning), or with emphasis on the motivation and driving-force. Again, there is a rather large difference, as only 9% of the students described their learning based on elements associated with content – that is, a description of this '*something'* to be learned as a feature of a significant learning experience – whereas 23% accounted for their learning through driving-force and motivation.

The third step, in the analysis, takes an inductive approach conceptualising Illeris' three dimensions of learning: content, driving-force and environment. The findings from this analysis will be presented in the following sections highlighting concepts with the supporting quotes.

Acquisition: Content

The content dimension was described by only 9% of the students exemplifying their experience of a significant learning accomplishment. The examples mostly relate to a subject that the student particularly likes:

> '*my course of Introduction to Programming in first year of my bachelor's'*
>
> and
>
> '*when I switched from Civil Engineering to Computer Science I got a pretty big boost'*

or explain how content is acquired such as

> '*Understanding complex physical phenomena is a difficult challenge which I faced several times during my studies. What I found useful is to try and understand everything from the basics'.*

The content descriptions are in general superficial and not very concrete in relation to what made these examples a best learning practice.

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Acquisition: Driving-force

The driving-force dimension can be conceptualised as extrinsic and intrinsic motivation (Deci & Ryan, 1985), as emotions and as willpower being the predominant concepts.

The extrinsic motivation examples point in the direction of exams, for example,

> '*learning for an exam, I started early and learned from flashcards with spaced repetition and was able to remember a lot of the topic, even after the exam'*

> or

> *'I ended up with a bad result and the exam also went bad. Because of this, I was motivated and dedicated to doing a better project on my second semester, which means I worked really hard, and ended up with a good result and the best grade possible'*.

Another student was motivated by freedom:

> '*a reason was that I had a lot of freedom to try out new stuff and come up with creative solutions to the posed problem'*.

In addition, some students are motivated for studying by future employment or even future earnings such as,

> '*when I see the real purpose of the subject. How to convert that knowledge into money and profit. That is when it get really interested'.*

A few students gave examples of intrinsic motivation through a learning practice:

> '*I like to colour code my subjects and also each lesson. So keeping this short and simple, colours help me learn and I'm always inspired and motivated when my material is organized in that manner'.*

Students also gave examples of emotions in relation to their best learning experiences. Most of them were related to psychological study environment such as,

> '*it helps me feel that I can rest and really learn something'*

> and

> *'to be in a psychological mood that favors studying: not being too stressed, sad or nervous'.*

Students also explain that

> *'a comfortable environment and to know the people around them, in order to be more open to the experience of sharing and learning'*

are very important for their learning.

Finally, students mentioned willpower as being part of an experience of significant learning accomplishment. A student described a learning situation as

> *'Calculations. Copy an example, after that try as many times as I am able to do it without help. Repeat it on the next day as well'.*

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In general, students were less exact in describing their learning process related to acquisition. The individual processes in achievement of learning appears to be not as obvious or to be harder to describe. Content, what is learned, was especially not the focal point of any description of a best learning practice. Motivation, however, is for some students and in some situations seen as a driver for a learning practice.

Interaction: Environment

Students frequently described the interaction dimension, on the other hand, as a process for a good learning practice. According to students' descriptions, interaction can be conceptualised as practice/laboratories, project-work, team/peer-student, the teacher, and a material world.

Practice and laboratory

Several students defined significant learning accomplishment through practice or laboratory work with hands-on experiences:

> '*I would have to say that hands-on experiments and discussing the results with a supervisor immediately after have had the most "oh, hey, I understand something" moments'*
>
> and
>
> '*during the laboratories, we were given a task and I could ask at any point for help. It was important for me because it is really valuable when you get stuck to ask for help'.*

Also engaging with practice seems to be a highly valued learning practice:

> '*the most significant learning accomplishment for me was when we had 3-day workshop with representatives of company related to my field of studies'*
>
> and
>
> '*The best learning practice I had was through a practical project all the quadric-mester long. I was able to test the theoretical lectures through this project each time one ended. Therefore my knowledge of the courses was better'*
>
> and
>
> *'In the first year, we created a plane motor in 3D on our computer. We have never done something like that before'.*

Project-work and problem-oriented learning

Another very frequently described best learning practice is project-work, both as an individual learning practice:

> '*Working with project based learning and getting to experiment and testing your own hypotheses during the writing of my bachelor project has been a situation where I had a significant learning experience'*

and in teams of students, project-work is highly appreciated:

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'*one example are real-life projects that we, at xx are obliged to accomplish. Together with a team, each individual works on comprehensive and complex problems from real-life, throughout the duration of course (ca 3 months)'.*

Some students described their process of learning relating not only to project-work but also to the process of solving a problem

'*In my opinion, I've learnt very efficiently during group project. It was an IT project and working at 4 we were supposed to solve a problem*

or engaging in a project with poorly defined and poorly supported projects.

'*Project work where we had some orientation, with some defined objectives but with different possible approaches. The project lasted for 2 months'*

and

'*The better learning experiences I had were through (often) poorly initiated and poorly supported projects, where the assessment was often done fully at the end of the project through a report, without much transparency regarding what was expected beforehand'.*

One student simply described the best learning practice as

'*learning by doing – with a project.*

Team and student-peer

The interaction with student peers is most frequently among students descriptions. Students seem to prefer collaboration with student peers in different learning processes, or in project-work:

'*we had to do a group project (3-4) associated with the class that was very inspiring and interesting that made me learn more and engage me more to this specific class'*

and

'*learning together with fellow colleagues was most effective for me, interacting in small groups with professors in solving the problem task*'

and also while studying:

'*I guess the best learning practice was when me and my friends just sat at some cafe and studied together. I think co-working and group studying is the key to successful learning'.*

The Teacher

The teacher and the interaction with the teacher is also often described as part of the students' experience of significant learning accomplishment.

'*I highly inspired and engaged, when the teacher explains the material interestingly and engages the students in the subject, shows how much he likes this subject and deliver the material in a light and interesting way'*

and

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‘*we had a great professor in physical chemistry who was really engaging. He had great examples from everyday applications for something that can be quite tricky to understand. And thus visualising very theoretical concepts’.*

It seems very much to be the engagement of the teacher:

‘*university courses that I enjoyed the most were the ones where the professor was passionate about the subject they were teaching us about. When you see someone’s passion about something – you start to like that thing too. Now there are some subjects that I study with enjoyment and I plan to do my master studies in those areas’*

and also when it is fun to learn:

‘with my favorite teacher ever. The subject was about Java programming, but she made it fun by creating a project about Game of Thrones’.

Material world

A few students described their learning practice based on a material context:

‘*in the library with decent light and during the day’*

and

‘*need my headphones and all study materials’.*

Only a handful of students indicated their material world or study environment as having an impact on their best learning practice.

We saw from this analysis that the students’ s of their learning experience can be explained within the analytical framework of the three dimensions presented earlier.

Conclusion and Recommendation

The analysis of students’ descriptions of their best learning practice was initially categorised into the processes acquisition and interaction. As Illeris (2009) accounts for in his understanding of learning, a learning process consists of two fundamental processes – acquisition and interaction – and both processes need to be active in order for learning to take place. Even so, it is interesting to see how students are able to articulate their best learning practice reflected in these processes. That is, whether it is a description justified by individual achievement or whether the description is justified in collaboration and context – in other words, a distinction between the individual and the outside world. Even though students are better at describing their interaction processes, this does not mean that acquisition does not take place. According to Illeris (2014, p. 16), there may be a time shift in the two processes in which reflection takes place. But then again, perhaps it is not surprising that students largely describe their learning with attributes related to an interpersonal and societal nature than that of a biological (e.g., mental or emotional) nature. Describing your context and material world apparently is more straightforward than describing your emotions and reflective processes. However, from the data collected, we are merely able to make these assumptions.

The analysis also categorises students’ descriptions of their learning experience into Illeris’ three dimensions – content, driving-force and environment. This analysis was purely an analysis of descriptions categorised as acquisition in the first step, but here they were further categorised as content and driving-force. From this analysis, we see that there is less awareness of content than of driving-force when describing best learning practices. We see that students more often describe their motivation or emotions rather than the content – for example, what they are actually learning as part of the best learning experience.

However, as one digs deeper into the three dimensions, we see trends in preferences in learning practice, and some clear concepts emerge. The overall concept is project-work. This is what students most often refer to in their description of a best learning practice, while several further describe the project-work as organised in a problem-oriented way. Another concept that appeared frequent is learning practices being organised as laboratories, assignments or exercises, and practice. Students describe their learning experiences as hands-on, and several highlighted the importance of a teacher being present and available during the session for support and help. This, however, is different from the descriptions of project-work, where students describe poorly designed and loosely structured project-work as the best learning experience. The data does not provide any evidence for why a teacher is required in hands-on sessions and not in project-work; what we see, however, is a difference in the duration of these learning activities where laboratory exercises are very short exercises counted in hours as opposed to project-work being counted in weeks or often months. This time difference might explain the importance of a teacher being present while students navigate poorly defined and loosely organised learning activities. These poorly defined and loosely structured learning exercises could indicate that students aim for more student-centred learning method.

The concepts of teamwork and student-peer work is also dominant in the interaction processes. It seems as if students in general find learning to be a social process, as pointed out by Vygotsky (1962). The described examples of teamwork are very often related to some kind of project-work and it appears that project-work and teamwork, in many students' understanding, work hand-in-hand.

As mentioned earlier, students abstain from describing best learning practices based on acquisition processes. We saw only a few and those were mainly content related to, for example, a specific subject, rather than grounded in the students' acquisition processes. This could indicate that students do not have the knowledge, language and insight into reflection processes, for example, and therefore are unable to describe acquisition processes as best learning processes. Thus, students might need to gain more knowledge on reflection processes and how they acquire knowledge and skills. In general, students might improve learning by gaining more knowledge on 'how we learn'.

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Engineering employability: Local and international student views in an Australian context

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ABSTRACT

CONTEXT

Employability has been an important topic for research over the years with many definitions and models emerging. Owing to the changing nature of engineering careers, the concept of 'self-managed careers' is emerging, with the importance of sustainable employment for a successful career. Diversity in the Australian engineering higher education sector is significant, owing to representation of international students. The literature identifies differences in international students' learning behaviour and challenges relating to employability compared with locals. Student understanding is the 'missing perspective' in employability studies.

PURPOSE OR GOAL

The goal of this study is to explore engineering students' understanding of the concept of employability and employability categories, and investigate differences in understanding between local and international students.

APPROACH OR METHODOLOGY/METHODS

A qualitative phenomenological study was conducted. Data were collected from local and international engineering undergraduates at RMIT University, through focus groups and interviews in both face-to-face and online modes. To analyse participants' views on the concept of employability, thematic analysis was used. Qualitative content analysis was carried out to analyse views on employability categories, mapping data into the categories in the CareerEDGE model of employability. NVivo aided the analysis.

OUTCOMES

The results reveal that the students' understanding of employability is more in terms of 'getting employment' than 'sustainable employment'. The most valued employability categories were generic skills, experience, and understanding & application of degree knowledge. Local students valued experience more while cultural intelligence was important for international students. Personal attributes and emotional intelligence emerged as noteworthy categories while career planning was discussed minimally. An unanticipated finding is the emergence of employability categories not present in the chosen CareerEDGE model, namely cultural intelligence and personal attributes.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The results of this study indicate that the approach taken by Higher Education Institutes (HEIs) to develop students' understanding of employability may need to change. Implications are identified for researchers and educators in terms of employability research and pedagogical practices with international students. Recommendations are made for further research work.

KEYWORDS

Engineering employability, CareerEDGE model, international students

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Introduction

Employability of graduates is an area which has been researched upon widely, owing to the gap between industry demands and what graduates can actually offer. According to the literature, the concept of employability is defined as "the capability to move self-sufficiently within the labour market to realise potential through sustainable employment" (Hillage & Pollard, 1998, p. 2). Thus, employability is not about initial employment or simply getting employed (Brown, Hesketh, & Wiliams, 2003; McLeish, 2002). Employability models (Dacre Pool & Sewell, 2007; Hillage & Pollard, 1998; Yorke & Knight, 2004) define employability categories such as knowledge, skills and other attributes that contribute to graduate employability. The literature also identifies employability as a relational, contextual and individual phenomenon (Clarke, 2008; Nilsson & Senior, 2010).

Interest in Engineering employability has been mainly driven by the economic impact from skill shortage, growing diversity in engineering programmes globally and high student attrition rates (Winberg et al., 2020). The expectation of graduates of a linear career with lifetime job security is being replaced by career patterns that are more flexible, boundaryless and of short-term nature (Clarke, 2008). This decreasing job security, coupled with engineering being a 'heterogenous' profession encompassing a wide array of positions and tasks (Nilsson & Senior, 2010), has augmented employability challenges for engineering graduates.

In the Australian engineering higher education sector, international students are over-represented in the cohort of graduates who face employment challenges. Difficulties in securing work placements is the most prominent (Gribble, 2014; Jackson, 2017) while low self-perceived employability is reported despite positive work-related experiences (Barton, Hartwig, & Le, 2019). Further, international students (mainly non-native English speakers) are seen as silent and passive characters in learning activities (Heron, 2019; Lin, 2018) as well as showing differences in perception in terms of self and career competencies (Bennett, Kapoor, Singh, Kaur, & Maynard, 2015). However, students who are native English speakers could be passive as well, suggesting persona as an influencer (Remedios, Clarke, & Hawthorne, 2008).

Employability research is largely carried out focussing on different stakeholder perspectives (such as employers, graduates and educators), different contexts, disciplines or industries. However, student views could be seen as the 'missing perspective' (Gedye & Beaumont, 2018) despite recent efforts (Thirunavukarasu, Chandrasekaran, Subhash Betageri, & Long, 2020). A deeper understanding of the student view is important for effective employability learning and teaching, enhancing attractiveness of study programs and universities, as well as countries as international education destinations.

As such, the goal of this study is to explore employability from both local and international student perspectives and investigate any differences between the two cohorts. The two research questions examine 1) participants' understanding of the term employability and 2) their views on what employability categories are important for engineering graduates.

Method

A qualitative approach was taken for this phenomenological study, as the intention was to examine the essence of the phenomenon of employability through participants' perception (Richards & Morse, 2012). The study is exploratory in nature rather than for verification of previous findings, thus it is not intended to draw generalisations.

Data were collected from local (n=17) and international (n=13) engineering undergraduates at RMIT University (mixed year group), through focus groups and interviews in both face-to-face and online modes. The international students were all non-native English speakers with a majority from Asian countries (n=11). The two cohorts were similar in terms of work experience (considering both engineering work placements and part-time work): only 2 participants from each cohort had no work experience.

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Transcription was done verbatim, by the principal researcher. Participants' views of the term 'employability' were analysed using thematic analysis (Braun & Clarke, 2013). Directive qualitative content analysis (Hsieh & Shannon, 2005) was used to analyse student views of employability categories. Data were then mapped to the categories of the CareerEDGE model of employability (Dacre Pool & Sewell, 2007). NVivo was used as a supporting tool for analysis.

CareerEDGE model of employability

The CareerEDGE model (Dacre Pool & Sewell, 2007) is widely known as a comprehensive (Small, Shacklock, & Marchant, 2018) and practical model (Jollands, 2015) of graduate employability, extensively used for career management teaching and research. There are five basic categories described as Career (learning and development), Experience (work and life), Degree (knowledge, understanding and skills), Generic Skills and Emotional Intelligence (EQ). Through reflection and evaluation of these components, the higher-order categories of self-efficacy, self-confidence and self-esteem are built, leading to employability.

Findings

Employability as a concept

Students' responses towards their understanding of employability as a concept are presented under two themes – 'gaining employment' and 'beyond employment'. ('I' and 'L' are used to identify international and local students respectively).

Theme 1 - Gaining employment

Most participants viewed the concept of employability as gaining employment, as seen from Table 1. They discussed employability as 'the ability to find employment'. The probability of finding employment was associated with an individual's employability – "How much you are likely to be employed in a workforce" (I9). Some participants associated employability as an assessment of their competencies leading to employment – "A measure of how easy it is to assess your skills and see how it is for someone to employ you" (L1).

The concept of employability was also discussed in terms of suitability or 'fit for a role' – "Here's a box we want you to fit into, how well would you fit into that box?" (L10). If an individual's knowledge, skills and personal attributes are fitting the requirements of the role, then such a person was seen to be employable. Participants also discussed 'fit' in terms of matching of goals between potential employee and employer-

> *If a company sees you and your goals align with them, that makes your employability much easier. (I5)*

It was also identified that fitting into the culture of the work environment and alignment of values adds to employability.

> *Do you encourage inclusivity and creativity... [the potential employee is] not someone [who is] just going to be completely against what they [the company] believe in and what they want to try and create. (L3)*

Another emerging idea was about being the 'right candidate' among others in the recruitment process. Employability was seen as an attractiveness to employers compared with other candidates - "It's how likely you are to be selected from a bunch of students or graduates" (I10).

Some participants seemed to equate the concept of employability to the 'possession of specific components' that help them secure employment such as skills, experience and extra-curricular activities. 'Skills' was recurrently mentioned by students as an important competency.

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You have to have the all the skills to leave university which is kind of like a bubble wrap thing and be exposed to the real world. I think that's what I feel employability is, having the actual skills you need. (L14)

As such, employability is seen as a 'readiness for transition from university', from a place of security to the realities of the actual world.

Theme 2 – Beyond employment

This theme covers participants' responses that associates the concept of employability beyond simply getting employment. Although this was not a recurrent idea in the data (as seen from Table 1), it is nevertheless identified as an important theme, as the concept of employability not only includes gaining employment but maintaining employment ((Brown et al., 2003; Hillage & Pollard, 1998; McLeish, 2002). In thematic analysis, something in data can be important without appearing very frequently (Braun & Clarke, 2013).

A few participants viewed employability as being successful at work – "How effective someone is when they are employed" (L5) while another associated employability as "Finding the correct career path going forward" (I7). Another viewed employability as contributing to the society.

Table 1: NVivo coding results - Concept of employability

	Total (# of codes)	Local students, n=17 (# of codes)	International students, n=13 (# of codes)
Theme 1 - Gaining employment	24 (86%)	16	8
Theme 2 – Beyond employment	4 (14%)	2	2
	28 (100%)	18 (64%)	10 (36%)

Local vs International perception

Table 1 also presents a comparison of the results between local and international students. Two main observations can be made. One finding is the striking similarity between the two groups in their view of employability as 'getting employment' as opposed to maintaining employment. This finding has both similarities and differences to a study with engineering students (Kövesi & Kálmán, 2020), where Hungarian students are reported to have short-term perspectives while French have long-term vision on employability. Secondly, Table 1 suggests that the local students were more forthcoming than their international peers, consistent with the latter's reputation for passiveness (Heron, 2019; Lin, 2018). The local students contributed 64% of the comments, but as a cohort were only 17 (57%) of the 30 participants.

Employability categories

Students' responses about the most important employability categories are presented in this section, mapped against the basic categories of the CareerEDGE model. In addition, two other categories emerged from data, namely 'Cultural Intelligence' and 'Personal Attributes'.

From the results in Table 2, it is clear that 'Generic Skills' is the category of employability most familiar to the students. Teamwork and communication were the generic skills mentioned most frequently. Communication was seen to be important as "Engineers never work alone" (I1). Participants also viewed teamwork and communication as inter-related skills.

You cannot go outside and build your own wing as everything is based on teamwork. And being able to communicate within a team, so communication either verbally or written. (L14)

Leadership, time management, people skills and adaptability were some of the other generic skills discussed by participants, but to a lesser degree than teamwork and communication.

After 'Generic Skills' the second most discussed category was 'Experience'. The participants recognised "A high desire for experience, practical hands on experience" (L10). The

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experience gained through internships, cadetships or placements were discussed as important, not only for gaining technical expertise, but for developing generic skills as well.

> *Experiences are generally the best… Metric for knowing if someone's going to do a good job, but also in parallel with that are interpersonal, collaboration and communication skills. (L16)*

Students also talked about how experience gained through extracurricular activities such as projects, competitions and technical clubs help them in their employability as they -

> *…ticks the box to the academics, but also ticks the box of that experience and practical knowledge that's outside the classroom. (L10)*

The third most frequently cited category from the CareerEDGE model was 'Degree' (which includes subject knowledge, skills and understanding). Most participants viewed the degree as a basic qualification and discussed the importance of understanding the topics learnt, going beyond the use of degree as a mere qualification.

> *The degree you have like, yes, I have a paper... I graduated [on] this, but like do you know what you graduated? Did you just like copy the answers? (L14)*

The technical skills and expertise related to the degree were highly regarded by participants, and some even saw as contributing to their social responsibility as well.

> *The [technical] skills would definitely also be one of the most important ones because you are dealing with structures or whatever that are supposed to function and keep people safe. (I1)*

'Emotional Intelligence' was discussed infrequently by participants. This concept is explained as the ability for a person to manage individual emotions and those of others to foster better relationships and happier work life (Dacre Pool & Sewell, 2007). Participants views were about the importance of engineers demonstrating "Empathic listening and similar attributes" (L16).

The four elements of the 'Career Development Learning' category (Dacre Pool & Sewell, 2007) namely decision learning, opportunity awareness, transition learning and self-awareness (Dacre Pool & Sewell, 2007), were not mentioned by participants.

'Cultural intelligence' was important for some candidates, as they saw that understanding "the workplace and Australian culture" (I6) were important for their employability, as previously reported by (Tran & Pham, 2016). This may be distinguished from emotional intelligence, as cultural intelligence "picks up where emotional intelligence leaves off" (Earley & Mosakowski, 2004, p. 1) and is defined as "…an individual's capability to function and manage effectively in culturally diverse settings" (Ang & Van Dyne, 2015, p. 3), hence may be considered in addition to the five basic categories of the CareerEDGE model.

Another category to emerge in addition to those in the CareerEDGE model was the importance of 'Personal Attributes'. Participants discussed how qualities such as initiative, commitment, motivation and resilience are important for engineers. Several studies have critiqued limitations of the CareerEDGE model (Jollands, 2015; Smith, Ferns, & Russell, 2014; Tymon, Harrison, & Batistic, 2019), but not often in respect to need for more categories (Jollands, 2015).

Local vs International perception

Table 2 also presents a comparison of the results between local and international students. Again, local students were more forthcoming in their comments, making 70% of the overall comments. Two other observations may be made. 'Experience' was mostly discussed by local students. In addition, it is interesting to note that only local students talked about 'Emotional Intelligence' while only international students discussed 'Cultural Intelligence'.

Higher order categories

The higher order categories of the CareerEDGE model were rarely mentioned. This contrasts with findings of a study of engineering graduates, who identified soft skills such as self-initiative, self-esteem and self-efficacy as important 'soft skills' (Nilsson & Senior, 2010). This suggests the focus of undergraduates is on 'getting a job' rather than maintaining work.

Table 2: NVivo coding results - Employability categories

Categories		Total (# of codes)	Local students, n=17 (# of codes)	International students, n=13 (# of codes)
CareerEDGE model	Generic Skills	26 (38%)	18	8
	Experience	14 (20%)	13	1
	Degree (knowledge, skills & understanding)	13 (19%)	10	3
	Emotional Intelligence	4 (6%)	4	0
	Career Development Learning	0 (0%)	0	0
New	Cultural Intelligence	5 (7%)	0	5
	Personal Attributes	7 (10%)	3	4
			48 (70%)	21 (30%)

Discussion

This study set out to explore the perceptions of engineering undergraduates in terms of employability as a concept and employability categories. One of the significant findings of this study is that participants perceived employability as 'getting employment' rather than in the long-term sense. This finding has been previously reported in the literature (Kövesi & Kálmán, 2020). The study has also found that the categories of employability identified by the participants are generic skills – mostly teamwork and communication, experience and understanding & application of degree knowledge, as reported in a number of previous studies (Jollands, 2015; Shuman, Besterfield-Sacre, & McGourty, 2005; Winberg et al., 2020). One unanticipated finding is the emergence of employability categories that are not present in the Career EDGE model, such as cultural intelligence and personal attributes.

In the literature, employability is discussed as a phenomenon that goes beyond 'getting employment', with an emphasis on the long-term aspect of sustaining employment becoming more prominent in definitions (Brown et al., 2003; Hillage & Pollard, 1998; McLeish, 2002). However, in this study, the participants had a narrower and lower level of understanding of employability. This may be attributed to their career stage (Nilsson & Senior, 2010). It is perhaps not surprising that engineering students may be more focussed on the transition to the working world and gaining employment, rather than longer-term aspects, compared to graduates. Nevertheless this raises concerns, as employability cannot be seen simply as a bridge that needs to be crossed, but rather a journey in a dynamic working world with complexities and insecurities (Nilsson & Senior, 2010). In a study comparing employability perceptions of French and Hungarian undergraduates, Kövesi and Kálmán (2020) found that French students had a more well-developed conception of employability with well-defined job preferences and long-term goals, while the Hungarian students' was more short-term without clear career goals. This suggests undergraduates can develop a mature conception of employability depending on their career education.

The findings of this study on employability categories are broadly consistent with other literature reporting on employability categories important for engineers (Jollands, 2015; Shuman et al., 2005; Winberg et al., 2020) as well Engineers Australia's Stage 1 Competencies for Professional Engineers - knowledge, skills, application and personal attributes (Engineers Australia, 2017).

'Career development learning' was not identified as an employability category, but certain elements, such as 'transition learning' were discussed under the concept of employability. This may reflect the positive labour market outlook with growth in graduate opportunities in the job market (Jackson, 2017). Other studies have reported an awareness of career development learning in engineering undergraduates (Jollands, 2015; Okay-Somerville, Allison,

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Luchinskaya, & Scholarios, 2020) but these included data collection using surveys where career planning was explicitly included.

Personal attributes and cultural intelligence emerged as noteworthy employability categories, as these are not explicitly included in the CareerEDGE model. Employability is now seen more as an individual phenomenon (Clarke, 2008) and the importance of personal attributes for engineers is becoming more prominent in the literature (Creasey, 2013; Nilsson & Senior, 2010).

The second aim of the study was to investigate the differences in perception among local and international students. The results showed several significant differences. Firstly, local students were more forthcoming in their comments, consistent with reports that international students may be more passive (Heron, 2019; Lin, 2018). Further, international students were less vocal about the relationship between experience and employability. This is an interesting result considering the majority of international student participants had work experience (Barton et al., 2019). Another Australian study reported a similar finding, attributed to the international students not seeing work placement as contributing to their perceived employability (Barton et al., 2019), but without elucidating why this might be. This difference between local and international students may be an interesting area for further investigation.

Finally, another important finding of this study concerns emotional and cultural intelligence. Elements related to emotional intelligence were mentioned by only a few participants, reflecting a recognised gap in engineering education exacerbated by lack of teamwork (Román-Calderón, Aguilar-Barrientos, Escalante, Barbosa, & Arias Salazar, 2021). Of particular interest for this study was that while a few local students mentioned these elements: none of the international students did so. Conversely, a few international students identified cultural intelligence as part of employability, while none of the local students did. The importance of cultural intelligence for employability was previously identified in one study as more prominent for international students (Tran & Pham, 2016). These differences between local and international students may be another interesting area for further investigation.

Conclusions

The findings from this study make several contributions to the current literature and have implications for HEIs, educators as well as researchers.

The results of this study indicate that the way conceptions of employability are developed in students in HEIs may need to change. Students need to develop a broader understanding of employability as a long-term phenomenon that depends on the dynamic nature of the labour market. This would prepare them better for the realities of a future with non-linear short-term career paths (Clarke, 2008). Students could be encouraged to develop their individual career approach beyond initial employment with a focus on well-defined long-term goals (Kövesi & Kálmán, 2020). As self-managed careers are looking more likely the future of engineers, highlighting the importance of personal attributes such as initiative, adaptability and resilience, career planning and emotional intelligence would add value to employability education.

New employability learning activities should also consider adoption of pedagogical practices specifically designed to enhance international student contribution (Bennett et al., 2015) such as the use of socio-cognitive strategies at classroom level to improve self-esteem (Bennett et al., 2015). This study also suggests new research data collection methods may be needed for research with international students, beyond traditional methods of focus groups and interviews in verbal format. In addition, for employability research, a possible extension of the CareerEDGE model is suggested, to consider employability categories such as cultural intelligence and personal attributes, depending on the target population and study context.

This exploratory study helped the researchers identify rich areas for future research – why do international students seem to undervalue work experience? How could students be made more aware of emotional and cultural intelligence, to better prepare them for culturally diverse

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work environments? How do factors other than local/international status such as work-related experience and individual persona influence students' employability learning? Research is continued under these areas, aimed at further unpacking the story behind the data.

It is important to bear in mind that study participants were volunteers who are deemed to be proactive and thus might not be representative of the whole student population. Internet connection issues experienced by two (international) students acted as a limitation for online data collection. Since this is a qualitative study, aimed at exploration rather than verification, the findings may not be generalizable and the qualitative nature of the research needs to be countered when interpreting results. Despite its exploratory nature, this study offers valuable insights into the perceptions of engineering students' employability and future research, with possible contributions to enhancing attractiveness of Australian study programs as an international education destination.

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Exploring Interdisciplinary Identity Development Using Possible Selves: An Exploratory Study

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ABSTRACT

CONTEXT

This exploratory study focuses on an interdisciplinary graduate program in the United States that brings students from science, engineering, technology, or mathematics (STEM) programs together with students in business, policy and governance, natural resources, and other fields to address disaster resilience and risk management. Given the complexity of interdisciplinary collaboration and the need to work across disciplinary boundaries it is increasingly important to develop interdisciplinary capacity in STEM graduate students.

PURPOSE OR GOAL

The purpose of this exploratory study was to explore how participants conceptualize a possible identity as an interdisciplinary scholar over time in order to characterize the structural and individual factors that might prevent one from developing an interdisciplinary identity.

APPROACH OR METHODOLOGY/METHODS

This exploratory study draws on identity-based motivation, using the possible identities framework to understand two qualitatively different development trajectories for two STEM graduate students in the interdisciplinary program. We draw on longitudinal semi-structured interviews over three years with two participants who exhibited markedly different identity development trajectories. Data were analysed using the possible identities framework, which allows us to investigate how participants' desire to be an interdisciplinary scholar changes over time because of their experiences in the interdisciplinary program.

ACTUAL OR ANTICIPATED OUTCOMES

Preliminary analysis indicates that participation in the program does not guarantee that students will desire or develop an identity as an interdisciplinary scholar. Students participate in interdisciplinary programs based on a variety of internal and external factors, and similarly, their identity development depends on multiple factors, including students' backgrounds and their perspectives on the goals of doctoral study.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

We find that interdisciplinary identity development is an individual process that can be constrained or enabled by several structural factors. Interdisciplinary graduate programs can facilitate interdisciplinary identity development, only if structural and individual factors are addressed in tandem. These exploratory findings suggests that interdisciplinary programs may sit at a complex intersection of students' personal goals and orientation and the structural constraints of the institutions. These intersections must be understood more fully in order to develop effective interdisciplinary programs that foster interdisciplinary identity development.

KEYWORDS

Interdisciplinary, Graduate, Identity

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Introduction

In response to calls from both universities and government agencies in recent decades, schools have seen a marked increase in interdisciplinary graduate programs that educate students to think across boundaries. The U.S. National Science Foundation (NSF) has funded interdisciplinary training programs for graduate students since 1998, first through the Integrative Graduate Education and Research Traineeship (IGERT) and now through the NSF Research Traineeship (NRT) program (NSF, 2019). In 2014, representatives from graduate institutions across 14 countries issued a joint statement establishing the importance of interdisciplinary graduate education and research (McCarthy & Woolfrey-Fahey, 2014). Such calls are further supported by educational research highlighting the need to train interdisciplinary scholars, who can move between disciplines and take on the perspectives of different disciplines (Borrego & Cutler, 2010; Newswander & Borrego, 2009).

In response to these calls, interdisciplinary graduate programs have emerged across the U.S. and elsewhere. However, both structural and individual barriers to successful implementation of interdisciplinary programs persist (Boden et al., 2011). One challenge lies in the fact that current university systems are organized around disciplines. This structure creates barriers such as resource allocations, incentive structures, and course credit issues. Moreover, the siloed nature of universities can lead to interdisciplinary programs in which learning is simply structured as a disconnected set of modules from different disciplines (Foley, 2016).

In addition to structural barriers, however, interdisciplinary graduate programs face individualized challenges in helping students simultaneously develop competencies in their home disciplines and those that enable them to work across disciplines (Lattuca et al., 2017). This challenge is compounded by the ways in which students see themselves – the identity (or identities) they assume and are granted across their educational experience. At an undergraduate level, students tend to view themselves through the lens of their individual disciplines (Entwistle, 2009). A graduate degree enhances this "reflection of a disciplinary identity" (Holley, 2017, p. 1), but in doing so can "[produce] over-specialized, disciplinary-based researchers who struggle to adapt to industrial and professional workplaces" (Mathunga et al., 2006, p. 307). As a result, if the goal is to train graduate students to take on interdisciplinary perspectives in both their graduate work and their future careers, programs must not only give students interdisciplinary skills, but also build interdisciplinarity into their professional identities in ways that support sustained engagement. Work in identity-based motivation is particularly relevant here in that it links the ways in which individuals see themselves, in the present and in the future, to their current motivation and actions. Further, in the context of disaster resilience, interdisciplinary identity development is increasingly necessary as the complexity and frequency of disasters increases.

Theoretical Framework

The established links between identity and motivation raise questions about how graduate students see their own identities as both disciplinary and interdisciplinary scholars, and how their perceptions influence their professional development and engagement in interdisciplinary programs. To begin to explore these questions, we draw on the concept of possible identities (also referred to as possible selves) to understand the ways in which graduate students in the interdisciplinary Disaster Resilience and Risk Management (DRRM) program perceive their present and future identities. Possible identities represent "working theories of who one may become, based in current assessments of one's own strengths, weaknesses, talents, and characteristics, as well as assessments of what is possible for people like oneself" (Oyserman & James, 2011, p. 119). Beginning with the work of Markus and Nurius (1986), and later taken up by Oyserman and others, researchers have examined the ways in which both hoped-for and feared possible selves influence individuals' current actions, including academic choices and outcomes. Research in this area suggests that a

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future identity is most likely to positively influence current actions when it is “congruent with other aspects and goals of the current self, be connected to the present self, and be possible to attain” (Kajfez et al., 2016, p. 22). These criteria are defined in Table 1.

Table 1: Dimensions of Possible Selves Needed to Influence Present Actions

Dimension	Definition
Connected	The possible identity is aligned with the person’s values and core sense of self; it is an extension of the current self and feels closely connected to one’s present.
Congruent	The actions needed to attain the possible identity are aligned with the person’s current self.
Possible to Attain	The person believes that the future identity is possible to attain through appropriate action, and that difficulties that may arise can be overcome. (Notably, if an individual believes that the future identity is easy to obtain and requires little or no action, they are as unlikely to take action as if they believe it is too difficult.)

Possible identities as a framework, then, provides a lens to explore how students see themselves relative to a given interdisciplinary context, which in turn can help guide program development. As a first step toward such actions, this exploratory case study examines the development trajectories for two STEM graduate students in an interdisciplinary graduate program, focusing on two research questions:

1. In what qualitatively different ways do graduate students’ conceptions of future possible selves shape their development as interdisciplinary scholars?
2. In what ways do university structures constrain or enable interdisciplinary identities among graduate students?

To address our research questions, we adopt a constructivist approach, focusing on how participants perceive interdisciplinarity as a possible identity. Subsequent work will examine longitudinal data for all participants in the interdisciplinary program, both in STEM and non-STEM disciplines, to consider changes in students’ perceptions over time and corresponding actions they take or do not take relative to developing an interdisciplinary identity.

Methods

This exploratory case study (Yin, 2018) draws on longitudinal semi-structured interviews with two STEM graduate students who have completed at least two years in the interdisciplinary DRRM program. Each student is considered a case and their trajectories are compared to develop an initial framework for understanding interdisciplinary identity development across participants in the program. We employ an a priori coding scheme grounded in possible selves to analyze the data (Miles, Huberman, & Saldana, 2019). Moreover, we posit that the use of possible identities and longitudinal data could be transferred to other interdisciplinary contexts to understand interdisciplinary identity development in other interdisciplinary programs.

Research Site: Disaster Resilience and Risk Management (DRRM) Program

The study context is an interdisciplinary graduate program at a large land-grant university in the mid-Atlantic region of the United States. Built on an earlier iteration funded internally by the university, the current program is funded through the National Science Foundation (NSF) Research Traineeship (NRT) program, with plans to ensure long-term sustainability through both internal and external funding. The graduate program focuses on disaster resilience and risk management and brings together students and faculty from engineering, business, the sciences, and planning and governance. All students and faculty are associated with a

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disciplinary department; the interdisciplinary program grants a graduate certificate but not graduate degrees. Participants' advisors are required to engage in the interdisciplinary program, and participants must have at least one committee member from outside of their discipline who is associated with the program. While interdisciplinary committee members can give input throughout the process, participants' degree-progress is dictated by their discipline and advisor.

While the program's courses are open to graduate students across levels, funding is allocated primarily for doctoral students. Funded students as well as students completing the program's graduate certificate complete at least 12 hours of DRRM coursework (typically 4 courses), along with a 1-credit interdisciplinary seminar each semester, in addition to their core, disciplinary coursework (typically 30 hours or 10 courses). Most students can count the DRRM coursework toward their departmental degree requirements, but for some students the additional coursework itself is a barrier. The required program coursework provides students with interdisciplinary grounding in issues related to DRRM, while the seminar offers a space for students to develop a community of practice and learn what it means to be an interdisciplinary scholar in this area. Participants in this study had participated in at least the first two years of DRRM coursework (their exact point in the program at the time of analysis is masked to maintain participant anonymity), including four semesters of the seminar and an interdisciplinary foundational course.

Data Collection

This study draws on semi-structured, hour-long interviews with participants at the conclusion of each year in the program. All interviews were conducted by two of the program's graduate research assistants, who are both educational researchers who have observed the introductory course as well as the seminar and thus have built significant rapport with the participants over time prior to data collection. The interviews were audio-recorded and transcribed by a professional transcription service. While the interviews covered a broad range of topics, this paper draws primarily from participants' responses to the following interview question:

> Do you consider yourself an interdisciplinary scholar/practitioner? Why or why not?
>
> *Follow-up prompts:*
>
> a. To what extent do you view yourself as an interdisciplinary scholar?
> b. To what extent do you want to view yourself as an interdisciplinary scholar?
> c. To what extent have you been able to practice being an interdisciplinary scholar?
> d. What experiences could help you get there?

This research was approved by the Institutional Review Board at the authors' institution, and the participants in this paper consented to the research study.

Participants

To select participants for this exploratory case study, we set two inclusion criteria: 1) participated in at least two annual interviews and 2) pursuing a PhD in a STEM-discipline. Moreover, since this is an exploratory study, for those meeting the inclusion criteria, we used maximum variation as the sampling criterion; that is, we select two participants (Students A and B) whose identity trajectories were most different from one another. Because the DRRM program is small, we mask demographic characteristics in order to maintain participants' anonymity.

Data Analysis

To understand students' development as interdisciplinary scholars, we first used a priori coding (Miles, Huberman, & Saldana, 2019) based on the possible identities framework to examine the extent to which participants considered an interdisciplinary identity as connected to their current identity, congruent with their current identity, and possible to attain. Using a holistic approach to each transcript, participants were placed in one of three categories for each dimension: Yes, Unsure, or No (e.g. connected, unsure, not connected). Participants' desire to become an interdisciplinary scholar was analyzed based on their responses to follow-up prompt b in the interview protocol ("To what extent do you want to view yourself as an interdisciplinary scholar?"), with responses coded as Want to Be, Do Not Want to Be, or Unsure.

Author 2 conducted an initial round of coding, reviewing responses to the questions about being an interdisciplinary scholar holistically to assign each participant to one of the three subcodes for each dimension. Author 1 reviewed the initial coding and indicated agreement or disagreement. The authors agreed on all of the codes, so no negotiation to consensus was required.

Positionality

The research team for this study consists of four scholars who are all engineering education researchers embedded within the interdisciplinary program. Deters is a Ph.D. candidate in Engineering Education and has worked as a graduate research assistant with the DRRM program since 2018. Menon is a Ph.D. student in Engineering Education who began working with the DRRM program in 2020. Paretti is a Professor in Engineering Education and leads the educational arm of the DRRM program, teaching the core program course and leading educational assessment efforts. Webb is a Ph.D. student in Engineering Education who began working with the interdisciplinary program in 2021. Deters, Menon, and Webb are funded participants in the interdisciplinary program and have developed rapport with the other student participants.

Limitations

The data for this study come from one context-specific interdisciplinary program within a single institution; as a result, the findings are not intended to be generalizable to other programs or institutions. Moreover, they present perceptions of a limited number of participants. However, as an exploratory study, the findings highlight several potential issues that can help inform program development and this research may be applicable to other programs. Further, the approach to understanding interdisciplinary identity used in this study provides the basis for longitudinal work across a broader sample of students in order to understand both actions taken and changes in perception over time.

Results

As noted, the two participants in our exploratory analysis illustrate contrasting conceptions of participants' futures as interdisciplinary scholars. Through their experiences and words, we can see the ways in which participants did or did not perceive interdisciplinarity as congruent, connected, and possible to attain relative to their present self. Further, we can identify structural aspects of their experience that constrained and enabled their identity development.

Student A: "Become an Expert in My Discipline First"

Student A recognized the importance and value of interdisciplinary collaborations from their experiences prior to pursuing a PhD but remained highly invested in developing their disciplinary expertise throughout their doctorate program. In their year one interview, Student A perceived a future interdisciplinary identity as connected but not congruent – an interdisciplinary identity aligned with their values (i.e., connected) but the actions needed to attain that identity did not align with their goals for their graduate program (i.e., not congruent). Student A could see themselves attaining an interdisciplinary identity in the

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distant future, after completing their PhD. That is, being an interdisciplinary scholar was not the primary goal for Student A during their PhD program. This student noted:

> *But as a PhD student, it's a kind of [about doing] independent research […] 100 percent collaboration research is not […] a good thing [for] a PhD student.*

The interdisciplinary graduate program provided Student A with funding to pursue their research interest and collaborate across disciplines with others who are working in a similar domain. By the time the year two interview was conducted, Student A's actions were congruent to achieving an interdisciplinary identity. However, their focus on gaining disciplinary knowledge and expertise did not waiver. In the second interview, the student expressed:

> *As a student, we need to become expert in our discipline first, and then [collaborating] or working with other disciplines should be the second step.*

What changed for Student A from the first year to the second was the definition of *interdisciplinary*. While navigating through interdisciplinary research and collaborating across other STEM fields, the student wrestled with the idea of what qualifies as interdisciplinary. Student A explained their confusion:

> *I'm a little bit confused of my identity sometimes because I'm in [STEM discipline A - hidden for anonymity], but my research seems like related to more in [STEM discipline B] field sometimes. So, most of the papers I'm reading is related to [STEM discipline B] journals. So am I in [STEM discipline A] and working for [STEM discipline B]? Those kinds of things. But that means I'm an interdisciplinary researcher so, I would say yes.*

While Student A's collaborations with other faculty and students during their time in the program indicates congruency to an interdisciplinary identity, they found it difficult to differentiate between what counts as disciplinary and interdisciplinary when disciplines overlap. Overall, Student A was more connected to their discipline and more committed to acquiring disciplinary expertise throughout the duration of their program. Furthermore, they admitted to being confused as to whether they identify as an interdisciplinary scholar or even want to, in the future, but saw it as a possibility upon completion of their PhD.

Student B: "Interdisciplinary scholar - that is the one thing I need to be"

Student B, in contrast, was very clear about their interdisciplinary identity and goals from the beginning of their PhD journey. Motivated to pursue a PhD because they felt that they didn't know enough to effectively collaborate at the firm they worked for, they felt disconnected to their discipline and more connected to the interdisciplinary program. In their year one interview, Student B felt connected to a future interdisciplinary identity – it aligned with their values, and they even noted that "[an interdisciplinary scholar] is the one thing I need to be."

To Student B, an interdisciplinary scholar is an individual who can bring together different knowledge areas. An interdisciplinary scholar, according to Student B, does not have to have deep disciplinary expertise, but rather focuses on facilitating connections between disciplines. Student B further explained their definition of an interdisciplinary scholar in their year one interview:

> *I think it means that I have the liberty to solve applied problems, applied complex problems in real time, like modern problems. I think that you can't be so specialized in something so obscure. You can't be too deep into something so tiny in order to solve these really, really big problems. I think some people need to have that really, really fine disciplinary expertise, but I think you also need to have some people that can bring all that together somehow and link it together or understand how it links together, like have more of a systems perspective that's not so entrenched [in a single discipline].*

Although Student B did not think they could call themselves an interdisciplinary researcher at the time of the year one interview, they were very clear about their desire to be interdisciplinary as they acknowledged that real-world problems are not bounded by a discipline:

> *Mother Nature does not construct her problems with a disciplinary lens. So, a lot of the really people focused problem-solving classes tend to be kind of interdisciplinary.*

Student B believed that an interdisciplinary identity was attainable and expected the interdisciplinary graduate program to provide them with opportunities that were congruent to their goal. Over their time in the program, Student B worked across disciplines and collaborated with a number of different people from various fields. The program gave them the platform to communicate to different disciplines about their research, and they reported gaining confidence through such courses and research project presentations and collaborations. However, they felt constrained and limited by the academic setting and expectations of their advisor and department. Their research interests seemed to span over different disciplines, which, from comments they received from their advisor and others, may not be the ideal situation for a PhD student. The advisor and others felt that the student did not have the deep knowledge and expertise in their discipline, which led them to lack a sense of belonging in their department. As a result, despite an interdisciplinary identity being connected, congruent, and attainable throughout their time in the interdisciplinary program, they struggled with confidence and imposter syndrome. In their year two interview, Student B said:

> *I think because of these [kinds of] identity struggles about like whether I'm a good researcher, am I a good researcher? Um, these identity struggles kind of stem from maybe being an interdisciplinary student and not feeling like I have a place has not helped me with any sort of like confidence or imposter syndrome sort of like alleviating that. It only exacerbates that. Because you look around at, you know, your fellow students. And I told you that I try not to compare myself to other people in my department. I do that on purpose because I feel like I lack the knowledge base to be a researcher in that field. So being an interdisciplinary student is challenging for that reason where you think that you kind of have to justify your existence sometimes because maybe you don't have as deep of a knowledge base as the people in your department. You just have a different knowledge base. So yeah, that, that, that kind of insecurity about not feeling like I am sufficient in a certain department for a while um, impeded my ability to see myself as a PhD researcher.*

By the end of the program, Student B felt the need to be a part of a different environment in order to continue their primary goal of being an interdisciplinary scholar.

The Role of University Structures

Throughout their interviews, the students discussed different university structures that enabled and constrained their identity development, including the design of their doctoral program, their advisor's approach to interdisciplinarity, and the siloed nature of departments at the university. First, Students A and B had very differently constrained doctoral programs. Student A's program had a large number of required courses, requiring them to take the majority of their courses within their discipline, while Student B's program had a small number of required courses, allowing them to take many courses in other disciplines. Moreover, Students A and B's advisors offered different guidance about and support for interdisciplinary work at different stages of their Ph.D., which was in part informed by how they perceived expectations for dissertations within their department. The students navigated different disciplinary structures and advising styles, but both experienced tensions between their interdisciplinary program and the disciplinary silos of academia. Student A was more comfortable with a disciplinary focus, and while they collaborated across other related STEM disciplines, they did not identify this work as interdisciplinary. However, Student B, for whom interdisciplinarity was congruent, connected, and possible to attain relative to their present self, felt limited by the siloed nature of academia. While both Students A and B valued interdisciplinarity in their research, the role of university structures affected them differently because of their contrasting relationship with their future self and interdisciplinary identity development.

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Discussion & Conclusion

Both participants discussed navigating structural challenges associated with interdisciplinary education, similar to those barriers noted in Lattuca et al. (2017), including challenges balancing their efforts between their disciplinary degree-granting program and their interdisciplinary graduate certificate. The two participants in this study both discussed how their experiences were shaped and constrained by these existing university structures, and each participant responded differently. Student A chose to focus primarily on their discipline, seeing interdisciplinary work as something that could happen in the distant future. Because an interdisciplinary scholar identity was a distant possible self, their responses about whether this identity was connected, congruent, and possible to attain oscillated. On the other hand, Student B chose to focus primarily on interdisciplinary work, and felt that they did not fit into the structures of their discipline. While this student fully embraced ‘interdisciplinary scholar’ as a future possible self, they struggled to navigate the strict boundaries of their discipline.

The experiences and trajectories of Students A and B through their disciplinary and interdisciplinary programs raises questions about how we design interdisciplinary programs. Tensions between university structures, like disciplinary silos, reward structures, and even the layout of physical buildings, and interdisciplinary programs are longstanding (Boden, Borrego, & Newswander, 2011; Gardner et al., 2012; Holley, 2009; Lattuca, 2001). These barriers existed in the previous iteration of nationally funded interdisciplinary programs (IGERTs) and still exist today with NRTs. As Student A and B’s stories show, the continued prevalence of structural barriers impacts how students navigate their possible identities and ultimately impacts the success of these taxpayer funded interdisciplinary programs. This work reinforces the need to account not only for the structure of universities, but also for the orientations students bring (i.e., towards disciplinary expertise or towards interdisciplinary expertise), and to foreground both the alignments and the tensions that exist as students navigate these structural barriers. That is, students may wish to build disciplinary expertise but be funded through an interdisciplinary program, or they may seek interdisciplinary expertise, but be constrained by departmental expectations.

These exploratory findings suggests that interdisciplinary programs may sit at a complex intersection of students’ personal goals and orientation and the structural constraints of the institutions. We need to understand those intersections more fully as we think about the future of interdisciplinary education. Accordingly, more work is needed to expand this exploratory study into a larger study that looks across more participants and more interdisciplinary programs.

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What's wrong with grit? – Considerations and Better Alternatives for Engineering Education Research

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ABSTRACT

CONTEXT

Grit is conceptualized as a combination of passion and perseverance. Engineering education researchers are increasingly interested in studying grit as factor in student persistence, retention and success. The number of engineering education publications on grit is steadily rising each year, and there has been enough research on the topic that a systematic literature review was recently conducted. Despite the growing interest however, studying grit is problematic for a variety of methodological and philosophical reasons.

PURPOSE

The purpose of this paper is to identify and explain eight methodological and philosophical problems with the concept of grit in the context of engineering education research. Our aim in doing so is to help engineering education researchers reflect more critically on its use and identify research questions that avoid the methodological and philosophical pitfalls identified. The paper contributes to this year's theme of 'capability development' by providing researchers with critical perspectives for better understanding the current research landscape and planning future studies.

APPROACH

This paper treats *grit* as a discourse and utilizes a post-structural discourse analysis approach to analyse its problematic assumptions and functioning. The evidence supporting the analysis and argument is historical, sociological, philosophical, and methodological in nature. Drawing on perspectives and insights from these other disciplines allows us to introduce critiques not yet widely recognized in engineering education.

OUTCOMES

The eight methodological, philosophical and functional problems with grit that this paper elucidates are divided into three aspects. The first aspect is *assumptions and blind spots* in study conceptualization. The second aspect is *construct and evidentiary* issues. The third aspect is *effects* on the engineering education system.

CONCLUSIONS

The reasons to reconsider researching grit are numerous and multifaceted. Perpetuating the problematic features of grit research is not in the best interest of students or the field. Both will be better served by framing persistence and retention studies with questions about institutional, structural, and cultural factors instead.

KEYWORDS

Grit; studying down; methodology

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Introduction

Grit is conceptualized as a combination of passion (or consistency of interest over time) and perseverance (Duckworth, 2016). Engineering education researchers are increasingly interested in studying grit as factor in student persistence, retention and success, often in the context of diversity. As seen in Figure 1, the number of engineering education publications on grit is rising, and has jumped dramatically in the past six years (ASEE, 2021). (Although not every hit in this search refers to the psychological construct of grit, the rise in those that do is telling). There has now been enough engineering education research on the topic that a systematic literature review was recently published (Direito, Chance, & Malik, 2021). The term is even making its way into recruitment and promotional materials. A brochure for a college engineering eagerly tells students to come “Test your competitive grit with the Global Formula Racing team” (OSU, 2018, p.3).

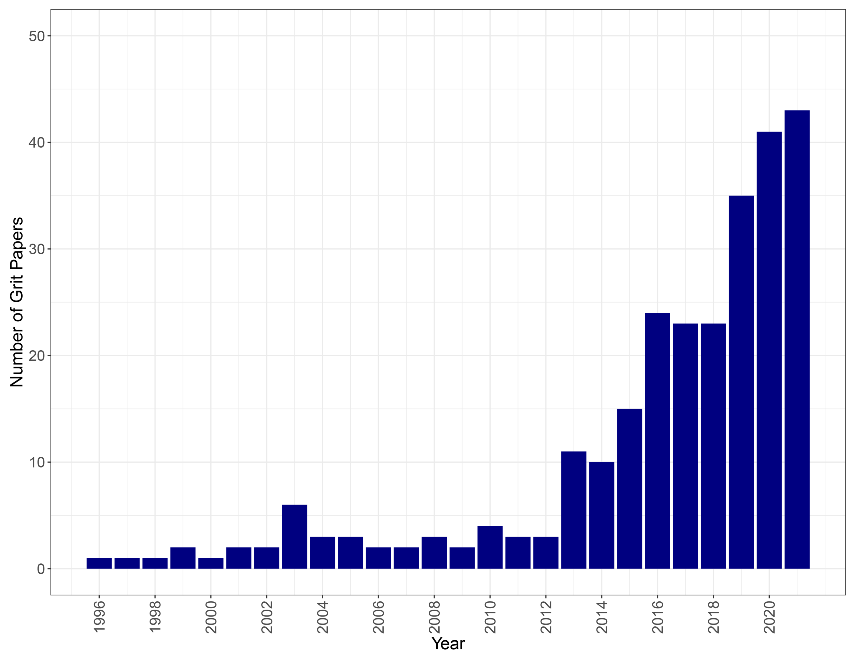

Figure 1: Number of ASEE conference paper ‘hits’ for grit by year*
*based on data from (ASEE, 2021). Note: May not reflect the entirety of 2021.

Despite the growing interest within the field however, studying grit is problematic for a variety of methodological, philosophical, and effect-related reasons. The purpose of this paper is to identify and explain eight such problems with the concept of grit in the context of engineering education research. Our aim in doing so is to help engineering education researchers reflect more critically on its use and identify research questions that avoid the pitfalls identified. The paper contributes to this year’s conference theme of ‘capability development’ by providing researchers with critical perspectives for better understanding the current research landscape and planning future studies.

This paper treats *grit* as a discourse and utilises a post-structural discourse analysis approach to analyse its problematic assumptions and functioning (Hall, 2007; Howarth, 2000). Elsewhere *grit* has been called an ‘ideology’ (Gorski, 2016) and a ‘hegemonic narrative’ (Tefera et al., 2019), which are in alignment with our chosen terminology of ‘discourse’. A similar approach has previously been utilised to critique the concept of ‘fairness’ in higher education leadership literature (Beddoes & Schimpf, 2018). Throughout the paper, when grit is italicised, it is meant to imply the *discourse of grit*, rather than the attribute of grit. Given the nature of this paper, it does not follow the traditional structure for engineering education papers. The eight interrelated methodological, philosophical, and

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functional problems with grit that this paper elucidates are divided into three aspects. The first aspect is *assumptions and blind spots* in study conceptualisation. The second aspect is *construct and evidentiary* issues. The third aspect is *effects* on the engineering education system. The next section of the paper presents and discusses each in turn. The conclusion suggests better questions to help researchers move away from grit research.

Eight Problems with Grit

Assumptions and blind spots in study conceptualization

1. Studying down: Studying down is the tendency in social science generally, and engineering education research (EER) specifically, to study (and locate problems within) marginalised groups (Beddoes, 2017, 2019; Nader 1974; Sprague, 2005). In the context of diversity, studying down is one instantiation of what Faulkner (2009) calls the deficit model approach to diversity – one that frames the problem and solutions around changing marginalised students. The problem with studying down is that it leaves dominant groups and those in positions of power (in this case, faculty/staff, administrators) as well as institutions, structures and cultures unproblematised. As Sprague (2005) explains:

> *… Research questions are more likely to focus on members of disadvantaged groups and explore their deficiencies, while the attributes and practices of those with social power are much less likely to be exposed to social science surveillance. And in addressing social problems, the emphasis is more on the attributes of those experiencing the problem than on considering what it is about the current social order that makes the problem likely. (p. 12)*

Grit is the latest in a long line of studying down research topics that have attracted engineering education researchers. One such long-standing example is self-efficacy, and similar critiques have been levied against that line of research as well. For example, Slaton's (2011) critique of self-efficacy is equally applicable to grit and its inherent studying down because such research directs:

> *…our attention to the behaviors and psychological states of individual minority students, obscuring the social context in which entry and success in engineering fields play out…Socio-cultural conditions (such as endemic racism, sexism or ageism), and the institutional practices that embody those inequities (such as majority-focused pedagogical theory, or biased treatment of minority students by instructors and administrators) are of more or less limited consequence to many of these researchers and those who deploy their findings. (p. 3)*

Further information about why studying down is dominant in EER and examples of studying up can be found in Beddoes (2017, 2018, 2019) and Beddoes & Panther (2018).

2. Ignoring social power-privilege, perpetuating the myth of meritocracy: The discourse of grit and the myth of meritocracy (or the belief that one's success is dependent solely on their own hard work or abilities) are two sides of the same coin. They both hide the fact that being a member of a dominant group conveys certain privileges that support one's success (Ferber, 2012; Gorski, 2016; McIntosh, 2012; VanDeventer Iverson, 2007). Beddoes (2021, 2022) uses the term power-privilege to highlight that "dominant systems of power work to establish and sustain particular advantages" (Sefa Dei et al., 2007, p. xii). In the context of engineering, being white and being a man convey privileges such as the presumption of competence, being "seen" as an engineer, being "heard" in group settings, relative freedom from sexual harassment, and a sense of belonging and feeling welcome (Beddoes, 2021, 2022; Douglas, 2015; Eastman et al., 2019). Salient financial and cultural privileges include not having to work while in school and understanding financial aid systems (Pawley, 2019). These forms of privilege are intersectional (Beddoes, 2021; Case et al., 2014; Ferber, 2012). As an ideology, *grit* fundamentally obscures the role of power-privileges in influencing who succeeds and who does not. Schreiner (2017) discusses this at length in the context of K-12 education. By obscuring privilege's roles in supporting success, the discourse of grit then also perpetuates the myth of meritocracy. In this light, it is not surprising that *grit* appeals to

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many in engineering education where the myth of meritocracy also finds considerable purchase (Cech, 2013; Slaton & Pawley, 2018).

3. Universalizing a singular motivation out of many: Students pursue engineering degrees for a variety of reasons (Margolis & Fisher, 2003; Matusovich et al., 2010). Not all of those reasons are related to passion for or interest in engineering per se. For instance, some students are motivated to pursue an engineering degree as a means to a profitable career, upward social mobility, a career outside of engineering, or because of influence from family (Margolis & Fisher, 2003; Matusovich et al., 2013; McLoughlin, 2009; Painter et al., 2017). Yet, by putting passion squarely at the centre of success, the discourse of grit normatively universalises the motivation of passion. It normalises the student who has loved tinkering since childhood, the student who wants to spend 18 hours a day coding. The work of Margolis & Fisher (2003) shows that this idealised image of a student passionate about engineering (based on only one type of student), causes others who do not fit that norm (do not share that passion) to see themselves as not belonging in engineering and to consider leaving. Focusing on grit and its attendant passion means that engineering educators may inadvertently exclude or marginalise students with other – equally worthwhile and valid – motivations and interests.

Construct and evidentiary issues

1. *Construct validity:* Grit is most commonly measured through survey instruments, frequently following the instruments created by Duckworth and colleagues (2007, 2009) (Credé et al., 2017; Direito et al., 2021). However, there have been methodological disagreements about the structure (construct validity) of grit. In the context of survey research, construct validity attempts to assess whether a research instrument measures the concept(s) or theoretical construct(s) it was designed to capture (Messick, 1989). Construct validity is typically tested with factor analysis, a statistical method for analysing if survey items measure similar, higher order constructs (called factors), identifying which questions map to which factors and examining if there is any relationship between factors (Kim & Mueller, 1978). In short, establishing construct validity is critical to ensure that the concepts researchers theorise align with the empirical measures they use.

Duckworth and colleagues (2009, 2007) define grit as composed of two sub-constructs, *continuity of interest (CI)* and *persistence of effort (PE)*, which they define as the ability to hold the same interests over time and to work hard toward a goal, despite difficulties or setbacks, respectively (Direito et al., 2021). Duckworth and Quinn (2009) argue that the questions in their instrument measure (or load onto) the CI and PE sub-constructs, which themselves load onto an overall grit construct, and they provide results to establish validity of this construct structure. However, several researchers have challenged Duckworth and Quinn's (2009) results, arguing that they incorrectly specified the type of model they tested for grit, and that the model they tested is equivalent to grit being composed of two correlated constructs (CI and PE) with no higher order 'grit' construct (Morell et al., 2021; Muenks et al., 2017). This matters for studies of grit because whether it is best described as two correlated measures or as an overall measure which has two related sub-constructs implies two different ways of calculating grit results and subsequently affects any inferences or implications that are drawn.

Furthermore, empirical work has demonstrated additional challenges with grit's construct structure by revealing that it varies depending on the population under examination (Datu et al., 2016; Morell et al., 2021; Muenks et al., 2017). These results imply a lack of invariance in grit's structure across different populations and raise questions about attempts to compare results across groups by age and cultural background. While a few studies have found some evidence of invariance for grit as a construct, these studies either did not examine alternative models for grit's structure (Fosnatch et al., 2019) or examined a limited set of models that may have affected their results (Datu et al., 2016). If there is a lack of invariance in grit's

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structure across age and culture (and possibly other untested demographic variables) this complicates any attempt to conduct longitudinal, interventional, and comparative work.

2. Evidentiary problems: Many researchers have theorised about and analysed the relationship of grit as a construct with academic outcomes or measures of academic success, such as GPA and retention (Direito et al., 2021; Credé et al., 2017; Chang, 2014; Choi et al., 2016; Ivcevic & Brackett, 2014). However, many of these studies examining grit's connection to academic outcomes in engineering education (e.g., retention, exam scores) report weak or contradictory results (Direito et al., 2021), which raises questions about its utility as a research construct. Outside of EER, drawing on a larger pool of research in psychology, education, and related fields, similarly tenuous relationships are seen. A meta-analysis revealed that grit correlated with GPA at .17, with retention at .16, and with intent to persist at .18 (Credé et al., 2017). (A perfect correlation is 1, and anything below .3 is generally considered low.) Importantly, the studies in the meta-analysis did not just include studies with weak to moderate relationships between grit and academic outcomes, but also studies that find *no relationship* between grit and academic outcomes. Therefore, grit's relationship to academic outcomes may be weaker or more nebulous than the combined results imply.

In summary, disagreements, and wide variations in findings about the construct validity and subsequent structure of grit as research measure, as well as weak or contradictory evidentiary findings on how grit may relate to key academic outcomes raise serious questions about the use of grit in EER. Considering the issues identified in this section, researchers interested in studying grit are encouraged to critically reflect on whether a construct laden with these challenges can advance the field in meaningful ways. Rather than encouraging further grit research to address and try to resolve the conflicting findings however, our position is that, given the problems identified in this paper, abandoning grit research entirely is the more useful, responsible, and meaningful route.

Effects on the engineering education system

1. Perpetuating a culture of poor mental health: Engineering students' mental health is troublingly poor in some regards (Danowitz & Beddoes, 2018, 2020). Beddoes has conducted interviews with current and former engineering students to identify aspects of engineering and engineering education cultures that undermine mental health. Those interviews revealed that several distinguishing features of engineering programs negatively impacted students' mental health, and caused some to leave engineering. Those findings will be published in the future (Beddoes & Danowitz, under development). What is of note here are the relationships between *grit* and some problematic aspects of engineering (education) culture identified in that study. Most notably a culture where stress, overwork, 'toughness', and the ability to succeed (or persevere) at any cost are valued, a "cut throat" culture where there is no room for people who cannot keep up, a culture where, consequently, suicide and poor mental health are normalised to the point of expectation. Interviewees expressed a sense that engineering students are expected to be capable of handling anything thrown at them regardless of its impact on their well-being. The discourse of grit plays into this ethos with its elevation of perseverance as ultimate good and its rhetorical, historic and symbolic association with *toughness* (Jaeger et al., 2010; Stokas, 2015). If *grit* is an increasingly mobilised discourse in engineering education, it risks perpetuating these aspects of engineering culture by further entrenching a value system that expects overwork, toughness, and succeeding at any cost. Engineering education should not be guided by the militaristic ethos where much of Duckworth's (2016) grit research originated.

2. Contributing to lack of change in diversity, equity and inclusion: In the context of diversity, equity and inclusion (DEI), grit research represents more of the same – in the sense that it studies down by problematising marginalised students. Such research has been going on for thirty-plus years. However, those three-plus decades of evidence suggest that grit research is not likely to change anything because similar research (and interventions based on that

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research) have not led to significantly improved representation in engineering. For example, at the undergraduate level in the United States, women's participation in engineering increased only 2.5% (from 18.4% to 20.9%) between 1997 and 2016 (NSF, 2019). Even more troubling is the fact that participation of some groups, such as Black and African American engineering students, has actually decreased since 2006 (Fletcher et al., 2017). At all levels, engineering is still a "low participation field" compared to other science fields (NSF, 2019). It is clear then that the significant amount of research devoted to increasing DEI in engineering has largely not succeeded in broadening participation to the extent intended. As argued elsewhere, one leading reason this is so is because the vast majority of that research has been studying down rather than studying up (Beddoes, 2017). And, as argued above, *grit* is the latest manifestation of that tendency to study down. Therefore, decades of evidence would suggest that grit research is not going to increase DEI in engineering in any meaningful ways.

3. Maintaining problematic dominant structures and culture: Grit contributes to maintaining the status quo within engineering education beyond just lack of change in representation however. It maintains dominant structures and culture in several interrelated ways. First, the discourse of grit is fundamentally about teaching students to accept and function within the status quo. In engineering education, the status quo has been critiqued on many fronts, from generating a lack of interest in public welfare concerns (Cech, 2014) and empathy (Walther et al., 2020), to having a very narrow sense of ethics (Foley & Gibbs, 2019), to having a culture of stress (Jensen & Cross, 2021), to being racist/raced, sexist/gendered, and ableist (Beddoes, 2012, 2019; Holly, 2020; McCall et al., 2020; Mills et al., 2010; Pawley, 2019; Riley, 2008), to not adequately preparing students for the workplace (Brunhaver et al., 2018), among other things. *Grit* fundamentally normalises those aspects of engineering education by not challenging them and teaching students they should adapt to them. Saltman (2014) implicated grit in neoliberal education reforms calling it a "pedagogy of control" in service to the "disimagination machine" (Giroux, 2013) that teaches students to be submissive and not challenge or think critically about social justice or inequities. Again, Slaton (2011) has made similar points about self-efficacy, contending that in self-efficacy research "discriminatory cultural norms, such as racism, and institutional conditions that embody those norms may either be left out of explanatory models all together or treated as conditions with which individuals should contend" (p. 4). In the context of engineering education, *grit's* historic and symbolic association with masculinity risks re-entrenching that aspect of engineering culture in ways that make it potentially more problematic than self-efficacy however. Even more troubling is the possibility that such structural problems could come to be seen as good because they *create* grit (or romanticise the struggle), as Ris (2015) explains was historically the case for poverty and K-12 students in the U.S. Indeed, there is some evidence of this belief structure in engineering education already, with some professors believing that they are doing women a favour by continuing to let them have negative experiences (Beddoes & Panther, 2018).

Second, if students cannot, or choose not to, function within that status quo, *grit* places the blame for failure squarely on those students for not being gritty enough (Golden, 2017; Schreiner, 2017). As Gorski (2016) put it, *grit* turns structural problems into individual failings. Consequently, we can see how this invokes the myth of meritocracy by hiding key structural factors in success by cloaking them as individual merit, worthiness, intellect, or hard work.

Conclusion

Given the eight reasons elucidated above, grit research is not likely to benefit individual students or the engineering education system as a whole, and may in fact cause harm. Nor do the eight interrelated problems we identified constitute an exhaustive list. There are, for example, questions about personality research more generally, what is fixed and what is malleable, and what is original about grit. Why then has engineering education grit research gained such popularity in recent years? The likely reasons are because it taps into the

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dominant research landscape of studying down, because it taps into a dominant ethos of meritocracy and celebration of weed out culture, because it is not threatening to engineering educators' work or identities, and because it is expedient. Yet, these expediencies are problematic because they should not be the guiding criteria by which one chooses research questions. Research methods are forms of social power; they are world-making. What is interrogated and problematised, what is challenged or maintained, what is hidden or ignored, all play a role is shaping what comes to be, what is known, and how communities see the world. We have a responsibility then to ask better questions. To that end, Table 1 offers better alternatives to grit research questions. Asking better questions is undoubtedly harder on multiple levels. It may require being critical of colleagues, administrators, your institution, and, perhaps, yourself and a discipline you identify with (Beddoes, 2017). It may require reading from unfamiliar fields that do not purport to have easy answers. But that does not mean it should be avoided. Ultimately, both students and the field of engineering education research will be better served by studying up and asking questions about institutional, structural and cultural factors, and power-privilege instead of grit.

Table 1: Better alternatives to grit research questions

Instead of this	Ask this
In what ways is grit related to academic success?	What institutional, structural and cultural barriers keep students from succeeding?
How does grit vary across demographic groups?	How is power-privilege distributed among various groups in ways that influence outcomes?
How can students' grit be increased?	How can instructors' understanding of inclusive pedagogy be increased? How can engineering education systems be made more equitable and just?
How does grit motivate students to persist in the face of challenges?	What changes can be made so that systemic challenges do not disproportionately negatively affect marginalized groups?

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Comparison of Interpersonal skill competency for Australian Graduate and Experienced engineer frameworks

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ABSTRACT

CONTEXT

Engineers require excellent interpersonal skills and self-awareness (Crosthwaite et al., 2018; J. E. King, 2007; NAE 2004). Successful team-based practice and collaboration necessitate enhanced interpersonal skill competency, attributes, and attitudes (R. King, 2008; NAE 2004). Experience and formal education play a key role in development of these skills. Since the shift in the 1990s to outcomes-based attributes, Engineers Australia's (EA) accreditation frameworks have continued to drive standards of engineering programs and professional engineers in Australia (EA 2017a, 2018; Lloyd, 1991; Male et al., 2011). The Stage 1 (Graduate) and Stage 2 (Experienced Professional) frameworks establish enabling and practice competencies (EA 2003). How and where engineers are expected to develop the competencies required to progress from Stage 1 to Stage 2 is not clear. Understanding these expectations of interpersonal skills can assist engineers to better develop these skills.

PURPOSE OR GOAL

The research investigates expectations of interpersonal skill development in Australian engineers. It addresses two questions: What interpersonal skills, behaviours and attitudes are Australian engineers expected to develop according to EA Stage 1 and Stage 2 competency frameworks? What are the key differences and gaps between Stage 1 and Stage 2 Indicators of Attainment (IAs) in interpersonal skills and behaviours?

APPROACH OR METHODOLOGY/METHODS

We systematically compare EA Graduate and Experienced Professional Standards for the interpersonal competencies of communication, team membership and leadership, relationships, self-management, management and collaboration. Gaps and differences between the two frameworks will be identified and interpreted to understand the expected growth between the two career stages.

ACTUAL OR ANTICIPATED OUTCOMES

Significant focus has been placed on ensuring undergraduate students are work-ready, but these interpersonal attitudes, attributes and behaviours are largely expected to be developed in an industry setting. While some interpersonal skills and behaviour between the two Standards align, areas such as community engagement and providing feedback present a large learning gap. We conclude by offering recommendations about how and where engineers might develop the competencies required to progress from Stage 1 to 2.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Identifying areas of expected interpersonal skill growth informs approaches to engineering practitioners professional development and education at university and beyond. As the market for micro-credentials and short-courses expands, there is potential to target attitude, behaviour and skill competencies required of experienced engineers with Stage 1 and 2 competencies in mind.

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KEYWORDS
Professional engineers, interpersonal skills, competency frameworks, life-long learning

Introduction

Engineering professionals require excellent interpersonal skills (Crosthwaite et al., 2018; J. E. King, 2007; NAE 2004). The interconnected nature of engineering work requires high levels of collaboration within and outside of engineering teams. High levels of self-awareness and interpersonal skills enable more successful engagement and collaboration with others and are pre-requisites for leadership skills (Lopes et al. 2015).

'Interpersonal skills' is one of several of terms used to describe "*the way people relate to and interact with others*" (Willmot & Colman, 2016). Hayes (2002) defines interpersonal skills as inherently goal-related: a suite of skills and behaviours that increase chances of a desirable outcome. However, this does not define from who or to whom the desirable outcome satisfies. Other terms include 'soft skills', interactive skills, social skills, emotional intelligence, people skills, and social competence (Hayes, 2002; Willmot & Colman, 2016). These terms encompass skills such as communication, leadership, teamwork, managing successful personal diverse relationships, collaboration, networking, and cultural understanding (Lappalainen, 2009, p. 123; Lopes et al., 2015).

This dimension of engineering practice has historically been desired, gaining greater prominence with the rise of university-based engineering education in the 20th C. Private industry highlighted to universities the need for graduates with higher levels of communication skills, and have continued to emphasise the role of interpersonal skills alongside technical aptitude in graduates (Lamb & Cawood, 1994; Munir, 2021).

Preparing graduates for employment is a key aspect of professional accreditation programs and university curriculum. Numerous interventions have been studied at the tertiary level which focus on identifying and developing interpersonal skills through the curriculum (Lopes et al., 2015; Smith et al. 2009; Van Der Molen at al. 2007). Measurement of these skills is considered difficult, with self-reporting measures, surveys and observation used to evaluate interventions (see Lopes et al., 2015; Mazzurco & Murzi, 2017). While formative, these interventions are bounded in tertiary education, rather than practice.

Engineers Australia (EA) is the peak professional body and accrediting agency for undergraduate engineering qualifications in Australia. They define competency standards for Graduate (Stage 1), Experienced Professional (Stage 2) and Executive (Stage 3) engineering practitioners. The Standards "*seek to provide objective statements of the skills that are genuinely needed for effective practice, on which the community and the profession can rely."* (EA 2003, p. 7), outlining "*the minimum competencies… members…may be relied upon to possess"* (EA 2003, p. 3). Conversely, the Standards respond to industry needs, driving expected practice, competence and consistency of engineering professionals.

Since the transition to competency-based outcomes in the 1990s, EA has sought to assess *"whether or not an individual actually possesses these skills, without prescribing how they should have been developed"* (EA 2003, p. 7). Stage 1 establishes the minimum standards for 'modern professional engineers' upon graduation from a four-year Bachelors degree. Accreditation is sought by the university seeking to accredit their degree. In Stage 2, accreditation is sought by individual practitioners with 3-5 years practice (EA 2021b). These practicing competencies build upon Stage 1 and are expected to be developed at work. The accreditation process reflects this as individuals responding to Indicators of Attainment (IA) in a written response and interview, drawing upon examples from their experiences.

The progression from Stage 1 to Stage 2 is similar to other signatories of the International Engineering Alliance's (IEA) Washington Accord (IEA 2021). This multi-lateral agreement between national bodies responsible for accreditation of tertiary-level engineering provides mutual recognition of qualifications, skills and abilities of graduate engineers. The

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Washington Accord attributes and professional competencies establish expected standards of engineering practice across signatories and promote shifting requirements and priorities in engineering practice, such as consideration of sustainable development (World Federation of Engineering Organizations, 2021).The importance of interpersonal interaction is an area of increasing prominence in the Washington Accord, identified as a key area of engineering practice (World Federation of Engineering Organizations, 2021).

Our study compares EA's Stage 1 and 2 Standards to reveal the expected interpersonal skills and behaviour development between graduation and 3-5 years of practice, and understand how they build on each other. Through identifying gaps between the two frameworks, we can understand how gaps are currently bridged and how they may be overcome moving forward. This allows practicing engineers to better navigate their learning and assist education providers and employers to better support their graduate engineers.

Method

This paper seeks to compare the EA Stage 1 and 2 frameworks to identify similarities, differences and gaps in learning between the two with respect to interpersonal skills. The key questions are firstly, what interpersonal skills and behaviours are required in EA Stage 1 and 2 Competency Standards? And secondly, what are the key differences and gaps between EA Stage 1 and 2 Indicators of Attainment (IAs) in interpersonal skills and behaviours?

In this study, ‘interpersonal skills’ entails any interaction, consideration and relation to others. This draws on Hayes (2002, p. 3) definition of “*the ability to behave in ways that increase the probability of achieving desired outcomes… used in… interactions… to bring about a desired state of affairs*”. This includes listening, awareness of self and others, presenting information to others, negotiating, asserting and influencing, collaborating, managing relationships and consideration of others (Hayes, 2002; Lappalainen, 2009, p. 123; Lopes et al., 2015).

To assess the Stage 1 and 2 Competency frameworks with respect to interpersonal skills, comparative document analysis is used (Bowen, 2009). Document analysis provides insight into the contents of the documents, the intended readership, and the context in which they were produced (Atkinson et al., 2011; Bryman, 2008, pp. 554–555). This approach allows data to be examined and interpreted to gain understanding, intended meaning and knowledge (Corbin & Strauss, 2008). As a qualitative investigation, document analysis is an efficient and simple technique for such a small number of documents. A limitation is the credibility of a small sample size (Yin, 1994, p. 80). This is managed by using documentation surrounding the competency frameworks to provide additional context (Atkinson et al., 2011). This does not mitigate the inherent bias or agenda of contributing authors, which may be examined in comparison to other international frameworks in additional investigations.

The Stage 1 and Stage 2 Competency framework documents are appropriate documents as are they official (authentic), credible (from EA), representative of the type of document and such a case, and have clear meaning (Bryman, 2008, p. 544; Scott, 1991). As EA is the peak professional body for engineers in Australia, and the key accreditation body for educational offerings, these Standards outline the key competencies required by Australian engineers. For this study, the general Stage 2 Engineering Competency Standard will be used, not the specific Separate Competencies and IAs used form some Areas of Practice.

This studies’ primary documents are the EA Stage 1 and S 2 Competency Standards (EA 2012, 2017b). Supporting documents are the Australian Engineering Competency Standards (EA 2003), Writing Engineering Competency Claims (EA 2017c), Accreditation Management System Education Programs At The Level Of Professional Engineer Overview S01 (EA & Bradley, 2008) and Chartered Measure of Excellence (EA 2021b). These documents provide additional understanding of the application and use of the Competency Standards.

The two Standards broadly include an introduction, providing context to the document, expectations of practice through competencies and how the competencies can be

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demonstrated. Each have 16 Elements of Competency, divided between multiple areas. Each Element contains IAs which "*serve as guides to the sorts of engineering work that are likely to demonstrate competence in the Element*" (EA 2017c). Stage 1 comprises 69 IAs and Stage 2 has 104. While the two frameworks differ in how the Elements of Competency are presented, the IAs are comparable in length, meaning and relation to the Elements. These provide the finest specificity and description, providing rich interpersonal skills comparison.

Each Standard's IAs are assessed to identify the required interpersonal skills. The decision regarding the described skill could be explicit, such as 'collaborate' or 'engage'. However, skills inferred to be inherent within achieving the specified IA are also considered. An example is balancing environmental, safety and human needs, which relates to understanding and assessing risks, concerns and wants of others. To avoid assuming values and viewpoints of others, engagement is required. We then compare IAs across the Standards to identify common skills, themes, gaps and differences. Appendix 1 provides a full list of the comparison, identified interpersonal areas and associated IAs.

Results

Overall, it is possible to see a number of areas where engineers are expected to develop interpersonal skills, capabilities and attributes. Stage 2 expanded upon interpersonal skills and behaviours included in Stage 1. Stage 1 presents the key foundations for engineering, but the increased number and specificity of Stage 2's IAs, extending the expectations of practitioners. The commercial environment and increased responsibilities of a practicing engineer were clear in Stage 2 when compared to the educational setting of Stage 1. An overview will be presented below, with full results available in Appendix 1.

Interpersonal skills are inherent or enmeshed in the Stage 2 IAs to a greater extent than Stage 1, with most discussion (57%) in the professional and personal attributes area. The organisation of Elements and IAs demonstrate the increasingly holistic nature of engineering practice, in comparison to the graduate engineer. While in Stage 1 "*indicators should not be interpreted as discrete sub-elements of competency mandated for individual audit…*[they] *must be tested in a holistic sense*" (EA 2017b), the separation of Elements and IAs divide technical knowledge and non-technical skills. Stage 2 presents the complex and interlinked skill set of a professional engineer, with interpersonal skills inherent across activities.

The areas of communication, building relationships and balancing needs in solutions in the engineering design process describe similar requirements, often expanding or using greater specificity. Communicating "*ideas to technical and non-technical stakeholders*" was emphasised in both Standards. However, Stage 2 emphasises this further, with communication explicitly or implicitly stated in at least 8 IAs across several Elements, but only two in Stage 1, mostly in one Element. Both Standards clearly articulate the activities involved in the engineering design process and management of projects. This demonstrates the importance of continual application and mastery of these skills in practice.

Analysis and Discussion

The interpersonal skill competency from Stage 1 to Stage 2 sees expansion and growth – of awareness, expertise and involvement with others. This is expected, as Stage 2 builds on the competencies of Stage 1. Stage 1 Standards present a technically knowledgeable graduate, open to learning. Stage 2 expands on this, presenting a capable communicator, creating value through considering and working with a vast range of stakeholders, confident in their knowledge and ability. The areas of communication, building relationships, balancing needs in solutions and activities in the engineering design process describe similar requirements, such as seen in Appendix 1. From this review, similar proportions of IAs in both Standards relate to interpersonal skills (37-38%). This highlights consistent importance of interpersonal skills between the two stages.

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In the expansion of requirements from graduate to practicing engineer, new dimensions of awareness and areas of knowledge are required, including commercial aspects of engineering such as finance, legislation and tenders, as well as managing others and representing the profession. The key differences between the two Standards and their Assessment reveal how interpersonal skills are enacted, and what they relate to within an engineer's role. Key differences between the Standards are explored below.

Assessment

While evaluation and assessment of the two Standards involves practicing engineers, the degree of involvement of the learner differs. Stage 2 is instigated by the learner, following a process of self-assessment, industry review, submission of an application with evidence, and an interview. This requires responses to the IAs and demonstration of "*acting independently at an acceptable standard without help or supervision in all Elements"* (EA 2021a). In contrast, demonstration of Stage 1 competencies is done by the education provider. While there are examples of engineering students responding to specific elements such as those in the professional and personal attributes, they are not required to submit statements of evidence or demonstration of competency. This creates a learning gap for engineers seeking Chartered status, to self-assess and make competency claims. It also raises the question of how much graduates are aware of their own levels of required competency, and if they understand the learning and expectations required of Stage 2. Discussion and monitoring of professional competencies should engage learners at all levels in their development.

Engagement

The importance and mastery of communicating to diverse stakeholders is seen in both Standards. In Stage 2, there is a consistent focus on communicating and engaging with stakeholders outside the engineering profession. This includes 'the community', 'users', 'clients', 'investors' and 'customer'. Engagement looks like "*dialogue...to reach an agreed understanding of technical issues*", "*negotiating equitable ways to share any costs and benefits between stakeholders and the community*", "*work*[ing]*…to develop solutions*" and seeking appropriate advice to inform decisions (EA 2012).

In contrast, Stage 1 describes less responsibility in engaging broadly with 'community', instead focusing on "r*ecognise[ing] the value of alternative and diverse viewpoints",* but limiting input to "*expert assistance and professional advice"*. While graduates should be able to express information, engage in discussions and present to technical and non-technical audiences, there does not appear to be a two-way discourse in how this discussion influences the work of an engineer, or outcomes (EA 2017b). Stage 2 more clearly articulates where engagement with others is expected, and whose perspectives should be considered. A direct and transparent mapping of communication from Stage 1 to 2 could create a framework for learners to reach mastery, similar to the Systems Engineering Competency Framework (International Council on Systems Engineering, 2018, pp. 45–52).

The ability to engage with others appears to be primarily developed in the workplace. While graduates should recognise the value of diverse viewpoints, they are not required to demonstrate efficacy in engaging with them. The way many degrees are structured, this opportunity for engagement with 'community', industry and other professions is limited (R. King, 2008). This is an area of development for graduates, and gap between Stage 1 and 2.

Communication embedded in all activities

In Stage 1, communication is often described a discreet skill, while in Stage 2 it is presented as a tool to demonstrate knowledge or achieve specific goals. Stage 1 describes it as a skill to be honed. It is mostly concerned with the ability to express information in verbal, written and non-verbal ways, and are not necessarily embedded or assumed within IAs in the two technical Elements. In contrast, Stage 2 emphasises the importance of communication to achieve outcomes, inherent within tasks. This is seen through drafting tender documents and contracts, project management and financial tracking records. This reveals the shift from separating skills in formal education to contextualised and holistic employment of skills in domains of engineering practice. Greater support at universities and in the workplace could aid engineers' understanding, development trajectory and interrelation of interpersonal skills.

Seeking Input

While the importance of engaging with others is stressed in Stage 2, the integration of other viewpoints appears less influential for practicing engineers than graduates. The emphasis in Stage 1 of "*engag*[ing] *with professionals from* [STEM] *and commerce to exchange ideas"* (adapted from 3.3 c), as well as "*appropriately challeng*[ing] *engineering practices from technical and non-technical viewpoints"* indicates valuing and seeking advice from these viewpoints (EA 2017b). This presents graduates as open to integrating others knowledge into their practice. Stage 2 reduces this to include '*discussion with others and, where appropriate, integrate their views to improve deliverables*' (EA 2012), suggesting that as engineers grow in confidence, knowledge and ability, they do not need to integrate others input to the same degree. Or perhaps, this integration is implied through relationships developed as a practicing engineer, emphasised in Stage 2 separately. The ability to assess one's knowledge of a situation, acknowledge limits, identify and seek those who hold greater expertise demonstrates a high level of self-awareness, humility and social engagement. This is an important skill to cultivate throughout a career, helping to remain open-minded to others and be a life-long learner (Krumei et al., 2020). This could be more explicitly acknowledged in Stage 2, which is not an end point in an engineer's learning journey.

Self-awareness

Stage 1 presents an awareness of interpersonal dynamics, but is not explicitly acted upon in Stage 2. Stage 1 highlights the ability to identify "*the structure, roles and capabilities of the engineering workforce*" (EA 2017b). This speaks to an awareness of dynamics within and outside the systems you operate in. Further, it highlights a self-awareness and understanding of engineers' roles within the community and trust placed in the profession. While this may be assumed to manifest in engagement with many diverse stakeholders as a professional engineer, mastery of this skill was not explicit in the Stage 2 Standard. This should be further highlighted, or addressed as to how to identify and navigate the dynamics in engineering work. In contrast, the accrediting body for the United Kingdom, and a signatory of the Washington Accord like EA highlights the need for self-awareness at Stage 1 and 2 equivalency, calling for awareness of '*…the needs and concerns of others, especially where related to diversity and equality'* (Engineering Council, 2020).

Feedback

Providing and responding to feedback is present throughout Stage 2, but not Stage 1. Stage 2 describes the need to seek and provide peer reviews and comments to make improvements to personal and others work, as well as "*diagnose performance deficiencies and negotiate appropriate remedial measures*" (EA 2012). Providing constructive and helpful feedback appears to be developed entirely in the workplace, with no provision of feedback in Stage 1, only seeking. Greater scaffolding of the ability to assess the intended audience to provide the most helpful feedback at the time is required. This also connects with the relationship building and emotional intelligence required to provide feedback in a tailored and appropriate way, particularly when managing others. Greater emphasis on learning how to provide and receive feedback from peers and those in differing hierarchical positions is a key skill that evidently needs to be addresses prior to graduation from an engineering qualification. Boud and Melloy (2013) present a model of sustainable feedback, where feedback is a process used by learners to facilitate their own learning, rather than a control mechanism. They present a number of curriculum features to emphasise this model of feedback, which could be implemented as a learning strategy.

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Recommendations

The gaps identified indicate significant learning is expected to occur within 3-5 years of full-time professional engineering work. In this time, graduate engineers are expected to develop and demonstrate highly effective engagement with a range of stakeholders, develop networks to seek information from, request and provide feedback. Suggestions are provided below to navigate the skill and structural gaps between EAs Stage 1 and 2 Competency Standards, and how might learners be better supported to bridge these gaps.

Recommendations for Australian workplaces:

- Embed self-assessments and benchmarking against the Stage 2 Competencies as part of annual reviews, or include EAs Industry Review. Other similar accreditation standards require Continuing Professional Development (CPD) planning and activities reporting, which could also be incorporated into annual reviews (Engineering Council, 2020; The Institution of Engineers Sri Lanka, 2021). This could be supported by a log book or portfolio, where learners document their experiences.
- Creating structural training opportunities for graduates to develop their skills. This may be training programs, targeted mentorship, or opportunities for feedback.

Recommendations for Australian engineering education providers:

- Involve students in understanding and articulating their demonstration of the Stage 1 Competencies. Further embed activities requiring students to reflect on their learning, to understand where they may require further development and how to assess their abilities. A log book or portfolio may assist in connecting study activities with skill development, such as those suggested by Kilgore et al. (2013) and Williams (2002).
- Emphasise the role of feedback in the curriculum, including training and development of providing useful feedback to others, advocated for by Nicol et al (2014) and demonstrated by O'Moore and Baldock (2007) and Boud and Molloy (2013).
- Further create opportunities for students to engage with 'the community,' cross-disciplinary learning and clients, such as through service-learning or interdisciplinary projects such as Duffy et al. (2008), Hirsch et al. (2001), Taajamaa et al. (2013).

Other ideas for Standards:

- Explicit articulation of the importance of interpersonal skills and emotional intelligence as a professional engineer, like the UK-SPEC (Engineering Council, 2020).
- Articulation of the importance of self-awareness, life-long learning and ability to influence within Standards.

Conclusion

Engineers are expected to be capable technologists, problem solvers, project managers, networkers, team members and experts. Fulfilling these roles requires high levels of collaboration and refined interpersonal skills. Comparing the expected growth of these skills through the EA Stage 1 and Stage 2 Competency Standards, engineers are expected to develop and apply their interpersonal skills between these two stages. Education providers, workplaces and EA can help engineers better bridge this expected development gap, creating engineers who are better supported to succeed and create more positive outcomes for those their work touches.

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Competencies that lead to high performance as a project engineer in a management consulting engineering company

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ABSTRACT

CONTEXT

Over the last century there has been increasing application of projects and project management techniques as foundations for business operations. In engineering industries, this has resulted in the emergence of project engineering as an area of specialisation, and there is a need to understand what this encompasses in the context of Western Australian engineering practices in the mining industry.

PURPOSE

This study aims to contribute to the body of research focusing on engineers and the mining industry. The main objective is to establish broad competencies required to achieve high performance as a project engineer. As a priority, it aims to improve overall understanding of the role of engineers, specifically project engineers, in project completion.

METHODOLOGY

A Critical Incident Technique (CIT) methodology was used for the interview and analysis. CIT is a cognitive task analysis (CTA) method described by Flanagan (1954) to diagnose key actions or requirements that make the difference between success and failure in the performance of a task in five key steps: objectives, plans and specifications, collecting the data, analysing the data, and interpreting and reporting.

OUTCOMES

The key competency areas discovered were 1: Expertise, 2: People management and interpersonal skills, 3: Actions and approach to work. The overall objectives of project engineers as described by the participants fell into either of two categories: to support the project manager, or to facilitate the delivery of a project on-budget, on-schedule and in accordance with the contract.

CONCLUSIONS

The project engineer is a hybrid of technical expert and project manager, where technical expertise is broad rather than specialised. The key discovery made in this work is that a high performing project engineer also cultivates an approach to work that is based around continuous learning. The engineer must extend their expertise beyond technical outputs and focus on project tasks and roles. This research has implications for engineering education relating to the need to develop alternative skillsets (for example, leadership, people management and linking interdisciplinary tasks) alongside traditional engineering competencies.

KEYWORDS

project engineer, critical incident technique, competencies

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Introduction

Projects and Industry

In the early 1990s the term ‘projectification’ was coined by researchers to describe the increasing trend of organisations executing their work in project-style solutions (Kujala, Artto, Aaltonen & Turkulainen, 2010). Kujala et. al. described this as ‘a trend towards servitised offerings and life-cycle solutions’ (2010). This project-oriented business model developed in part because of globalisation of economies and an increased trend towards outsourcing (Kujala et. al., 2010). For example, a mining organisation will generally outsource the design, procurement and construction of its processing plant to a contracting engineering consultant. The contractor may be responsible for the delivery of engineering, procurement and construction (EPC) services that constitute the project that they are contracted to complete (Walker, 2015). A management consulting engineering firm is one that specialises in providing engineering services to deliver these ‘projectified’ bodies of work.

The Western Australian Government reported $27.2 billion AU of major resource projects similar to this being under construction in the month of March 2020 (Williams, 2020). The mining and construction sectors produced $120.7 billion AU in Western Australia (WA) in the 2018-19 financial year, accounting for 42% of WA’s gross state product (GSP) (Williams, 2020). These figures reflect the size of the industries that rely heavily on organisations with project-based business models, and therefore rely on project engineers.

This research focuses on the role of project engineers in a management consulting engineering organisation (referred to henceforth as Company X) that delivers Engineering Procurement and Construction (EPC) and Engineering, Procurement and Construction Management (EPCM) services for minerals processing plants. The organisation exemplifies an approach to work encapsulation and execution in projects that is typical in WA’s engineering industries including minerals, infrastructure and oil and gas (Walker, 2015).

Project Engineers

The current understanding of project engineers in Australia is lacking because the role is relatively new to the industries (compared to the technical engineer or project manager) and differs sufficiently from other types of engineer that many pieces of existing research cannot be assumed to be accurate (Hodgson, Paton & Cicmil, 2011). This leaves room for valuable discoveries related to how project engineers operate and how developing certain skills or competencies (through engineering education or otherwise) can positively impact performances in this role. As a result of the positive link between high-performing project engineers and delivery of on-time, on-budget and in-scope projects (Miles, 2013), this potential for advancement can have significant impacts on an organisation’s capacity to execute projects successfully, particularly in the realm of engineering management consulting.

Over the last century there has been increasing application of projects and project management techniques as foundations for business operations (Hodgson et al., 2011). Across engineering industries, this has resulted in the emergence of project engineering as an area of specialisation, and there is a need to understand what this encompasses.

The image of a project engineer built by current literature is of an engineer with broad but shallow technical knowledge who bridges the gap between technical and project management specialisations. Miles (2013) described the project engineer as the person who ‘controls the critical links needed to create the project deliverables’. Tremblay, Wils & Proulx (2002) explain that a project engineer specialises by broadening their technical skills rather than focusing on a single sector.

The traditional engineering career pathway begins with a focus on technical engineering. As the engineer advances in their career, they are at some stage confronted with the choice:

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continue in their technical specialisation or diverge into a managerial role to become a project manager, taking on control, organisational and supervisory activities (Tremblay et. al., 2002, Hodgson et. al., 2011). The typical project engineer engages in both the technical and managerial sides of engineering from early in their career, yet does not fit neatly into either category.

Research Question and Contribution

The question guiding this research is:

> *"What knowledge, skills and behaviours lead to high performance in the role of 'Project Engineer' in an engineering management consultancy organisation?*

The research expands understanding of behaviours, skills and knowledge that are important to operating successfully as a project engineer. The organisation under examination is a mid-sized consultancy based in Perth, WA with branches across Australia and the globe.

Literature Review

Personal Skills and Competencies for Project Engineers

There is an abundance of research into the competencies, skills and aptitudes that contribute to success as an engineer, but there is also an abundance of terminology associated with the research area. This study does not prioritise between skills, knowledge, behaviours, competencies and other descriptors for actions and abilities that contribute to high performance. This is in order to minimise confusion between terms and represent the data more accurately according to the naturally emerging themes and trends. Male (2010) took a similar approach when investigating generic engineering competencies.

Analysis of the literature reveals some distinct approaches to types of competence or skills analysis in engineers. One approach relates to optimising the professionalism of engineers and does not focus on the disciplinary breakdown of skills. Engineers Australia (EA)'s engineering competencies are broken into three categories: knowledge and skill base, engineering application ability, and professional and personal attributes (EA, 2019). The distinction that EA has made through their use of phrases such as 'Application of…' and 'Professional use of…' describing their competencies is that a competency differs from a skill or knowledge area in its ability to be applied or executed in a practical setting.

Leadership qualities have also been a strong focus for competencies displayed by engineers (Farr, Walesh & Forsyth, 1997; Robledo, Peterson & Mumford, 2011). Farr's team found nine key leadership attributes for engineers as behaviours or skills to exhibit, such as being a good communicator or mastering change (1997). Robledo's team developed a different methodology, which identified the engineer's area of focus to be crucial (2011).

The range of methods and volume of valuable and relevant research that has been discussed here shows the potential for discovering insights into this area.

Success and High Performance

The objective of this study was to understand the role of project engineers and which factors of their performance contribute most extensively to successful project outcomes. What is the best way to quantify this success? There is a consensus in literature that individual career success leads to organisational success (Shockley, Ureksoy, Rodopman, Poteat & Dullaghan, 2015).

Objective methods that involve directly measurable criteria such as salary or number of promotions have been common (Heslin, 2005) and have been criticised in recent years as being insufficient to fully capture the success of individuals (Shockley et al., 2015).

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Alternative measures include the subjective methods, such as job satisfaction and perception of success (Shockley et. al., 2015). Tremblay et. al. (2002) suggest that engineers will tend to perceive high performance according to their own preferred career path. Either technical specialisation or managerial roles is seen as more successful depending on the individual's values.

For the project engineer, it may hold true that their perception of success is linked to their values. There are similarities in the need to balance technical knowledge and managerial capabilities as competing priorities (Hodgson et. al., 2011, Miles, 2013). Company X has a relatively flat hierarchical structure and has standardised bandings for pay, and so the perception of high performance by the participants will be the key measure.

This frame of reference can be established in interviews and analysis. Expertise and high performance can be identified by decision similarity in the group of participants (Kurvers, Herzog, Hertwig, Krause, Moussaid et. al., 2019). Kuvers et. al (2019) state that individuals within an organisation will be consistent with regards to how they perceive each other's expertise, yet this consistency is not necessarily reflective of actual performance. Findings can be calibrated in the interview process by first establishing key objectives of the project engineer role (establishing success through decision similarity), then ascertaining the impact that described competencies had on achieving those objectives (task effectiveness).

Methodology

Critical Incident Technique

A Critical Incident Technique (CIT) methodology informed data collection and analysis. CIT is a cognitive task analysis (CTA) method described by Flanagan (1954) to diagnose key actions or requirements that make the difference between success and failure in the performance of a task in five key steps: objectives, plans and specifications, collecting the data, analysing the data, and interpreting and reporting.

The CIT has been used in a diverse range of contexts and industries from organisational psychology to education and healthcare work (Viergever, 2019). The CIT elucidates key behaviours that people in a given profession should do or not do in order to have the best chance of achieving their goals (Viergever, 2019). Research conducted by O'Connor, O'Dea, Flin & Belton (2008) shows use of CIT to elucidate critical team skills for successful operations in a nuclear plant. This research draws significantly from the research by O'Connor and co-researchers as a good example of successful application of the CIT.

The principle of identifying specific examples that is used in the CIT aligns with the goal of identifying KPIs and objectives for the role of a project engineer. If the participant can first identify the objectives of a project engineer, supplementary questions in CIT style will provide data to conduct evidence-based performance assessment of the behaviours against these KPIs. Part of the CIT involves establishing categories for behaviours through analysing and processing of data to reveal the critical actions or skills. These categories reveal the various categories of competencies that lead to high performance.

Interviews

Participants were recruited from a list of project engineers compiled by the managing director of Company X, to ensure relevant expertise. All participants had extensive experience either at Company X or in the field of project engineering.

One-on-one interviews based on the CIT were conducted with 14 participants with significant experience in project engineering. Interviews were conducted in two steps. Step 1 was to clarify to the participants the general aims of the research. This is critical as it allows the participant to exercise their judgement to assess which incidents and examples are most

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relevant to the goals. Additionally, participants were asked 'What would you say is the main purpose of a project engineer at company X?' to establish a general aim.

In Step 2, the interviewer ensured scenarios described by the participant had sufficient detail and relevance to the general aim. This is the unique part of the critical incident technique. It involves the participant first identifying an incident and adding details such as extent of impact on the objective.

A semi-structured interview style was necessary to collect the data, as the project engineers overwhelmingly struggled to identify incidents that fit the categories requested in the questions. Participants tended to rely on generalisations of tasks in order to answer the questions, but were able to give detailed examples and dissections of these. Participants were generally able to strongly link incidents and competencies to the purpose of a project engineer as they described in the earlier questions. All interviews were recorded, transcribed and de-identified using Otter.ai, then stored securely on a server.

Analysis

First, transcripts were examined for leading questions and other indicators that data should be removed. Some leading questions were identified and removed in the transcription process. The data were then split into comments describing the role of the project engineer, and comments that described potential competencies. The data relating to competencies were then further divided into categories, resulting in the three key themes.

The findings were compared with the original objective to assess the validity of the themes and identify any divisions of opinion or competing aims, as required by the CIT method (Flanagan, 1954). Analysis of the results produced two groups of thought regarding the objective of a project engineer (described in the results below), with no outliers or other descriptors. The research includes contribution from 14 participants with significant experience in project engineering. Graduates and junior project engineers were excluded.

Adaptation of CIT

The CIT was an effective approach for investigating the role and competencies of project engineers in this case study, though there were several issues that meant traditional use of the CIT was not adhered to strictly. After conducting a few interviews and consistently struggling to get explicit examples following the script and prompts, the approach was changed marginally. Participants responded much more confidently when prompted to explain the role of a project engineer in more depth, and then asked the incident-focused question immediately based on a comment that had just been made. For example, a statement made about the role of a project engineer; *'…it's a key role supporting the project manager in specific areas'* leads easily into an incident when the participant was prompted to describe an example.

The identification of incidents was a good method for producing generalized examples, but participants tended to struggle with identifying 'critical' incidents. This made it difficult to establish a scale of importance for the various competencies.

Findings and Discussion

The goal of this research is not to establish the objectives of a project engineer, rather the competencies related to high performance. However, the objectives were defined in the interviews to assist with determining the relevance of a competency to high performance. Table 1 below summarises the objectives of a project engineer, described by participants.

Table 1 - The purpose of a project engineer

Objective	Description
To facilitate the delivery of a project on-budget, on-schedule in accordance with the contract.	Meeting budget, schedule and scope were the primary objectives, safety and quality were secondary but still important.
To support the project manager.	Act as support for the project manager in taking responsibility for managing and tracking packages of work as directed.

Table 2 presents three broad categories that describe the competencies required by project engineers.

Table 2 - Broad categories of competencies of high performing project engineers

Area of Competence	Description
Expertise	Broad expertise across technical disciplines focused on tasks, roles and technical output. Deep expertise in construction and site processes and issue identification.
People Management and Interpersonal Skills	Manage the flow of information and work between all groups. Interact effectively with others, building relationships and leveraging others' expertise.
Actions and Approach to Work	Have strong work ethic and continuous focus on project objectives. Place high value on continuous improvement.

Expertise

The 'expertise' competencies reflect the technical elements that project engineers at company X specialise in. Previously there has been lack of clarity in literature regarding what technical expertise a project engineer requires (Miles, 2013, Hodgson et. al., 2011). The findings are consistent with research on technical expertise needed by systems engineers: a broad but shallow understanding of all engineering areas. Our findings build on this premise, indicating more than simply technical knowledge and understanding. The idea of 'broad technical knowledge' is extended to include the need for understanding of the roles of all project stakeholders and also the ability to prioritise and problem-solve within their expertise. This keeps the role of project engineer firmly in the seat of 'engineer' rather than solely 'manager'.

Thirteen of the fourteen participants emphasised the need for expertise in constructability and site operations. Most (eight of 14 participants) explicitly mentioned the importance of experience on site as a field engineer, generally relating it to being critical for early career project engineers. This was explained typically as an experience needed to learn important lessons about the impact of workflow from early in the project on final project delivery and construction. It may also be seen as a critical opportunity to practice and learn the necessity of many of the competencies from category three: *actions and approach to work*.

The area of expertise that was most divisive was the importance of interpreting and understanding contracts and scopes of work. Every participant mentioned either 'scope' or 'contract', but the participant who would be considered as the most expert of the group said the words 'scope' or contract' a total of 73 times in a one-hour interview. Going by number of mentions, the next four candidates, all considered to be top project engineers, mentioned scope or contract an average of 19 times, while the average of the remainder was six

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mentions. This implies that expert understanding and management of scope of works and contracts is a skill desirable and important for high-performing project engineers, but is either difficult to grasp or not needed at more junior positions in the organisation.

People Management and Interpersonal Skills

The second category of competencies emphasises the role of project engineer as a people-focused position. These competencies, compared to those from category 1, had equally strong links to the role objectives as described in Table 1. Many of the competencies from this group including relationship building, leadership, interpersonal skills and communication, were mentioned as critical competencies that all acted as tools to effectively manage workflow between stakeholders. The idea of understanding human nature was mentioned mostly by participants at the intermediate level, perhaps reflecting an initial foray into leadership skills, by paying more attention to the team and how to get the best out of their peers rather than performance of basic tasks.

Actions and Approach to Work

One engineer said:

> *‘There are certain people more suited to the job. I don't think it's something that just anyone can do. I think I've seen that with some of the PEs [project engineers] that have come through, you can identify people and see, he's got the temperament. He's got the hard work, and he's got the ethic. And he's got the practicalness to be successful as PE.’*

This quote reflects the actions and approach to work category, which combined data relating to individual abilities, actions and approaches, and key work tasks. Behaviours and approaches as competencies appear extremely important to the role of project engineer. Notice that this participant does not comment on personality, background or experience, but focuses on the way the hypothetical individual engages with the work and the learning. This is consistent with the way most participants spoke about their role. A project engineer will lean on the experiences of others until they have enough experience themselves, learn continuously, work hard, ask questions and focus on the outcome. These competencies were important at every level of engineering. This brings into question the role that identity, values and self-perception play in the high performance of project engineers.

In terms of work tasks, issue identification was perceived as more important than generating solutions. This may be because the project engineers all saw identifying issues as critical to their role, whereas middle-tier engineers perceive the generation of solutions to be more critical to the project manager. This contrasts with the view that problem solving “is the core of engineering practice” (Passow & Passow, 2017, p.475).

Conclusions

The project engineer is a hybrid of technical expert and project manager, where their technical expertise is broad rather than specialised. For those in mining at company X, expertise includes scope of works, contracts, and construction. People management is equally critical to successful outcomes as technical expertise. The high performing project engineer also cultivates an approach to work that is based around continuous learning.

The findings provide a more nuanced understanding of the role of project engineers and reveal key competencies displayed by high performing project engineers, extending work by Hodgson et al. (2010). This has implications for engineering education and practice. The need for development of professional skills in engineering students is indicated, supporting previous research (Male, 2010; Passow & Passow, 2017). This includes the teaching of approaches

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and attitudes to work. In the context of increased ‘projectification’ of engineering work, understanding of engineering contracts and project scopes is vital. The need for knowledge of engineering construction is highlighted, supporting the call to extend representation of engineering practice in engineering curricula beyond design (Satnani, Marinelli, Male, & Hassan, 2020). These elements of engineering practice should be embedded in engineering curricula.

The research revealed insights into the objective of a project engineer, being to facilitate project delivery either by managing budget, schedule and scope or by supporting the project manager. This emphasises the need for strong project management skills in the engineering education curriculum, and also raises questions about how engineers are taught to use their technical expertise in a project delivery scenario.

For individual engineers, development of the identified competencies may aid in career development and progression in project engineering. For organisations that employ engineers, understanding of competencies can inform and optimise career management policies and processes.

Further Work

There are many opportunities for further research.

Expand the Search: Using this research as a foundation, expanding the scope of the investigation to include project engineers from other industries or other organisations would be valuable. Further research will make clear which competencies are unique to company X resulting from their culture, industry and style of work, and which are generic competencies.

Establish a scale for measuring impact: Design research that will allow a scale of importance and impact to be established for each competency. This can be done with the participants from this study or with an expanded group. Information on the relative value of the various skills will provide insight into the nuances of project engineering in different applications.

Early vs Late Career Competencies: Research into how project engineers value or struggle with various competencies at different stages of their career may be invaluable to the mining industry. It could enhance learning and development strategies, clarify training requirements and improve the profession overall.

Education: Further to an investigation of early versus late career competencies, research can be extended to the development of these capabilities in tertiary education or post-graduate programs. Findings from this type of research can benefit engineers from other disciplines, who would broaden their skillset and have a more rounded education if taught project engineering competencies alongside traditional engineering competencies.

Qualities and Values: As mentioned when discussing action and approach to work group of competencies, there could be value in investigating the role that identity, values and self-perception play in the high performance of project engineers.

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Insights to research and practice from developing and deploying an early career engineers' trajectory survey

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ABSTRACT

CONTEXT

Online surveying is a commonly used research method to explore and validate theoretical constructs. The ease with which online questionnaires can be developed and deployed has led to their adoption by many academics. This survey method has many positive effects and negative effects that must be considered by the researcher before and during deployment.

PURPOSE

We created the Career Trajectory Survey (the Survey) to facilitate a better understanding of the career trajectory of early career civil engineers. This paper draws upon our experiences, intending to serve as both a theoretical and practical resource for other researchers planning to conduct an online survey. In particular, we assess the considerations about deploying online questionnaires to individuals outside the academic context.

METHOD

The Survey questionnaire was deployed to persons with an Engineering Bachelors degree who were located within Australia over an eight week period from May to July 2021. This deployment was undertaken after questionnaire validity checks were performed during a pilot survey. The 10-15 minute online questionnaire utilised the Qualtrics platform, with over 340 valid responses received. Invitations to participate were sent to engineering associations, engineering organisations and individuals through a social media campaign. Valid respondents were offered the opportunity to enter a major prize draw.

OBJECTIVES

This paper presents the Survey deployment plan, its ongoing amendments and insights gained. The basis for deploying a questionnaire to individuals working in industry differs significantly from deployment inside of the academic setting. The issues of participant recruitment, incentives, contacting industry organisations and engineering associations, and the possible pitfalls of a social media campaign are presented. This paper intends to serve as a practical resource for other researchers, particularly those working individually or in small groups, without official sponsorship.

RECOMMENDATIONS

We recommend that the deployment plan of any online questionnaire remains flexible. During this phase the data should be regularly interrogated, allowing for potential deployment changes as required. We advocate for the implementation of strong survey security protocols. Moreover, we advise of the typical low response rates of online surveys, the need for adaptability and the benefits of an advocate.

KEYWORDS Australia, Civil Engineer Career Trajectory, Survey Deployment, Response rate, Insights

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Introduction

This paper presents both academic survey development literature and practical recommendations to researchers regarding the deployment of an online questionnaire, particularly targeting respondents working in industry outside of the academic setting. Accurate data collection is an important phase of the research process, highlighting the importance of designing a survey deployment campaign.

We first introduce the Early Career Civil Engineers Career Trajectory study (the Study), research context and a summary of the work completed to date. We then discuss the development and deployment of the Career Trajectory Survey (the Survey) as well as the deployment campaign and anticipated response rates. Finally, we provide insights gained and practical strategies for survey development and questionnaire deployment. While many existing publications provide information regarding the design of a concise questionnaire (Boateng, Neilands, Frongillo, Melgar-Quiñonez, & Young, 2018; Creswell, 2014; Neuman, 2014), not many provide support regarding an effective deployment campaign to achieve high target group response rates.

Context

Internationally, there is a complex and not fully understood disconnect between one's obtaining an engineering qualification and working as an engineer. Consider Australia in 2018, with fewer than 35% of 25-29 year-old qualified Australian engineers working as a professional engineer (Palmer & Campbell, 2018). While a record number of engineers are graduating from Australian universities, the number of domestic undergraduate enrolments has been decreasing since 2015, leaving Australia highly reliant upon migrant engineers (Department of Education and Training, 2020; Engineers Australia, 2019). This necessitates the need to understand early career engineers' trajectories. Our Study uses a social constructivist worldview to undertake an exploratory sequential mixed methods study of early career civil engineers (our subject cohort). The Survey has included the deployment of an online questionnaire of individuals who have earned an engineering Bachelors degree and are currently residing in Australia, including those who work outside of the engineering field. Although our research particularly intends to investigate our subject cohort, the participation of individuals from a wider sample group, including those with other qualifications and experience levels will add to the research veracity. We identify our subject cohort as having graduated from a Civil Engineering Bachelors approximately five years previously.

Our Concept Model

The Early Career Civil Engineer's Trajectory Concept Model (the Model) theoretical underpinnings are observed through the Person-Environ fit theoretical lens of the Theory of Work Adjustment (TWA) (Dawis, 2004). Our Concept Model proposes that critical influential factors impacting the trajectory of an early career civil engineer are constructed upon the *Person*, their *Adjustment* and the *Environment* (Reis, Bunker, & Dawes, 2020). More detail is provided in our upcoming journal paper. Our Survey will support the validation of the Model.

Survey Development

Development of the Survey has been guided by the relevant literature on engineering practice and persistence (Palmer & Campbell, 2018; Sheppard, Antonio, Brunhaver, & Gilmartin, 2015), our concept model (Reis et al., 2020), survey theory (Neuman, 2014) and scale development and validation theories (Boateng et al., 2018). Construct and content validity have been checked through recognised methods including various levels of peer, expert and practising engineers' reviews for language, clarity and appropriateness (Creswell, 2014; Neuman, 2014). To further test and validate the Survey questionnaire a pilot of 26 Higher Degree Research (HDR) students was undertaken. The participants had a median of 7 years of experience after

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Bachelors completion, identifying the applicability of this sub-cohort to our larger study. The results of this pilot survey are discussed in our upcoming journal manuscript.

Benefits and Limitations of Surveys

Utilising surveys for research has grown in popularity. With the increasing application of online survey methods, the tools used to create questionnaires have become increasingly available to novice users. However, with society's increasing survey fatigue, researchers must be increasingly aware of the challenges of designing a concise and effective questionnaire. Surveys are created for many and varied reasons; thus, the developer must be clear about one's purpose and outcomes. A survey provides a sample, rather than a census, of the target population. If developed and undertaken correctly, a survey can correlate and generalise information, resulting in efficient learning about that population (Dillman, Smyth, & Christian, 2014). With those benefits in mind, the developer must also be aware of the potential difficulties with surveys and especially with the deployment of questionnaires.

Online questionnaires can reduce data entry errors, allow larger sample collection and allow backups for increased data security. This wider reach can be achieved with minimal costs, leading to increased response rates and the ability to collect confidential data (Boateng et al., 2018). However, potential survey errors must also be understood. These include coverage error (when the sample does not represent the population), sampling error (difference between a sample and general population), nonresponse error (difference between those that complete the survey and those that do not), and measurement error (respondents may be unwilling or unable to provide accurate answers) (Dillman et al., 2014). Before the deployment of a survey questionnaire, the developers must have a range of planned analysis methods. The implementation of these options may change dependent upon the number, demographics and quality of responses. Many well resourced online surveys have low response rates (de Leeuw, 2008), and research plans must adapt and adjust as the research progresses (Creswell, 2014).

Survey Deployment Strategy

Incentives

For some individuals, responding to another's request upon their time is an altruistic consideration. This often occurs in situations where the topic is of personal interest, or as a personal favour to the individual making the request. For others, it is a reciprocation to the offer of a token benefit (Dillman et al., 2014). People are more likely to respond to any request if there is potential for them to receive something in return. Many studies of engineering students and practising engineers, particularly those based in the United States (US), offer financial compensation to respondents. Small rewards are shown to be effective for increasing responses in some groups, including students (Conn, Mo, & Sellers, 2019). Between 2003-2007, the *Academic Pathways Study* paid each participant US$175 to complete the Persistence in Engineering Survey, and US$4 each to complete the *Academic Pathways of People Learning Engineering Survey* (Chen, Donaldson, & Toye, 2008). Other studies, including the *Situational Judgement Test* and the *Global Engineering Competency Scale* both utilised Qualtrics to identify respondents and pay them 'appropriately' (Jesiek, Woo, Parrigon, & Porter, 2020) (Mazzurco, Jesiek, & Godwin, 2020). In 2015, a study regarding job turnover intentions reported utilising an online recruitment website to recruit and pay each respondent US$0.75 (Dahling & Librizzi, 2015).

Quality signalling may be enhanced by offering a charity donation for each response received. For *pro-social* individuals, this may be as effective as offering a monetary incentive (Conn et al., 2019). For example, *Mental Health in Construction Research* (Nwaogu, Chan, Hon, & Darko, 2020) offers to donate $1 for each completed questionnaire response to a nominated charity, with a donation of up to $500 per charity. Although the incentives offered by these

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previous surveys correspond with the research into boosting survey response rates (Conn et al., 2019), we cannot determine their effectiveness, not many surveys report response rates.

Conn's study of Survey Response Rates concluded that a small number of large prizes is the most cost effective lottery structure (2019). In a survey, it is vital that to achieve the validity of responses, the developers must aim for a non-biased deployment campaign. Due to the wide demographic of our target groups, we decided to create a random prize draw of two $250 e-gift cards for respondents to the Survey. This value was deemed to be in line with current prize draws across our institution. Additionally, the values were chosen to be high enough to encourage the target groups to participate but low enough to discourage invalid participants from responding.

Data collection strategy

The Survey questionnaire was deployed for eight weeks from May to July 2021 (after receipt of ethics approval number 2000000256) from our Institution. The target population for the sampling in this study were individuals having completed an Engineering Bachelors and being present in Australia. Although our study investigates the occupational outcomes of early career civil engineers, the responses from participants from differing fields and experience levels will build upon the research validity. Both qualitative and quantitative data were collected using an online questionnaire hosted by Qualtrics (Qualtrics, 2021) via a secured cloud server. The Survey questionnaire design was optimised for mobile devices, aiming to increase completion rates. Additionally, the platform allowed users to return to the questionnaire for up to seven days, allowing time-poor respondents the opportunity to complete the questionnaire over a longer period.

To ensure this research contributes to a national perspective, nationwide organisations and associations were contacted and asked to distribute the invitation to participate in the survey to their engineering personnel or members respectively. Participants were recruited through adaptive sampling techniques, including both convenience and snowball sampling (Neuman, 2014). The Survey questionnaire was deployed to colleagues, contacts, peers, previous classmates, engineering organisations, engineering associations, *LinkedIn*, *Facebook*, and an Australian state department of transport. This strategy was similar to that undertaken by the ASCE Young Professionals Committee's Survey of Structural Engineering Professionals (Leong et al., 2013). To maximise participant engagement with the Survey, we utilised several methods of contacting target groups. This included telephone, email and social media campaigns, and attending engineering seminars. The time consumed by the research team to locate and contact potential respondents during this deployment provided strong insight into this form of commitment.

In deploying the Survey questionnaire, we contacted 40 engineering and construction firms, 23 engineering associations and posted it to two social networking sites. Although no private firms accepted our invitation to share the Survey questionnaire with their staff, the Queensland Department of Transport and Main Roads (QTMR) did. The invitation and flyer were shared in their daily e-news for a week and added to their *Yammer* site. Additionally, our Institution's School of Civil and Environmental Engineering permitted all Higher Degree Research Students to be contacted. Many of our research students attained industry experience before entering a research program, as identified by our pilot study.

Following receipt of our email, several engineering associations incorporated the Survey link in their periodic e-newsletters, which was similar to methods utilised by other researchers (Bairaktarova & Pilotte, 2020; Buse, 2011). Organisations that accepted our invitation to share with their members included: Engineers Australia (QLD), Professionals Australia (PA), the Australian Institute of Transport Planning and Management (AITPM), the Queensland Major Contractors Association (QMCA), and several chapters of the Institute of Public Works Engineering Australasia (IPWEA). Of the invitations issued, this resulted in response rates of 5% for organisations and 35% for engineering associations. The social media site *LinkedIn*

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was used heavily for the deployment of the Survey questionnaire, through several open posts and over 80 individual personalised messages. Additionally, we sent over 85 personalised emails to previous colleagues and classmates as well as current contacts and peers. Our institution's alumni Facebook site was used to contact Alumni from our institution; however, the single permitted post did not elicit any 'likes'.

In a confidential survey deployed through convenience sampling, the exact response rate cannot be calculated, as it is not possible to know how many people were invited or further shared the invite with colleagues (Chance, Lawlor, Direito, & Mitchell, 2021).

Emails to individuals were issued with a header of *"Would you like to win a gift card in the XXX Engineering Career Trajectory Study?".* Emails to organisations had a different header, "*XXX Engineering Career Trajectory Study – Invitation to participate".* The subject line of an email message is important to motivate the receiver to open it. The sender must also increase and emphasise the benefits of taking part, and enhance the research legitimacy (de Leeuw, 2008). The researcher needs to show potential respondents that their involvement serves a purpose. Moreover, a personalised message, showing the receiver or potential respondent the applicability of the research to their context can increase response rates (Chen et al., 2012). Throughout these amendments to the deployment strategy, the research team must display a consistent research intent, ensuring potential respondents understand the research purpose. To assist other researchers with the creation and deployment of questionnaires we have included the Survey flyer in Figure 1. To increase the trustworthiness of the flyer, we included our institution's logo as well as details of our ethics approval and contact details.

Figure 1 The Survey Flyer

Anticipated Response rates

Nonresponse is a potential issue for any survey, and it is anticipated that a large survey has a low response rate. "Even the most well resourced surveys carried out by experienced survey organizations suffer from nonresponse" (de Leeuw, 2008). Many surveys do not report response rates. Although there are no guidelines for anticipated response rates, an email based survey has a maximum anticipated response rate of 25% (Vanette & Krosnick, 2018). This value is confirmed by the response rate from a US Institution's graduate leadership survey, in which only 23% of professionals at their recruitment day completed their questionnaire (Hartmann, Stephens, & Jahren, 2017). Our Survey is comparable in scale to the Australian Competencies of Engineering Graduates study. This questionnaire was deployed through the University of Western Australia Alumni and engineering associations, receiving 300 responses with approximately a 12% Alumni response rate (Male, Bush, & Chapman, 2010). This correlates with the 12% Alumni response rate of the Graduate

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Pathways Survey (Coates & Edwards, 2011). The modest response rates reported by these Alumni surveys of Australian engineers guided us to anticipate modest response rates.

Research studies that deploy a questionnaire to an exact number of respondents are more likely than others to report response rates. Examples of response rates include those of employees (41%) (Harden, Boakye, & Ryan, 2018), alumni (52%) (Hotle & Katz, 2018), and association members (42%) (Reese, 2003). Due to the convenience and snowball sampling method of our Survey, an overall response rate cannot be determined, this conforms with other research (Morello, Issa, & Franz, 2018).

Survey Responses

We received over 340 valid responses to the Survey. By examining the deployment response graph, presented in Figure 2, for two days after each distribution method, we gained feedback on the relative effectiveness of each. Typically, individuals decide to respond to online self-administered questionnaires within the first two days of invitation (Dillman et al., 2014). Our response rates are higher from invitations sent to alumni or contacts than from other engineers identified through social media. The significant response rate from the QMCA could be due to the accompanying message from their CEO. His email advised members of the industry's incoming workload and the importance of retaining engineers in their industry, encouraging members to participate.

Much of the original deployment plan relied upon the agreed involvement of Engineers Australia, ultimately the survey link was shared by EA Queensland (EA Qld). The planned response from the 21,000 EA Qld members who we targeted is believed to be small, as shown in Figure 2. The responses received in the 48 hours following this e-newsletter were mainly from civil engineers, with an industry and position title matching those from the QTMR deployment on the same day. If the takeup had been from the wider EA Qld demographic we would have received responses from engineers from wider disciplines, industries, and position titles. This low response has been attributed to the survey link being placed at the end of a long e-newsletter, with no mention of the prize draw, under a heading of 'call for comment'. Through the deployment phase we attended three EA Qld events, many attendees at these sessions were interested in the research and retrieved a flyer. However, in the subsequent 48 hours, only one response was received utilising the QR code issued at all three events. We cannot prove why this was so; perhaps people only took the flyer to be agreeable in the social situation, or used the reminder to access the survey through our other access means.

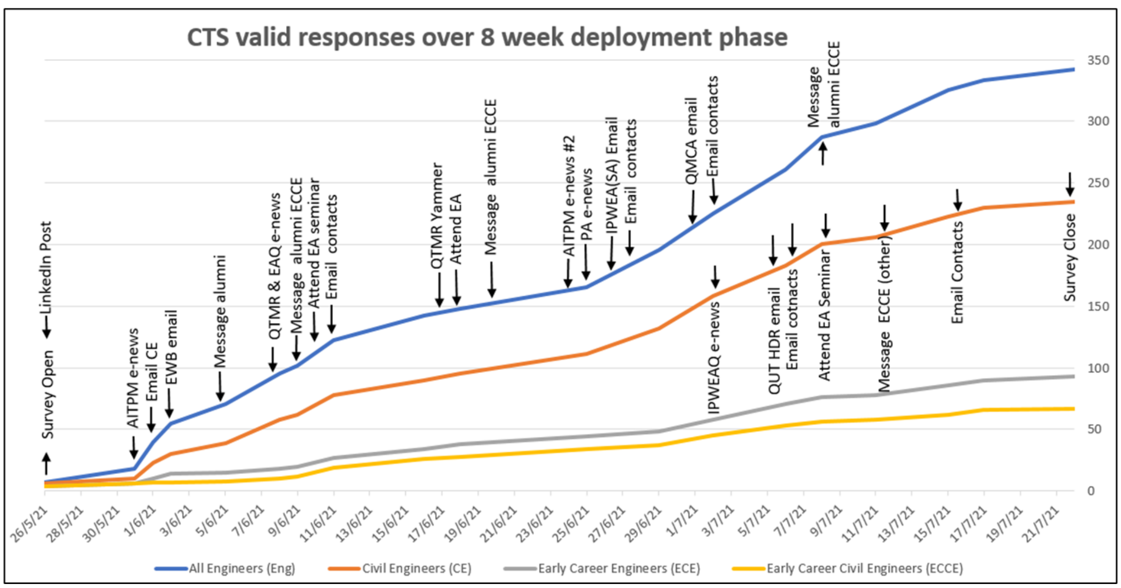

Figure 2 Cumulative Valid Responses

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We found *LinkedIn Premium* to be the distribution method with the highest response rate. We contacted alumni from our institution and asked them to share with colleagues and contacts. Whether or not these individuals personally completed the survey cannot be identified due to the confidential nature of the data collection. However, the graph shows that within 24 hours of bulk emails to alumni there was an increase in responses. This may also be due to the intended snowballing effect. Two individuals, including one not known to the research team, personally contacted us to voice their opinion about the importance of this research to the wider industry, highlighting many of the issues they view as important within the wider engineering industry. This emphasises the importance of incorporating short answer responses in any online questionnaire, as we have, allowing participants to provide information and context to their closed question responses. In future, we may incorporate a different link for each method of distribution, including organisations, associations, individuals, and social media platforms. This would permit the identification of the deployment methods gaining the most responses, either valid or invalid, allowing us to identify successful deployment methods. Additionally, it would allow responses obtained from the source of the highest percentage of invalid responses to be more tightly scrutinised.

The need for sponsorship

Research in engineering professional studies are typically conducted through well resourced Alumni offices or across large numbers of institutions. Several US studies utilised the resources of up to 30 (Sheppard et al., 2015) (Singh, Zhang, Wan, & Fouad, 2018) and 51 institutions (Okahana, 2019). These large US based surveys have received up to 7000 responses, the scale of which is significantly different from our research study. Several research studies have used firms that recruit through their institution (Morello et al., 2018) (Hartmann et al., 2017) or include additional questions in the university wide graduate survey (Naukkarinen & Bairoh, 2021). (Dillman et al., 2014) reported that deployment will receive higher response rates if there is a sponsorship provided by a senior member of a legitimate organisation. We achieved low response rates from the questionnaires deployed to individuals arbitrarily, as shown in Figure 2. However, requests made to individuals with a prior working relationship with the research team or the university were more likely to be received favourably. This included our contacts with the AITPM and EA Qld (both sponsored by a present or past board or committee member) and QTMR (sponsored by the QTMR Chair at our institution). Coincidentally, senior members of IPWEAQ and QMCA were alumni of our institution, increasing their engagement with our research. This highlights the need for a small research team to obtain advocacy or sponsorship from an individual who can provide strategic or influential direction.

Coverage and Sampling Checks

Halfway through the eight week deployment period, we reviewed our data for coverage and sampling errors. Reviews of the incoming data impacted the deployment strategy, allowing us to target demographics that had responded at rates lower than anticipated. We compared responses with previous analyses of the 2016 Australian census (Crosthwaite, 2019; Palmer & Campbell, 2018). This data was used to determine an applicable range of response percentages from each response group, including gender, experience, and industry sector of respondents. From this review, we identified the low number of responses from those working in the construction industry and contacted the QMCA. Additionally, we identified the low number of responses from females in the tertiary sector and contacted our HDR students. After the questionnaire close, a preliminary cross-tabulation analysis comparing industry and experience level against gender confirmed our ability to engage with a wide demographic. Respondents that identify as female or nonbinary are represented in all but one of these cross-tabulations. Moreover, the number of respondents per industry category are comparable with anticipated percentages (Crosthwaite, 2019). Approximate participation percentages include Construction and Operations (19%); Professional, Technical and Management Consulting (46%); and Education, Training and Research (14%). The high participation rate of 19% for

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those working in the Government and Public Sector is likely due to the systematic distribution by the QTMR and IPWEA.

Response Validity Checks

During deployment, we continuously reviewed the incoming responses to check validity. We needed to ensure that the security protocols of the survey platform were correctly initialised and functioning. Qualtrics security protocols warn of potential duplicate responses through fraud detection, including duplicate IP addresses. However, those responses identified as potential duplicates should be probed before deletion. An organisation's external IP address may not show an individual computer's internal network address (WhatIsMyIP.com, 2021). By example, many potential duplicates were received on the day of distribution through QTMR. A review of these potential duplicate responses included a comparison of the participant's role description, position title, and potential non-response of closed questions. Interrogation of short-answer questions is another method of identifying potential invalid responses. After review, many of these potential duplicates were considered to be valid. Thus, removal of potential duplicates should be undertaken with care, utilising more than one method of identifying invalidity. For example, responses including position titles of 'the engineer' and 'I'm an employee' were then investigated for validity and removed.

In the first week, the LinkedIn post that launched the Survey received over 1000 views and 20 shares; however, this did not lead to a large number of responses. During the first 36 hours after the LinkedIn launch, there were 60 invalid responses and only 25 valid responses. The security settings, including geolocation, bot detection and duplicate IP addresses, identified potential invalid responses but did not remove them from the survey flow. After enhancement, the security protocols were relatively effective throughout the deployment. Approximately 34% of responses were deemed invalid or incomplete, with 63% of these identified as being outside Australia's geolocation and an additional 24% with a response time of fewer than two minutes. In future, we will ensure that two levels of expert review of security protocols are undertaken before deployment. We recommend that other researchers be mindful of the global nature of social media, particularly with respect to uncontrolled sharing of access to a prize draw. The analysis protocol to identify valid responses is presented in Table 1.

Table 1 Analysis protocol to identify valid or incomplete responses

Step	Protocol	Notes
1	Note number of responses received	This will identify percentage invalid or incomplete
2	Identify geolocation outside Australia	This Qualtrics security protocol was not fully enabled for the first 36 hours
3a	Identify responses of 0 seconds or those identified by Qualtrics as Bots	Properly activated Qualtrics security protocols do not allow invalid respondents to enter
3b	Identify responses of less than 2 minutes	These are mainly straight-lined responses or bots
4	Identify: *Qualtrics Relevant ID Fraud Score* >30 *Qualtrics ReCaptcha Score* <0.5 *Qualtrics Relevant ID Duplicate* - True	Refer Note 1
5	Identify the required percentage complete of each response. This cutoff value may differ for each analysis method.	Responses over 75% complete had finished the Likert questions required for the Factor Analysis.
6	Identify responses with significant numbers of missing answers to closed questions.	Respondents are not forced to answer questions, thus requiring review of closed answer questions.
7	Review remaining responses for the authenticity of short answer responses and position title.	Several invalid responses have nonsensical text, refer discussion.
Note 1: Review these responses for validity before removal, large organisations often utilise one external IP address, individual internal network users are not identified by Qualtrics. Refer discussion.		

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The potential for survey fatigue was reviewed during the deployment phase. The average completion time was 13 minutes (removing extreme outliers), this is considered acceptable compared to the 10-15 minutes advertised. To reduce respondent fatigue and drop out an internet survey should be limited to 10-15 minutes (de Leeuw, 2008). Of the respondents who commenced but did not complete the Survey online questionnaire, the average time commitment was 6 minutes (after removing outliers), thus we considered that survey fatigue was not an issue. To examine the national reach of this research survey, the geolocation of a respondents IP address was recorded by Qualtrics. However, we consider that many large organisations communicate an IP address geolocation that identifies the organisation's head office rather than satellite offices. A small number of responses show regional geolocations. This contrasts with the advice provided by many of our regional contacts upon completion.

Positive Aspects of our Deployment Campaign

From the first author's perspective, there have been many positive aspects of deploying the questionnaire ourselves, rather than engaging (paying) a third party to collect data. The knowledge of the database gained during this period has directed the flow of the deployment. Moreover, contacting previous colleagues, as well as rekindling and making new industry contacts has provided both personal and professional growth.

Practical Advice for Researchers

This paper intends to provide practical advice to researchers intending to deploy outside the tertiary context. In this vein, we present some of our insights gained from this survey:

1. Display a consistent research intent.
2. Plan your questionnaire deployment schedule. Be aware of the significant time taken to contact large numbers of individuals, associations and organisations.
3. Be wary of the global and uncontrolled nature of social media. Be careful if offering a prize draw on an open-access social media platform.
4. Note the perils of only one distribution method. Stay flexible in your deployment methods, but ensure any changes remain in line with your ethics approvals.
5. Don't expect too much from contacts and colleagues. The survey may not be as important to your contacts as it is to you.
6. Anticipate a low response rate, and plan distribution and analysis options to manage accordingly.
7. Ensure that layers of expert review are provided for the security protocols.
8. Provide separate URL links to enter the online questionnaire for each distribution method.
9. Review your incoming data regularly for consistency, demographics and validity. Multiple responses received through one large organisation may be communicated from a common IP address.
10. Obtain an advocate or sponsor, either corporate, alumni, or university based.

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Conclusions

This paper is part of the larger Early Career Civil Engineers Career Trajectory Study, which uses a social constructivist worldview to implement an exploratory sequential, mixed methods research approach. Our Study intends to provide a better understanding of the career trajectories of early career civil engineers.

The recommendations in this paper are intended to serve as a practical resource for other researchers, particularly those working individually or in small groups, without official sponsorship. We recommend that the deployment plan remain flexible and that during this phase the data be regularly interrogated, allowing for potential distribution changes. We advocate for researchers to implement strong security protocols for online questionnaires, particularly those deployed through social media. Most importantly, we remind researchers that many surveys receive low response rates and that the distribution and analysis protocols should be prepared for these potential outcomes.

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Student Learning Outcomes from Work placement: A Systematic Literature Review

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CONTEXT

Under Engineers Australia (EA) accreditation requirements for engineering education programs, graduate engineers must develop competencies within their chosen discipline at the point of entry to practice. Universities across Australia implement Work Integrated Learning (WIL) as a method to prepare students for the world of work and to give students the chance to develop the elements of competencies required by EA. For this project, we are particularly interested in work placements or vacation employment during undergraduate degrees.

Many universities across Australia have consistently reported the “positive benefits” of work placements. Some benefits included increase in employability, job readiness, and professional identity, and to make the transition from university to work more effective. Despite the growing number of publications that highlight the benefits of work placements in improving competencies that are transferable, employers have consistently suggested that engineering graduates have skill deficits in communication, leadership, and social skills. These are some of the same skills outlined by EA.

PURPOSE OR GOAL

The main question arises as to what competencies engineering students are developing during their work placements. This Systematic Literature Review identifies existing research on generic engineering competencies to determine which one’s undergraduate engineering students develop during their work placements. This review is the first phase of a larger research project focussed on virtual work integrated learning.

APPROACH OR METHODOLOGY/METHODS

The literature search identified the intersection of three concepts (engineering students, work integrated learning, and competency) in selected databases. Databases included A+ Education via Informit, Educational Research Abstracts, Web of Science, Sage Journals and Proquest. Records of 1493 publications, between 2000 and 2020, were found. 35 journal articles meeting the inclusion criteria were included in this review.

ACTUAL OR ANTICIPATED OUTCOMES

This review synthesises the quantitative results and qualitative data to establish a list of generic engineering competencies, refining their definitions and descriptions, and highlighting interrelationships between competencies.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The results of this work will be of interest to researchers in engineering education, university work integrated learning facilitators, curriculum designers in engineering, and those who supervise undergraduate students in their workplace.

KEYWORDS

Generic engineering skills, students learning outcomes, work integrated learning.

Introduction

Work Integrated Learning (WIL) aims to train and prepare students for the world of work. It is *''an umbrella term for a range of approaches and strategies that integrate theory with the practice of work within a purposefully designed curriculum''* (Patrick et al., 2009). WIL is embedded in most engineering programs across Australia, New Zealand, Europe and the United States. The focus of this research will be on physical work placements.

WIL has been shown to provide students with benefits to increase employability, job readiness and professional identity to make the transition from university to work more effective (Ferns et al., 2014; Jackson, 2015). There is a large number of studies focusing on the significance and benefits of WIL experience for the advancement of graduate employability capabilities and skills (Crebert et al., 2004; Peach et al., 2014; Trede, 2012; Jackson, 2015; Reynolds et al. 2016).Despite the growing literatures that highlight the benefits of WIL in improving transferable skills (Patrick et al., 2008; Male, 2010; Jackson, 2014), employers have consistently suggested that engineering graduates have skill deficits in communication, leadership and social skills (Male, 2010). Studies on engineering employability skills mainly included: engagement and teamwork; professionalism and attitudes such as honesty and dedication; ability to learn; business skills; an interdisciplinary approach; leadership; customer focus and knowledge procurement and analysis (Male, 2010). These are consistent with those defined by Engineers Australia (EA) (2015) in the engineering program accreditation requirements and desirable employer-identified skills (Hamilton et al., 2015).

In previous years many projects have been conducted to investigate competencies required for engineering work. A major project that focused on various stakeholders. The SPINE: Successful Strategies of Global Engineering Education Benchmarking Review completed at the Royal Academy of Engineering in the United Kingdom (Spinks et al., 2006), University of Illinois survey (Meier et al., 2006) and an Iowa State University study (Brumm et al., 2006). The SPINE study (Bodmer et al., 2002) identified communication, leadership, and social skill gaps. The largest competency gaps found in many reviews and surveys in Engineering Education are in similar areas (WCEC, 2004; Ashman et al., 2008; Bons & McLay, 2003), yet those are some of the same competencies outlined by EA stage 1 competencies required by graduate engineers. However, the literature remains to show gaps within those skills.

Abdulwahed et al. (2013) conducted a literature review on the general abilities identified in engineering education throughout the world. Aside from the previously mentioned often claimed capabilities, they also acknowledged the significance of a variety of business-related categories such "*decision making abilities*", "*business and management skills*", and "*entrepreneurship skills*". Many researchers in the presented studies have mentioned that generic skills must be integrated within the students' learning activities in engineering education. For example, strengthening student's teamwork abilities could be achieved by allowing the student to experience personal interaction from other backgrounds and fields (Male et al., 2011).

The importance of incorporating generic engineering skills into students learning outcomes is evident in the literature. A study conducted by Direito, Pereira, and Duarte (2012) on student's perceptions of generic engineering skills have found that students recognise generic skills as important in engineering professional practice. Similarly, research conducted by Passow (2012) to find out the importance of generic engineering skills as defined by the Accreditation Board for Engineering and Technology (ABET) in the United States have confirmed that graduates from different engineering disciplines regarded problem-solving skills, communication, data-analysis and teamwork as highly important. These results coincide with Male (2011) findings from the Definition and Selection of Competencies (DeSeCo) framework that defines an 11-factor model of generic engineering competencies. Based on a sample of 300 established engineers, 250 senior engineers, and

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12 Industry members, it was concluded that generic engineering competencies can be presented by the 11- factor model.

A framework that outlines essential competencies for a particular job or organisation to attain success is regarded a model of competency. A collection of maximum seven to nine skills is typically necessary for a specific job, depending on the work setting and organisation, as illustrated in the competency model (Schippmann et al., 2000). A number of models were developed globally for several professions and organisations (McClelland, 1973; Cheetham et al., 1996).

A comprehensive theoretical framework for conceptual understanding was provided by the DeSeCo project (OECD, 2002). The competencies specified by the DeSeCo projects are only observable and taken by an individual's real actions in specific situations. The complex nature of competencies also encompasses the individual's character or capabilities, setting and external criteria (OECD, 2002). The DeSeCo framework describes performance observations which are an empirical way to assess competence as expressed in actions (Rychen and Salganik, 2003). Previously in the field of engineering education, Besterfield-Sacre et al. (2000) expressed this notion and this was also reported by the Iowa study (Brumm et al., 2006) in which competencies were also observed by actions. Integrity and quality orientation were among the competences identified in the Iowa research, which are human qualities that go beyond knowledge and abilities. Therefore, the DeSeCo framework aligns with other frameworks proposed by previous researchers in engineering education.

This systematic literature review (SLR) is conducted using the DeSeCo framework from the research of Male et al. (2011). In their study, the DeSeCo framework was implemented because its approach was international, interdisciplinary, and acknowledged the complexities of competencies (Male et al., 2011). Four complexities from the DeSeCo framework were particularly essential in their study plan (i) competencies are not distinct from one another, but rather are interrelated; (ii) the importance of competencies is influenced by context; (iii) the stakeholder selection effect competence selection; (iv) Competency selection is influenced by the outcomes for which they are chosen.

This SLR recognises the complexities of competencies and will include papers from all over the world (internationally) and from all engineering disciplines (interdisciplinary). As a result of the aforementioned factors, this study adopted competencies from the study conducted by Male et al. (2011). The exploratory factor analysis was used on competency items to verify that each competency was most closely connected to the variable it represented. Any item having a factor loading of less than 0.4 was eliminated from consideration. The extracted 11 factors explained 50% of the variation in the remaining 49 competency items (Male et al., 2011). The factor was conceptually designated to the items that represented it.

This SLR will focus on studying the generic engineering competencies using the 11- factor model of generic engineering competencies from DeSeCo framework. The generic engineering competency factors are communication, self-management, entrepreneurship, professionalism, ingenuity, management and leadership, teamwork, engineering business, practical engineering, professional responsibilities, apply technical theory. This competency model identifies factors that are more distinct than items currently stipulated for accredited engineering education programs in Australia, in the Stage 1 Competencies (Male, 2011).

Methodology

This systematic literature review aims to review published works related to generic engineering competencies experienced by undergraduate engineering students, and recent graduates. Specifically, it aims to address the following research questions:

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RQ1. What generic engineering competencies (knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skilfully) are developed by engineering students' WIL experiences?
RQ2. What are the research methods used to identify those competencies?

Eligibility criteria

Certain inclusion and exclusion criteria were used in this SLR. This SLR focused on journal articles published during the period January 2000 and December 2020. The inclusion criteria were that the research was published in a peer-reviewed journal and presents competencies within practice or training approaches related to undergraduate engineering students and recent graduates. The exclusion criteria were anything other than empirical research published in journals. Non-English research or research where only the abstract in English were also excluded.

Search strategy and study selection

The WIL field and the term 'competencies' traverses disciplines so relevant publications are located across a range of journals, indexed in various databases. To compile a list of suitable databases and keywords, the search strategy was designed to capture all studies that met the eligibility criteria, considering nuances of different databases. Databases included A+ Education via Informit, Educational Research Abstracts, Web of Science, Sage Journals and Proquest. Key search words (Figure 1), informed by the most frequently used competencies terms defined by Passow (2008) and WIL terms identified by Patrick et al. (2009) capture a relatively wide description of WIL. Study selection was guided by several discussions with supervisors (Figure 1). Records identified through database searching (n=1493) and those identified through other sources such as google scholar, bibliography of identified papers, etc... (n=150). Duplicates were removed, abstracts (n = 1443) were screened to determine inclusion or exclusion. Where abstracts met eligibility criteria, full papers (n = 35) were read. Conclusion about inclusion of studies was reached through discussion between supervisors and researcher at this step.

Results

The journal papers that met the inclusion criteria were used to conduct this systematic literature review.

Quantitative results

Answer to research question 1: What generic engineering competencies are developed by engineering students' WIL experiences? To answer this question quantitatively, skills were identified in each paper, and grouped to align with the 11-factor model of generic engineering competencies. After grouping the generic engineering skills, a count was performed to show how many times the skills in each category are mentioned in the selected papers, as shown in Table 1 below. Column "%" indicates the percentage of the selected papers that mention generic engineering skill included in the respective category.

Answer research question 2. Table 2 shows the research methods used in the selected papers. It is unsurprising that surveys dominate the data collection methods and we hope to see more qualitative studies in the future.

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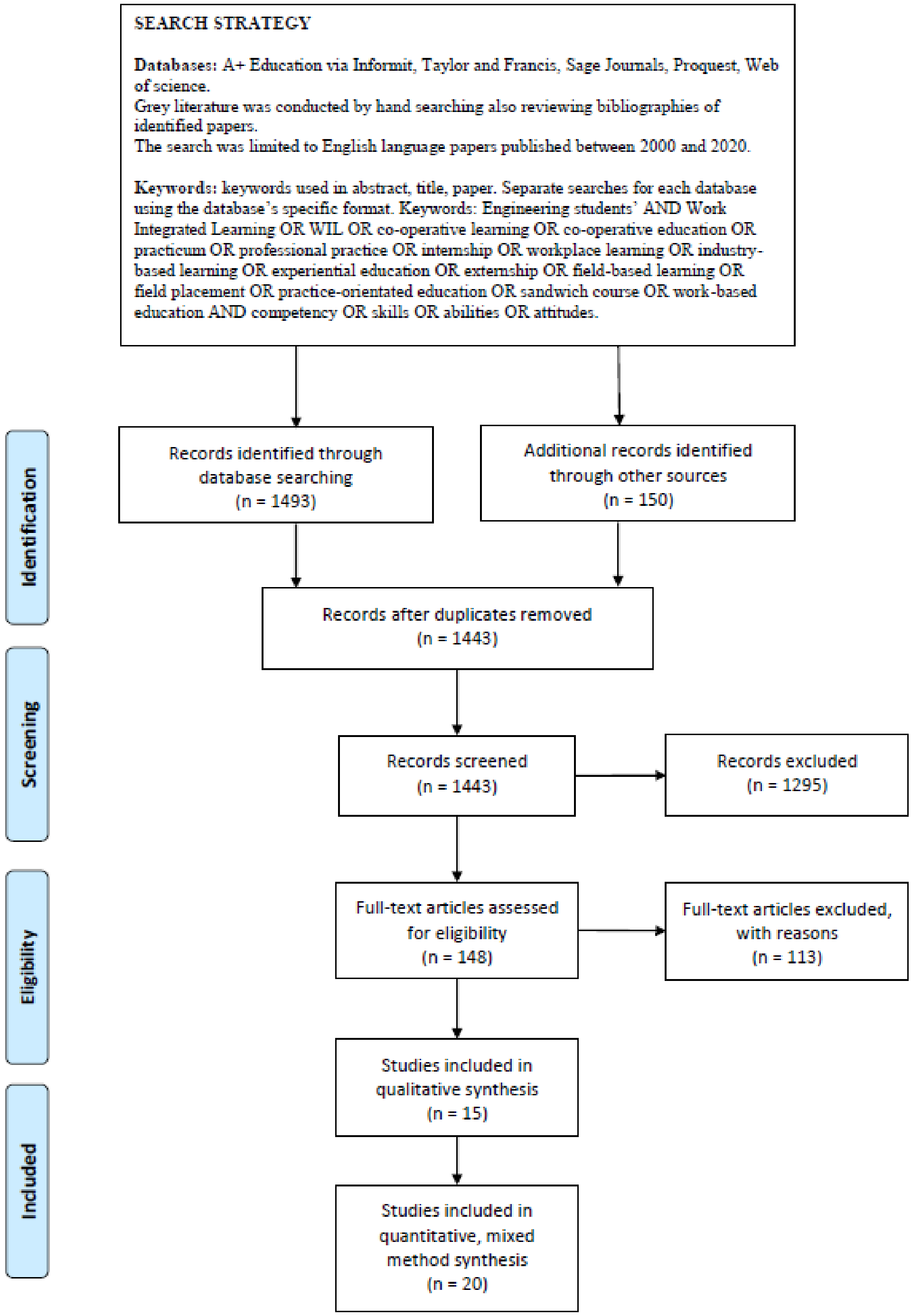

Figure 1: PRISMA flow diagram of search strategy

Table 1: Eleven factor model of generic engineering skills and how many times they appear in the selected papers

Generic engineering skill	Frequency	Percentage %
Communication	34	97
Creativity/Problem-solving	28	80
Working in diverse teams	28	80
Management and leadership	27	77
Professionalism	27	77
Self-management	24	69
Apply technical theory	23	66
Contextual responsibilities	20	57
Engineering business	9	26
Innovation	9	26
Practical engineering	9	26

Table 2: Data collection methods in selected papers.

Data collection method	Studies
Survey	28
Interviews	13
Focus groups	7
Observation	5

Qualitative Thematic Analysis

Qualitative studies have explored interrelationships between generic engineering competencies. Six common findings/themes were found however, only 4 themes will be reported in this paper due to space limitations.

Theme 1: The eleven empirically defined competency factors can be used to develop and assess student learning outcomes.

The results of this study have found that the eleven competency factors rated as highly significant regardless of individual competency ranking that fluctuated among the various engineering disciplines. Compiling the competency results that are essential for engineering work from the papers, they can all be grouped under the eleven competency factors presented (Crebert et al 2004, Le & Tam 2008). Those generic engineering competencies were defined as the core of the engineer's skill set and were essential for the development and advancement of engineers (Lenihan et al 2020). Work placements provided a platform that supported student's transition and development to the workplace.

Teamwork was frequently defined as working as an individual within a team with members from various social and cultural backgrounds (Sankaran & Mohanty). This aligns with the 11-factor generic competency "working in diverse teams". Entrepreneurship was found to be an important competency factor by various studies yet it is not mentioned in EA competencies for accrediting engineering programs in Australia - yet (Male et al 2011)].

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Participants have consistently reported that universities can better prepare and develop some of the generic engineering skills before students undertake work placement (Crebert et al 2004). They suggested that program coordinators should set goals and provide a vision in collaboration with industry supervisors to make the most of the workplace learning opportunity. It was also suggested that a greater emphasis should be placed on individual/team project work at university. Student's knowledge, competency and individual abilities could be best enriched and developed through university project work. Thus, selecting appropriate projects that utilise these set of skills along with providing informative feedback will in return have positive results for engineering students. Working in diverse teams, problem solving, designing and making decisions can be greatly enhanced using this approach (Sankaran & Mohanty, 2018).

Theme 2: Teamwork

Engineers are continuously required to complete projects within a team and in the quantitative results of this SLR "working in diverse teams" ranked equally as the second most important competency. The significance of teamwork was a focus of the literature (Scott and Yates, 2002; Holcombe, 2003; Sageev and Romanowski, 2001) and re-emphasised by the results as highlighted by the participants in the presented studies (Martin et al 2005). Freudenberg et al. (2011) results show that students and employers ranked teamwork, communication and initiative skills as most important. Fleming et al. (2009) argued that teamwork, cooperation and building relationships in effect help develop other skills such as communication skills. Particularly for students, understanding that cooperative social relationships are equally as important as providing technical information is an important realisation (Trevelyan 2010).

Interactive group learning and working in diverse teams were highlighted as work place learning outcomes in survey responses by students. Employers and students further highlighted the importance of this generic engineering skill in the curriculum. Scott and Yates (2002) confirmed that teamwork is essential as it helps in the development of other skills such as problem solving, critical thinking and ethical awareness. While acknowledging the significance and relevance of teamwork skills, not all graduates felt confident in their abilities to operate as part of a team at the onset of employment. This lack in confidence in transferring this skill to employment is reported as mainly due to the lack of emphasis given by university to develop these skills (Crebert et al 2004).

Theme 3: Communication

In Australia, engineers value communication as an important skill required for their work (Male et al 2011). In the UK, study results from the largest part of each cohort population considered communication skills to be most important skill (Spinks et al 2006). These were consistent with study results conducted in the US (Male et al 2011).

Communication in engineer's daily work involves speaking, listening, reading and writing. In literature on WIL international placements, students reported that they strengthened their foreign- language communication skills as well as gained insights and knowledge of cultural differences (Spinks et al., 2006). Communication in engineering practice involves more than just providing technical information to others. Shaping the perceptions of others and cooperative social relationships are equally significant (Trevelyan, 2010).

In Australian surveys, communication is the competency most frequently featured in deficiency results (Male et al., 2010). Graduate engineer's competency gaps reported by employers in Australia, the USA and UK most often featured communication and teamwork (Nair et al., 2009; Le et al 2008). However, an Australian study reported an improved oral communication but deficiencies in written communication remained (King, 2008).

Trevelyan (2010) explains the gaps in communication reflect the dominant focus on analytical techniques and engineering sciences and that is predominantly due to the educators misunderstanding of engineering practice as a socio-technical practice that necessitates both technical and social capabilities (Le et al., 2008). Educators can play a major role in developing student's communication skills by integrating communication skills learning session activities in the foundations of the learning process. More communication-related activities in the classroom, open discussions on problems, and projects that match technical concepts in spoken, written and visual formats can all help students acquire these important abilities. It's important to remember that strong communication skills can only be developed through consistent practice (Spinks et al 2006).

Theme 4: Reflection and feedback on workplace activities and university learning is crucial in the development of skills and students learning outcomes.

Critical reflection on workplace activities and university learning was a common theme highlighted in the presented studies. According to Harvey (2002), *"systematic reflection"* is required for students' learning to progress through work placement. Students definitely noticed the usefulness of systematic debriefing and reflection sessions and have commented about the importance of reflection in addressing competency outcomes following work placement.

Consistent with the literature on best practice, oral presentations; professional portfolios and reports summing up the WIL experience and developmental strategies such as reflection diaries and journals (Martin et al., 2011; Yorke, 2011) were viewed as significant. Industry evaluations of student performance were considered vital (Patrick et al., 2008) with supervisors/mentors instrumental in ongoing observation, review and feedback.

As well as incorporating critical reflection into the curriculum, feedback is sought to be vital for student's skill development. Students should be encouraged to seek out and negotiate chances for skill improvement while on placement, and students should formalize the process performance feedback from their industry supervisor throughout their placement. To enable effective skill development during work placement and as an established model of good practice Drummond et al., (1998) emphasizes practicing those skills with guidance and support which informs and encourages constructive reflection and improvement strategies. Key component of facilitating these opportunities include feedback from peer groups, work placement supervisors and self-assessment.

The successful transfer of skills largely depends on continuously practicing the skill in different context. Students have emphasized that integrating skill development from university to the work place involves few steps. These include, learning the basic theory at university, given the opportunity during work placement to refine skill performance; shadowed by self-reflection and review of performance upon classroom return to cement understanding and learning of established professional practice. These steps support the effective integration across the two settings (Coll et al., 2009; Billet, 2011; Jackson, 2015).

Limitations

A number of limitations were presented in this SLR. Some relating to the studies presented while others are directly related to the process of conducting SLR. Just as with any other SLR, the inclusion criteria presented in the methodology restricts searching the literature to the terms used, type of publication, review process and data used in methodology. This was used to eliminate studies that did not include empirical research data. Moreover, when screening for papers there were informative studies discussing generic engineering competencies but had no empirical research data and were therefore excluded. Although this study searched databases along with grey literature and in paper references it could possibly have missed papers that may meet the inclusion criteria.

While this study initially intended to capture undergraduate engineering students' learning outcomes following their physical work placement, it was difficult to only pick undergraduates while so many studies included recent graduates. As a result, studies that included recently graduated engineers, senior engineers and industry supervisors that discussed students learning outcomes from work placements or generic engineering competencies were also included.

Conclusion & Future work

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This systematic literature review assessed generic engineering competencies using the 11-factor model as a framework. It searched, collated and appraised available and relevant empirical evidence to provide an interpretation of search results. This systematic literature review can be used as a guide for engineering educators and stakeholders to inform decisions and descriptions of the generic competencies.

Future work following this review will extend to identify student learning outcomes in terms of generic engineering competencies following their virtual work placement. Future research in evaluating engineering virtual work placement is essential especially since the COVID-19 pandemic outbreak where many engineering work placements were experienced virtually. The next phase of this research will determine student learning outcomes in engineering physical work placements and investigate if virtual work placement students were able to experience similar/equivalent learning outcomes.

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Title: **Technology Assimilation Proficiency-Reflecting Graduate Attributes: A review of the literature on mining engineering practice and higher education in South Africa**

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CONTEXT

Technology assimilation (TA) is both a technical matter and a social process. The importance of TA emanates from the fact that it is a necessary condition to the industrialization, economic development, and social upliftment of nations or communities. People, either in their roles and activities as engineers, technicians, innovators, marketers, or as other participants, are intimately involved with and in the process of TA. The study investigates people attributes that reflect, or are associated with, TA proficiency. Furthermore, the study seeks to understand the core aspects within which such attributes manifest in mining engineering practice and higher education in South Africa.

PURPOSE

The study focuses on understanding how TA is understood in engineering practice and higher education in the South Africa. It also seeks to identify TA proficiency-reflecting graduate attributes that are required and valued, and the contexts within which these manifest, in mining engineering practice and higher education in South Africa.

APPROACH

The current study is the first stage of an envisaged two-stage investigation. All data and evidence in the current paper was sourced from reviewed literature. Due to the limited, if any, published materials on the topic, specifically as it pertains to South African contexts, a thematic approach was used rather than a systematic literature review.

The SA mining sector employs large numbers of graduates from the mining, electrical, mechanical, and mechatronic engineering disciplines. Attempts were therefore made to understand the documented TA-related contexts, roles, experiences, and activities of these four disciplines in the mining industry and higher education in South Africa. Furthermore, attempts were made to identify TA proficiency-reflecting attributes required and valued in such contexts.

TA is generally misunderstood in both engineering practice and higher education. An overall understanding of TA was established through critical analyses of the multiple perspectives on TA, and then synthesizing the reviewed literature into major themes.

ACTUAL OUTCOMES

A taxonomy of the factors that influence TA was developed. The taxonomy comprises two categories of '*Technology content-specific factors*' and '*TA process-related factors.* Furthermore, a preliminary list of TA proficiency-reflecting attributes was also compiled.

KEY WORDS

Technology Assimilation (TA); Graduate Attributes; and Taxonomy of Factors

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1 Introduction

Technology assimilation (TA) presents various benefits to an organisation, such as operational competitiveness and market share changes (Wolfe, 1994; Bozeman, 2000; Jie et al., 2015), as well as benefits to society, in the form of regional or national economic development and other socio-economic impacts (Rogers, 1962; Hlavacek & Thompson, 1973; Menghetti, 2002; Jie et al., 2015). However, when done poorly, TA can lead to un-recouped capital investment and unrealised operational competitiveness (Rogers, 1962; Hlavacek & Thompson, 1973; Menghetti, 2002; Jie et al., 2015). The process of TA can be slow, disruptive, and costly. Assimilation rates can vary across countries or organization, thus resulting differences in developmental outcomes and experiences (Holdom, 1989). It is therefore imperative to identify and develop the necessary TA proficiency-reflecting skills and competencies such as to avoid the negative outcomes of poorly implemented TA projects.

TA is a reality in engineering practice in South Africa. Many old and new technologies have been unsuccessfully adopted in many engineering fields (Menghetti, 2002; Sahin, 2006), including in the SA mining industry. Moreover, some technologies are initially adopted by an organization, but then disrupted or discontinued before organization-wide, comprehensive, effective assimilation is realised (Jie et al., 2015). The outcomes of unsuccessful, disrupted, or discontinued adoption can be mitigated through the identification and development of TA proficiency-reflecting attributes.

Increasingly, higher education in South Africa is seen as a contributor to the economy "through the production of skilled graduates" (Winberg et al., 2018: 234). This entails the attainment of graduate attributes (i.e., programme outcomes) (Winberg et al., 2018). Graduate attributes are generally viewed as the skills, knowledge, competencies, practices, cultures, and values fostered within higher education (Barrie, 2006; Jones, 2009; Bond et al., 2017; Anderson, 2017). The South African Council on Higher Education (CHE) points out that graduate attributes are "oriented towards different disciplines and fields", and that they also "encompass values, attitudes, critical thinking, ethical and professional behaviour, and the capacity of a graduate to take what has been learnt beyond the site of learning" (CHE, 2013:19). Furthermore, South African universities are required to identify appropriate graduate attributes and implement these across programmes (CHE, 2013). Graduate attributes (GAs) are therefore the link between a student's academic performance in higher education and post-qualification employability (Winberg et al., 2018).

2 Understanding TA

The literature contains a vast number of theories covering the subjects of technology, innovation, assimilation, and the determinants associated therewith. However, the subject of 'technology assimilation (TA)', on its own accord, has not been adequately explored. There is also very limited direct empirical data available about the process of TA. Misunderstandings pertaining TA are further exacerbated by the multiple perspectives on the subject. These perspectives are primarily influenced by disciplinary and methodological orientations.

In this paper, some simplifying assumptions regarding the complex process of TA can be explained through, amongst others, the integrated combinations of some aspects of *technology transfer theory* (TTT), *technology acceptance model* (TAM), and the *diffusion of innovations theory* (DIT). These theories and models are not synonymous to TA but are similar or analogous to TA in some respects.

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3 Research question

The study focuses on how TA is understood in engineering practice and higher education in South Africa. It attempts to establish an understanding by leveraging on TA-related contexts, experiences, roles, and activities in which graduate engineers are involved, in the South African mining sector and in higher education. It is hoped that TA proficiency-reflecting graduate attributes can be identified from understanding the contexts and activities in which the process of TA manifests.

The goals and focus points of the study are summarised in the research question below:

<u>Focal research question</u>: What does the literature suggest are the core aspects to be considered in understanding technology assimilation (TA) in mining engineering practice and higher education in South Africa?

To address the focal research question, the study aimed to collect data and evidence from published literature to accomplish the following:

- Establish how TA is understood in mining engineering practice and higher education in South Africa
- Identify TA proficiency-reflecting professional engineering attributes required and valued in mining engineering practice.
- Identify TA proficiency-reflecting graduate attributes (also known as 'exit level outcomes') fostered in higher education (if any) in South Africa.

4 Actual outcomes of the study

The outcomes of this study are as outlined in the subsections below

4.1 Synthesised perspective on the TA process

The synthesized perspective is premised on TA process as referring to the way technology or innovation diffuses across organisational activities, projects, or work processes, and then becoming routinised and embedded in those activities (Fichman & Kemerer, 1999; Purvis et al., 2001). It is reliant on the distillation of the concepts of *technology*, *invention*, and *innovation*, which are explained by a few authors, such as Rogers (1983), Eveland (1986), Fichman & Kemerer (1999) and Utterback (1971). A technology comprises *hardware aspects* and *software aspects*. Both the hardware and the software aspects of technology encompass knowledge (Rogers, 1983; Cordey-Hayes & Gilbert, 1996; Zahra & Gerard, 2002; Gonzalez, 2015), and therefore require proficiency and, more importantly for this study, assimilation. An invention is an original, newly created device or process. An innovation, on the other hand, is an invention that has been a subject of entrepreneurial action to give it economic significance. Therefore, TA essentially entails the introduction of new technology or innovation – such as new products, methods, procedures, machines, processes, or theory into the operational activities of an organisation, or a social system, for the purpose of realising some economic benefits. It is a process reliant on two integral, intertwined elements of *technology*, and *the people*.

The core aspects of the synthesized perspective on TA are as depicted in figures 1 & 2 below. TA is a process that takes place in stages – from '*basic research & innovation*' to '*impacts and social consequences of innovations'*. However, the process may not necessarily be unidirectional due the re-designs and adaptations that a technology may be subjected to

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in the interim stages. Furthermore, the various stages are interactive and overlap one another. Due to micro- and macro-mechanisms, the individual stages, and the overall process of TA, are often iterative.

Figure 1: Summarized perspectives on the process of technology assimilation

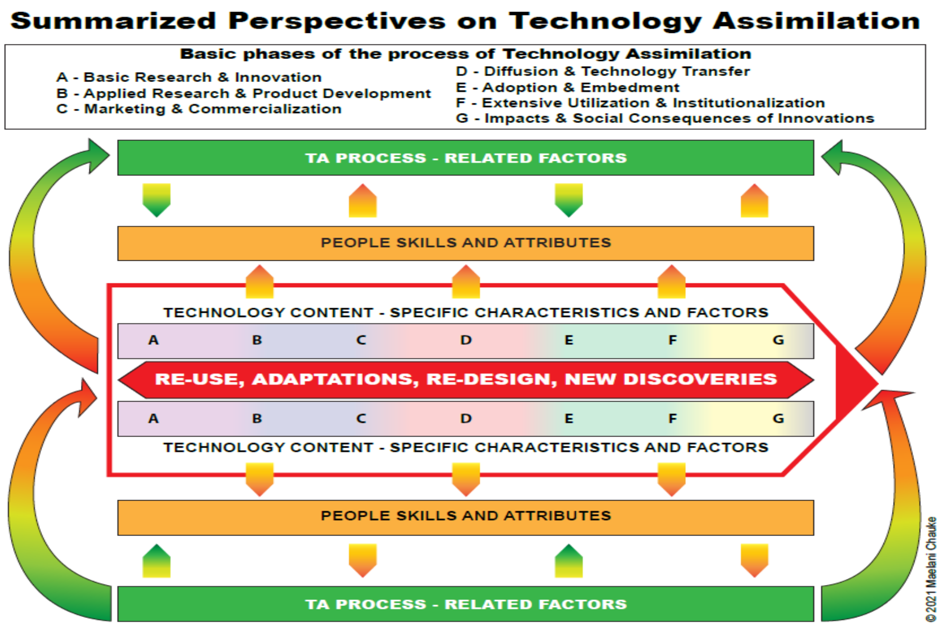

Figure 2: Taxonomy of factors influencing the process of technology assimilation

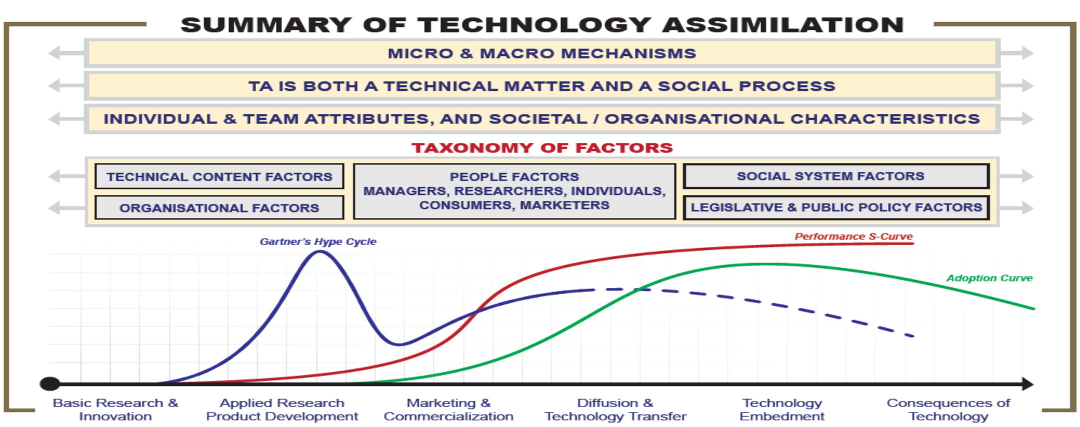

Figure 1 also emphasises the indispensability, and inseparability, of both '*technology content-specific factors*' and '*TA process-related factors*' in the overall of TA process. Both categories of factors are influenced by '*people skills and attributes*'.

Figure 2 depicts the various stages of the TA process in relation to the well-known '*Gartner's Hype Cycle*', the '*Performance S-Curve*', and the '*Adoption Curve*'. Each of the curves gives

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an approximate trajectory of, or impacts, on '*technology content-specific factors'* or '*TA process-related factors*' over the entire envisaged process of TA. The figure also emphasizes the centrality of *people factors*, and the associated *people skills and attributes*, over the entire process of TA.

4.2 Taxonomy of factors that influence TA

TA is a technical matter as well as a social process (Rogers, 1983). Furthermore, micro-, macro- mechanisms and sub-processes are involved in the overall TA process. More importantly, factors that inhibit or enhance the process of TA cannot be considered independently of the contexts within which they manifest. These factors, which were synthesised from the literature, are divided into two categories viz. *technology content-specific factors,* and *TA process-related factors*. The former includes factors, aspects, and characteristics such as *technical aspects*, *technological aspects*, *physical characteristics*, *utilitarian aspects*, *technology-specific knowledge and expertise*, and *infrastructural requirements* of a technology. The latter category, on the other hand, includes *organizational* factors, *people factors*, *social system factors*, *legislative and public policy factors*. Furthermore, TA proficiency-reflecting attributes are integral to all factors that influence TA, and to the overall process of TA.

4.2.1 Technology content-specific factors

The manner and extent to which a practical need or want is addressed is encapsulated in the technical, technological, physical, instrumental, ergonomics, or utilitarian characteristic or aspects of a technology (i.e., *technology content-specific factors*). In other words, a technology must satisfy technology content-specific requirements in other to qualify as an appropriate, relevant, effective technical means of addressing an identified practical challenge, need, or want. In essence, the initial success or failure of the TA process is influenced by the suitability of '*technology content-specific factors'* in satisfying an identified practical need. This study attempted to identity TA proficiency-reflecting attributes that are required and valued in South African contexts, as regards the potential ability to satisfy 'technology content-specific' requirements of projects or work activities.

4.2.2 TA process-related factors

*Organizational factors***:** Empirical research has demonstrated that organisational factors such as organisational structure, information, communication, and infrastructure enhance or constrain the process of TA (Rothwell & Robertson, 1973; Bayer & Melone, 1998; Wong et al., 1998; Armstrong & Sambamurthy, 1999). For instance, structural arrangements such as cross-functional teams, project matrix, and balanced matrix have been found to achieve higher assimilation success rates than either purely functional teams or hierarchical structures (Wong et al., 1998). Networking and flexibility brought about by modern information technologies have also been found to enhance TA (Wong et al., 1998). This study attempted to identify TA proficiency-reflecting attributes that are required and valued in South African contexts when dealing with organisational factors-related challenges.

People factors: People play critical roles in both their individual and organisational capacities (e.g., as managers, researchers, innovators, marketers) in the process of TA (Meyer & Goes, 1988; Bayer & Melone, 1988; Fichman, 1992; Bozeman, 2000; Zhu et al., 2006). Therefore, it is important to explore TA by taking into consideration the contributions and contexts of human systems (Eveland, 1986). More specifically, individual and people team attributes influence

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the success or failure of the process of TA. This study focused on the identification of TA proficiency-reflecting attributes that required and valued for dealing with people factors.

Social system factors: A social system comprises a set of interrelated units (people) that are engaged in joint problem solving to accomplish a common goal (Rogers, 1983: Wenger, 1998). Moreover, a social system constitutes a boundary within which an innovation diffuses (Rogers, 1983; Bozeman, 2000). Social structure, which gives regularity and stability of human behaviour in a social system, refers to the patterned arrangements of the units of a system (Rogers, 1983). Furthermore, information regarding the established patterns of behaviour (i.e., norms), beliefs, values, and attitudes of a society flows through social structure. Social structure, and other characteristics of a social system, also act as barriers or enhancers to the process of TA (ibid). Social system factors, amongst others, include power relations and the social consequences of TA. New graduates, for instance, operate within new social system factors (i.e., as separate, and distinct from higher education) in their new place of employment after the completion of their academic careers. From TA perspective, this study seeks to identify TA proficiency-reflecting attributes that are required and valued for dealing with social system factors.

Legislative and public policy factors: A country's legislative, regulatory, economic, and public policy frameworks influence the internal and external milieus within which an organization conducts its activities (Bozeman, 1994; Bozeman, 2000; Rogers et al., 2001). Empirical research has, for instance, demonstrated that the combination of regulatory and economic policies that allow for the transfer of technologies from national sources (e.g., government–owned national R & D laboratories or research universities) to private companies can provide the basis for economic growth of metropolitan regions (Rogers et al., 2001). Furthermore, combinations of 'cooperative technology policy' and 'taxation incentives', have also been empirically found to encourage intra and cross-sectional innovation and technology transfer (Bozeman, 2000; Rogers et al., 2001). TA projects are executed within the boundaries of different legislative and public policy frameworks (e.g., different from one country to another). This study thus attempted to identify TA proficiency-reflecting attributes that are required and valued for dealing challenges emanating from '*legislative and public policy factors'*.

4.2.3 Technology - and TA Proficiency-reflecting Skills and Attributes

The successful execution of any TA project depends on the satisfaction of, or compliance to, the relevant '*technology content-specific factors'* and '*TA process-related factors',* both of which are influenced by *people skills and attributes.* Technology is only one aspect in the overall process of TA. Although they may share some similarities, '*technology proficiency-reflecting attributes*', are different from '*TA proficiency-reflecting attributes*.

A preliminary list of '*TA proficiency-reflecting attributes'* was compiled in the study. The list consists of the attributes of *critical technology awareness*; *engineering creativity*; *innovation (skill)*; *digital literacy*; *knowledgeability/communication*; *continued professional development* (e.g., *life-long learning)*; *nuanced attributes collection*; *entrepreneurship; and teamwork.*

In the list above, the '*nuanced attributes collection'* includes skills and competencies such as *emotional intelligence, adaptability and flexibility, reflections on learning, curiosity, resourcefulness, independence, reflexibility, self-awareness*, and *resilience*.

All the listed 'TA proficiency-reflecting attributes' display various aspects of '*context-dependency'*, and thus require adjustment or mutation subject to a particular situation. Therefore, the effective employment of these skills sets is also dependent on the ability to customise and realign them to any new situation.

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5 Conclusions and recommendations

Despite limited published material on the topic of this paper, a thematic approach as adopted herein, can nevertheless help in exploring the topic.

The process of TA can be understood as summarized in subsection 6 and depicted in figures 1 and 2 above. The core aspects of TA are incorporated into the categories of '*technology content-specific factors'* and '*TA process-related factors'*. The successful execution of any TA projects entails the satisfaction of, and compliance to, the requirements of aspects and characteristics outlined under *technology content-specific factors'* (e.g., utilitarian characteristics – subsection 4.2.1), and 'TA process-related factors (e.g. using TA-appropriable structural arrangements in organizations – subsection 4.2.2).

'Technology content-specific' and 'TA process-related' category factors are both integral to the process of TA. Therefore, the development of TA proficiency-reflecting attributes cannot be skewed towards one category to the detriment of the other.

Due to limited published material of the topic, the applicability of TA understanding established in this paper, particularly as pertain mining engineering and higher education contexts in South Africa, could not be determined. The same applies to the factors that enhance or inhibit TA, and the TA proficiency-reflecting attributes.

It is recommended that the second stage of this study, and other similar studies, be used to collect empirical data and evidence which can be used to determine the relevance and applicability of the outcomes of this paper to mining engineering practice and higher education in South Africa.

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Beyond planned learning objectives: Entrepreneurial education as the source of accidental competencies for engineering students

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ABSTRACT

CONTEXT
A growing number of educational institutions and professional associations are emphasizing the importance of an entrepreneurial mindset and competencies in engineers and other technical professionals. The inclusion of entrepreneurship education components in engineering activities contributes to the development of technological innovations, which are aimed at solving essential social and human problems. However, despite the value of entrepreneurship education for engineers, there are limited approaches to evaluation that consider the complexity of the learning process and emerging practices.

PURPOSE OR GOAL

The purpose of this study is to understand the competencies that engineering students develop through participation in entrepreneurial educational activities. The learning process of engineering students was investigated through the lens of Accidental Competency Formation concept. Additionally, in this study, the authors evaluated how the chosen theoretical lenses provide understanding about the role of specific learning activities in forming students' competences.

APPROACH OR METHODOLOGY/METHODS

The authors followed the interpretive methodology and used in-depth semi-structured interviews as the data collection method. This research is qualitative and serves as a reminder of importance of students' perceptions and beliefs in understanding the effect of educational interventions on students' formation. Data was collected from 11 engineering students, who participated in the UTS Techcelerator 2020 program, which is a deep tech early-stage accelerator designed to promote prototyping skills for technology students.

ACTUAL OR ANTICIPATED OUTCOMES

The main outcome of the study is the elicitation of the three different accidental competencies such as self-regulation, adaptability and empathy, which are formed in the engineering students participating in entrepreneurial activities. Additionally, certain activities and elements of the Techcelerator program educational process were identified as having a particular impact on the formation of competencies, based on students' accounts.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This study provides a holistic approach that allows evaluating the role of entrepreneurial activities in the formation of engineering students' competencies, considering the complexity of the learning process. This conclusion is based on the fact that this study revealed formation of students' competencies that are not projected in program's learning objectives.

KEYWORDS

technopreneurship, engineering education, accidental competencies

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Entrepreneurship education in engineering

Entrepreneurship is an important component of economic development and social wellbeing in both developing and developed countries. At the same time, over the past few decades, technology startups have been playing an important role contributing to the main economic indicators of countries. According to the Crossroads 2020 report, 7 out of 10 biggest companies (by market cap) are tech firms where more than half of the specialists working for these startups are engaged in technological roles (STEM skills) (McCauley & Gruszka, 2020). The growing importance of tech start-ups has driven universities and other educational institutions to incorporate entrepreneurial subjects or extracurricular programs (e.g. accelerators) into their information technology and engineering courses. Thus, entrepreneurial subjects for engineers are now a substantial focus in many engineering programs delivered in Australian universities for example, the University of Sydney (Incubate accelerator program), UNSW (10x Accelerator). Other educational institutions have gone even further by offering entrepreneurial development trajectories within the framework of their undergraduate engineering programs. A minor in Entrepreneurship offered by the University of Adelaide is an example of this. In terms of extracurricular activities, there are some opportunities available for technical students to develop their entrepreneurial skills and mindset in Australia. For instance, engineering and IT students wanting to establish their own tech business now have access to a large number of entrepreneurial programs within the Australian entrepreneurial ecosystem such as standard educational courses, accelerators, incubators and other structured and unstructured programs (Maritz et al., 2019). A good example would be the Techcelerator program that was launched in 2019 as a deep tech early-stage accelerator to enhance students' prototyping and entrepreneurial skills. Therefore, it can be concluded that the importance of technology entrepreneurship has been endorsed by many Australian educational institutions, which has been further emphasised by the active incorporation of entrepreneurial activities into engineering and IT programs.

The importance of entrepreneurial skills for technical specialists was also highlighted in industry reports prepared by professional associations. For instance, the Australian Council of Engineering Dean's (ACED) issued the Engineering Futures 2035 scoping study where entrepreneurial competencies are denoted as essential for future engineering experts. In this study, the World Federation of Engineering Organizations (WFEO) 2018 International Forum on Engineering Capacity communiqué (Crosthwaite, 2019; p.37) is also referenced, where it was emphasised that:

"We should enhance comprehension of the role of engineering in society and the training of engineering ethics, humanity, nature and entrepreneurship."

The American Society for Engineering Education (ASEE) also accentuates that engineers need well-developed entrepreneurial skills. To further illustrate this, the Innovation with Impact (IWI) report (ASEE, 2012) concludes that by teaching entrepreneurial skills to engineers, it will be possible to shape a generation of technical specialists who will collaborate more efficiently, be culturally responsive while focusing on the development and design of innovation with impact.

Despite the widespread trend of implementing entrepreneurial programs in universities and other educational institutions, there is a small amount of research aimed at studying engineering and IT students' attitudes towards entrepreneurship, the impact of entrepreneurial interventions on their learning as well as the formation of competencies and professional attributes of engineering students (Bosman & Fernhaber, 2018). The challenge of studying the role and impact of entrepreneurship education for engineering students correlates to the fact that there are many definitions of entrepreneurship as well as because of the large number of assumptions about the specific competencies, mindset characteristics and knowledge that an entrepreneur should possess (Duval-Couetil et al., 2012). This diversity of views on entrepreneurship has formed the preconditions for the creation of an array of approaches to entrepreneurship education.

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It is also worth noting that when including entrepreneurial interventions into other educational programs such as engineering, it is important to understand how entrepreneurial education contributes to the formation of certain competencies. Additionally, an educational program must be certified by certain professional associations and must contribute to the formation of a certain set of graduate attributes. That is why it is important to know how several types of learning activities contribute to the formation of specific learning outcomes. This understanding might also further help to evaluate the effectiveness of integrated entrepreneurial programs.

Graduate attributes in engineering education

Most educational disciplines and sectors in the late 1990s saw a paradigm shift take place, with the focus shifting from inputs or processes to educational outcomes. Engineering education was not an exception. In Australia, the starting point for these changes was the publication of Engineers Australia's 1996 review "Changing the Culture: Engineering Education into the Future" (Engineers Australia, 1996). This review led to the development of the Australian Graduate Attributes (Engineers Australia, 2005). The new approach has broadened the scope of education since some non-technical aspects such as cultural awareness or ethical conduct have been added to the list of attributes. It is noted that some researchers assume the implementation of the outcome-focused approaches led to positive changes in the overall education process. One example is Lemaitre et al. (2006), who declared the focus on "professional competence has always been the ultimate goal of engineering curricula" (pp. 45). At the same time, it should also be noted that there are some critics of this outcomes-based approach. According to Miles (2003), targeted competencies are usually framed too broadly, which in turn makes their holistic development difficult. Additionally, some researchers and educators assume that the creation and implementation of these graduate attributes into educational programs has not solved the problem with the continuous existence of a gap between engineering education and the workplace.

It is also essential to mention that the introduction of the outcomes-based approach into educational programs focusing on specific competences and attributes has formed certain practices among engineering educators. When designing educational programs, some learning designers and coordinators might have the assumption that it is enough to choose a particular learning intervention (activity) to achieve a specific learning goal (development of an attribute) (Walther et al., 2006). Sometimes educators juxtapose planned attributes and educational interventions making a linear structure of the programs. When using this approach, educators do not take into account the complexity of the learning process and do not look at the education holistically. The existence of these challenges leads to the fact that at the moment, it is quite problematic to determine how extracurricular activities and other important extracurricular practices such as work integrated learning (WIL) as well as other meta-influences such as university culture affect the formation of competences.

As mentioned earlier, entrepreneurial education for engineers can be composed of different elements and have different formats, such as being optional (university incubators) or integrated into the curriculum (subjects). At the same time, there can be a combined format such as university accelerators when some students take part in the program voluntarily while other students can get some credit points for completing this program. As previously discussed above, accelerators are entrepreneurial interventions that have begun to be actively introduced into engineering curricula to encourage a formation of an entrepreneurial mindset among technology students.

According to Bliemel et al. (2016), accelerators can be defined as programs that involve parameters such as seed funding, a certain cohort of participants during the entire program, structured learning and development program, mentoring and co-location. It is evident from this definition that alongside the planned educational activities like workshops, accelerators also include many other less structured opportunities such as mentoring, cross-team

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discussion or interactions with customers for engineers to develop certain competencies associated with their professional formation. It is important to identify how the holistic structure of the given program affects the formation of educational outcomes to better recognize its effectiveness as well as the impact of accelerators on the formation of certain competencies among engineers. It is challenging to understand how such complex programs as accelerators involving various types of activities can be evaluated in terms of effectiveness and learning outcomes just by using traditional assessment tools. For such purposes, it is necessary to use approaches that consider the complexity of learning process.

In this article, we propose to use the view of Accidental Competency that holistically conceptualises the process of developing competencies as a complex system (Walther et al, 2006). According to Walther and Radcliffe (2007), 'Accidental Competencies are abilities important to performance in professional practices that are not linked to targeted instruction of the stated learning outcomes of the course' (p.45). The authors state that engineers shape competency through a variety of complex interactions, both within the framework of traditional interventions and under the influence of other elements that surround a student. The main idea behind this perception is that within the learning process framework, students acquire different types of competencies, such as accidental competencies, intentional learning outcomes and accidental incompetency. These are all formed under the influence of different clusters of a complex learning system, namely: learning activities, other curricular elements (exams, assessments etc.), student disposition (educational background, traits etc.), extra-curricular elements and meta influences (teacher as a person, prevailing culture etc.) The focus of this study will be around accidental competencies. This theoretical approach will enable us to take into account the complexity of accelerator programs as an entrepreneurial learning intervention while also identifying which accidental competencies are acquired by engineering students.

In this article, we state that in order to understand the effectiveness of entrepreneurial education for engineers, it is important to understand the formation of both planned goals and accidental competences. This complete understanding can help learning designers while simultaneously helping educators to develop curricula for the future T-shaped engineers.

The authors in this preliminary study considered the participants' beliefs in relation to developed competencies to determine exactly what abilities they think were developed. Choosing this approach, the authors proceeded from the point of view that beliefs can influence and predict the behaviour of an individual and shape his or her response and actions (Smith, 2016). A number of studies emphasise the importance of beliefs for self-efficacy, which, in turn, affects the behaviour of the individual (Bandura et., 1999), also the nature of knowing and intelligence (Dringenberg et al., 2019), capabilities (Eliot & Turns, 2011). Taking into consideration the theoretical approach and research focus, the following research question has been formulated for this study: *RQ: What are the engineering students' beliefs about their acquired accidental competences after participation in the accelerator program.*

Methodology

Since students' beliefs are not always explicitly articulated and can be both unconscious as well as conscious, semi-structured in-depth interviews were chosen as a method to explore the complex construct of participants' beliefs through the stories about their experiences during the accelerator program (McNeill, et al., 2016). In-depth semi-structured interviews with students allowed researchers to focus on the diverse variations of beliefs shared by participants and investigate all their aspects (Creswell & Miller, 2000). As accidental competencies could not be-predefined, this kind of interview gave the researchers flexibility during the conversation.

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As mentioned above, this is a preliminary study that considers only participants' beliefs about the acquired competencies. This study was conducted with participants of the UTS Techcelerator 2020 program, which is a deep tech early-stage accelerator designed to promote prototyping skills for technology students. This was a free 6-month program that ran from July to December 2020. UTS students who had a startup prototype were selected for participation through a multi-step application process that involved a range of information and selection activities during three months. During the participation in the UTS Techcelerator, students went through a number of structured learning activities such as workshops, learning circles as well as unstructured one-on-one consultations with experts and guest speakers. Moreover, participants were also given access to facilities, mentors and funding.

This program was chosen as a research site because the authors being employed by UTS had access to UTS Techcelerator. One of the authors is also the Director of Techcelerator program and could provide access to the program participants. In the 2020 cohort, 22 individuals from the Faculty of Engineering and Information Technology (FEIT) participated in the Techcelerator program representing the Bachelor's, Master's and Doctorate students. Due to the limited number of program participants, all of them were invited for interviews via email. Consequently, eleven participants from seven technology enterprises participating in the program expressed their interest in being interviewed for the study. These participants allowed researchers to collect a range of insights and provided sufficient data saturation - which is the common approach in determining a sample size. A mix of educational programs and genders of the participants was ensured. Due to COVID-19 restrictions, all interviews were 60 minutes in duration and conducted online via zoom.

From the learning perspective, UTS Techcelerator aims to achieve the outcomes that are focused on developing a range of practical skills and an entrepreneurial mindset among the participants. Planned outcomes included outcome one, outcome 2, outcome three, outcome four, outcome five and outcome six. In order to understand how these outcomes were formatted in this research, it is important to take into account the fact that the UTS Techcelerator is part of FEIT. Thus, the graduate attributes formulated in the university and faculty strategy determined the outcomes reflected in the Techcelerator program outline. (UTS FEIT graduate attributes are aimed to shape students who are attribute one, attribute two, attribute three, attribute four, attribute five, attribute six).

Understanding the outcomes was an important aspect to consider at the data analysis stage. These outcomes and related competencies declared in the UTS Techcelerator 2020 program formed the analytical strategy based on the Accidental Competency Formation concept.

The authors analysed the interviews focusing on the competencies formed as a result of participation in the program but were not declared in its planned outcomes. During the interview, the participants were asked about their perceptions and impressions of various accelerator experiences. Some of the questions were also focused on identifying the student's beliefs about takeaways as well as their achievement and challenges during the program participation. Then using thematic analysis, authors evaluated the acquired data. This approach allowed the researchers to examine and summarise perspectives of different participants and found unanticipated insights (Nowell et al., 2017).

Results

As mentioned earlier, the main goal of this empirical study was to understand whether traces of formed accidental competencies can be tracked in the responses given by the participants. Also within the framework of this study was an attempt to understand how this theoretical approach would be suitable for identifying unplanned learning outcomes. After analyzing the acquired data, the following results were obtained.

Self-regulation

Self-regulation and other self-oriented competences are not part of the lists of accelerator and faculty attributes lists. Zimmerman and Labuhn (2012) defines self-regulation as an ability to take the lead in helping oneself using proactive behavior and developing learning strategies to get out of difficulties. In this situation, an important characteristic is the ability to act proactively. Learning and other extracurricular activities (group work etc.) of the accelerator program were structured in a way that challenged participants to be involved into a variety of new situations and interactions with team, stakeholders, and customers. Further to this, the teams worked on their own individual projects (startups), compulsory reporting about the budget expenditures as well as a strict time frame of the program where it was necessary to present a minimum viable product. Due to this, the commitments shaped conditions for proactive behavior.

Participant 1. The client said that he would like to change some design elements in a short time. Since we did not have enough funds to hire a specialist, we had to quickly learn the basics of design and the necessary tools to create these elements. It was a new experience for us in solving problems without funds. Now I believe that I feel more confident working in design programs like Figma and dealing with unexpected situations.

After analysing qualitative data, it was identified that different learning activities and other influences manipulated the students' ability to feel more confident when they encountered sudden problems. This example shows how different categories of educational activities stimulate students to form self-regulation competence. For example, during structural and planned learning activities such as workshops, students got instructions on how to communicate with potential customers. Then, students within the framework of social interactions (extra-curricular activities) faced the problem of lack of money and customer suggestions (meta-influences). The students also proactively formed the strategy to solve this problem (they decided to learn some design principles) which helped them get out of this situation with newly formed competencies.

Adaptability

According to Herman (2013), adaptability is defined as the ability to adjust to different changes in the selection environment. Miller and Bound (2011) mentions accelerators themselves represent a competitive environment. Within the considered research site (accelerator), students had the opportunity to compare their achievements with the results of other teams. Within the framework of this program, there is also a series of milestones when students must present their intermediate results. These parameters characterize accelerators as a fairly competitive environment. Additionally, according to Bliemel et al. (2016), accelerators form authentic experiences of complex entrepreneurial activities when students consider a range of factors affecting success of their project and solve various problems.

Participant 2. I feel a big self-progress. At the beginning of the program, I felt overwhelmed, due to the large number of meetings, events and information. I could not keep up with the pace of combining the accelerator and other objects. However, the other students and mentors explained me some of the basic principles of time management and gave me some personal advice. Now I'm not afraid to ask for help.

This answer shows how a student in new conditions, with the help of various elements of the accelerator such as group work and personal consultations with a mentor, received new knowledge and methods for adapting to new conditions. This example portrays how different types of events and meta influences directly impact the formation of the student's ability to adapt to new, stressful conditions with more workload.

Empathy

Empathy is a commonly used phenomenon in different fields, ranging from social work and nursing to engineering and entrepreneurship. At the same time, empathy has many different definitions. For example, Cuff et al. (2016) found at least 43 definitions of empathy. It is essential to mention that there are some assumptions that empathy is an important element of communication, ethics or cultural awareness. In this study however, when reporting on empathy as an accidental competence, we use the definition of Walther et al. (2017). He developed a concept of empathy for the engineering context while taking into consideration the complexity of this attribute that is conceptualized as a skill, practice orientation and a way of being. As part of our research, it was determined that under the influence of entrepreneurial education, some students had all three facets of empathy.

When I realized that our clients had lost a lot during the COVID event since the public events were not allowed, I realized that we needed to reduce the price of our product and make it more affordable. It's great that our advisor recommended us to use the empathy map…...I underestimated the knowledge of other people. I didn't realize what a big market. I didn't realize how giant it was in Europe and China……..Because we thought of this great solution, but if the public doesn't need it or want it, there's no point

Here we can trace how accelerator activities such as interactions with clients and meetings with advisors contribute to the formation of all three facets of empathy in students. In this example, a student believes that some of the tools and knowledge (empathy map) helped him use the skill of perspective-taking and understand a client's outlook. Walther et al. (2017) consider perspective-taking as a learnable skill that is part of empathy. It can further be traced to a student who has started thinking about macro opportunities for his business, demonstrating the micro to macro practice orientation orienting towards larger systems-level implications (Walther et al., 2017). And finally, the participant also demonstrates the elements of service to society way of being declared that the products should be developed for the needs of society. It's worth noting that Walter's empathy model includes other elements as well, such as emotion regulation, epistemological openness, dignity and worth of all stakeholders etc., on different levels. However, in this study, it was possible to trace the formation of three facets afterwards and reveal the influence of accelerator activities on the formation of each facet.

Discussion

In this empirical study, the authors investigated the acquisition of accidental competencies by program participants using the concept of Accidental Competency. The influence of all categories including but not limited to extracurricular activities, meta-influences, student disposition and other curricular elements were taken into account. As a result, it was noted that participation in this entrepreneurial program (accelerator) contributed to the acquisition and formation of a number of accidental competencies such as empathy, self-regulation and adaptability of a majority of the students' participants.

This study also notes that by using a theory that considers the learning process a complex system and explores the impact of various learning activities, researchers may determine the development of competencies that were not originally set for the program. This understanding is important due to the established trend towards forming T-Shaped engineers who must possess a range of both technical and social skills (Crosthwaite, 2019). It is thus important to have a tool that allows practitioners to define a range of competencies that could also be included in the training programs of engineers. This approach can further make it possible to analyse existing programs that identifies accidental competencies and, therefore, expands their outcomes and strengthens them by introducing additional activities or by adapting existing ones.

Also, within the framework of this study, the essential role of all types of activities that affect the learning outcomes was highlighted. This is because after analyzing the data, it was confirmed that, for example, extracurricular activities or meta-influences could play the same important role in the formation of certain competencies as structured ones. Currently, there are attempts to integrate other practices such as Work-integrated Learning (WIL) into engineering education in addition to entrepreneurial interventions. The effectiveness of WiL also depends on many parameters, including other curricular elements or extracurricular

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elements or meta-influences. Therefore, the results of this study, which support the fact that different types of activities are equally important in the formation of different types of competencies, including accidental competencies and even accidental incompetencies, can help learning designers and educators to understand the important role of holistic approaches in developing and delivering educational programs as well as understand the important role of holistic and complex evaluating approaches.

Limitations

The primary limitation derives from the fact that the research focuses on beliefs while simultaneously defining acquired competencies. As there is a perception that beliefs do not always impact the actions of an individual, it is valuable to observe a participant or investigate a reported behaviour (Wyatt, 2015). Therefore, in order to define the connection between beliefs and real actions, studies of the educational context often consist of two components: exploring how participants state their beliefs and their behaviour after completion of the program (Guanes et al., 2021). Since the study is preliminary, however, it did not involve exploration of individuals' behaviour since it was conducted immediately after the end of the program. This research is therefore the basis for further study of the behaviour of participants after taking part in the program. This develops an understanding of the relationship between their beliefs and reported behaviour and makes further conclusions on acquired competencies.

Another limitation is related to the sample size, as only one program with students from the same university was investigated in this study. Since the outcomes of the programs should have been aligned with the graduate attributes of the faculty and the university, some identified accidental competencies might be relevant only for a given university. As a result, an extension of the sample would be beneficial.

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Engineering education and non-education research: a scientometric comparison of 7 countries

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ABSTRACT

CONTEXT

Over the last decade there has been a growing interest in the global evolution of engineering education research (EER) as a field of inquiry and a variety of approaches have been adopted to study this process.

PURPOSE OR GOAL

Studies mapping engineering education research in different parts of the globe have mostly been human-curated and thus limited to relatively small samples. Recent advances in computer data analysis permit machine-curated study of larger data sets and this paper adopts such an approach.

APPROACH OR METHODOLOGY/METHODS

The study assembles scientometric data on EER publications in Australia and compares it with that of 6 European countries: 4 Nordic countries (Denmark, Sweden, Finland, and Norway) and 2 Southern European countries (Portugal and Spain). This is achieved by identifying 651 authors that published in 13 leading EER journals in the period 2018-2019 and then analysing their entire research output throughout their careers in both educational and non-educational publications - 32934 publications in all.

OUTCOMES

There are notable differences in the career evolution and EER output across the 7 countries and these in turn influenced the h-index values of the researchers in our sample. For Australia, as in the cases of Finland, Norway and Spain, engineering academics published over three times more non-educational than educational. This in turn affected their h-index values. In addition, our data suggest that Australian educators, along with those in Portugal, Sweden and Spain, are typically 6 to 8.5 years on average into their publishing careers when they publish their first educational work whereas in the case of Denmark, Finland and Norway this tends to occur earlier in their careers.

CONCLUSIONS

Scientometric findings acquired through analysis of large bodies of data, as in this study, can have a valuable role in informing both institutional and national policy decisions regarding support for engineering education research and can also help individual engineering educators in planning their own research career.

KEYWORDS

Scientometrics, citation analysis, engineering education research, Australia

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Introduction

Over the last decade interest in the evolution of engineering education research (EER) has been growing and a variety of approaches have been adopted to study this process. Froyd and Lohman (2014) used criteria for defining the field of science education research (Fensham, 2004) to point out that while engineering education has been seen as an area of interest for educators since the end of the 19th century, over the last two decades there have been significant indicators of a transition to an interdisciplinary, more scholarly field of scientific inquiry into engineering education. Borrego and Bernhard (2011) have compared Northern and Central European approaches to EER with those of the U.S. using a framework from the European *didaktik* tradition, which focuses on answering the w-questions of education. Borrego and Olds (2011) employed an analysis of National Science Foundation funded projects as a way of characterizing development in EER in the US while Williams and Alias (2011) used a scientometric approach to track the evolution of EER in Malaysia.

Neto and Williams (2011) analysed historical studies of the European Journal of Engineering Education (EJEE) to provide insights on the European context. Other studies looked at specific European national contexts (Williams, Wankat and Neto, 2018; Edström et al. 2016; van Hattum-Janssen, Williams and Oliveira, 2015; Nyamapfene and Williams, 2017).

Strobel and colleagues at Purdue University applied bibliometric analyse to gauge the presence of interdisciplinarity in EER (2012) and the growth of loose networks within the EER community (2011).

The present study examines data gathered by using a quantitative scientometric approach to understand the characteristics of EE researchers who were affiliated with tertiary institutions in Australia. A small set of data from the Australian context was earlier reported based on analysis of three EER journals (Valentine, 2020) whereas the present study considers data from 13 publications. This allows us to create a more granular profile of Australian EER output. To put the data in context we compare the Australian figures with those previously collected by the authors relating to EER publication patterns of researchers in two European contexts: researchers based in two Southern European countries (Valentine and Williams, 2021a) and those in four Nordic ones (Valentine and Williams 2021b).

Methodology

Data Sources

Data were gathered from the Scopus API (http://api.elsevier.com and http://www.scopus.com) during January-March 2021 using the pybliometrics Python library (Rose and John, 2019). Data was gathered over several months due to limitations of the Scopus API.

A comprehensive list of EER publications from each of the respective countries was required. To create this list, thirteen research journals relevant to the field of engineering education (EE) were consulted (Table 1). For each journal, the list of all authors who had published at least one article between 2019-2020 (inclusive) was considered. The tertiary institutions of each author were checked, and this was used to establish which countries the author was affiliated with.

Comprehensive details for each author were then retrieved from Scopus. This included their full publication history. For subsequent analysis, only articles, conference papers, reviews, book, and book chapters were included. Other publication types such as editorials, letters, erratum or notes were excluded. Key details of each publication were captured including document title, source title (e.g. JEE), document publication year, document type (e.g. article), author keywords, subject category, citation count (note that this can change over

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time; this is a limitation of the study), and DOI. A total of 32934 publications until the end of 2020 were captured for the 651 authors.

Journal	Finland	Spain	Portugal	Denmark	Norway	Australia	Sweden
Advances in Engineering Education	0	0	3	0	0	0	0
Australasian Journal of Engineering Education	0	1	0	0	0	29	0
Education for Chemical Engineers	2	100	7	8	0	2	0
European Journal of Engineering Education	14	22	27	7	4	43	20
Global Journal of Engineering Education	1	2	0	0	0	5	0
IEEE Transactions on Education	1	19	2	2	0	12	2
International Journal of Electrical Engineering Education	1	31	0	0	0	4	0
International Journal of Engineering Education	3	218	10	4	3	11	9
International Journal of Engineering Pedagogy	2	1	11	0	0	1	0
International Journal of Mechanical Engineering Education	0	0	0	0	1	1	0
Journal of Engineering Education	0	0	0	4	0	0	0
Journal of Engineering Education Transformations	0	0	0	0	0	2	0
Journal of Professional Issues in Engineering Education and Practice (now Journal of Civil Engineering Education)	0	8	0	0	1	8	0
Total (duplicates removed)	23	397	58	23	9	111	30

Table 1: Engineering education journals where authors from each country were sourced from (note it was possible that authors may have published in multiple journals)

Data Analysis

Publications were subsequently classified as being either educationally focused or non-educationally focused. The purpose of this was to build an understanding of how educational and non-educational publications contribute to the research track record of each author. Because this involved analysis of thousands of publication records, it was not feasible to do this manually. A computer aided approach was therefore required to assist with automating the process. Accordingly, an algorithm was created, using a combination of keyword search and Scopus data fields.

An extensive manual scoping search involving several iterations (and testing) was undertaken to identify suitable Scopus fields and keywords (this is similar to how a scoping search is implemented for systematic literature reviews).

A publication was deemed to be educationally focused if:

1. *any* of the following Scopus fields:
   'authkeywords', 'subject_areas', or 'publicationName'
   included *any* of the following terms
   - 'education', 'student', 'teach', 'tutor', 'novice', 'MOOC', 'ASEE', 'SEFI'

   OR

2. the Scopus 'title' field included the term 'learn'
   - AND the term 'learn' appeared at once outside the term 'machine learn'

The inclusion of criterion 2 was necessary because "learn" was identified as a term that was absolutely essential for some papers to be correctly flagged as educational (i.e. there were no other terms which may have worked). However, an issue arose where papers in "machine learning" were then often flagged as educational when they were not (this is also why "learn" was restricted to the 'title' field). To try and address this issue, it was required that 'learn'

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appeared at least once in the title outside the context of the term ‘machine learn’. This increased the accuracy, but some machine learning publications were still incorrectly flagged as being educationally focused.

To test the efficacy and accuracy of this algorithm (compared to human judgement), a random subset of 1000 publications were manually coded by the authors as being either educationally focused or non-educationally focused. This was then compared to the output of the algorithm.

- 400 papers from the Portugal, Spain authors were checked
    - there was a 99.7% agreement between human judgement and the algorithm
- 300 papers from the Denmark, Finland, Norway, Sweden authors were checked
    - there was a 97.3% agreement between human judgement and the algorithm
- 300 papers from the Australian authors were checked
    - there was a 98.3% agreement between human judgement and the algorithm

There was an overall 98.6% agreement between authors and the algorithm (11 false positives, and 4 false negatives). This was deemed to be reasonable accuracy for analysing the larger dataset and making conclusions (with the acknowledged limitation that about 1.4% of publications may be incorrectly flagged).

Following this, information for each of the 651 authors was then established, including:

- the number of years the author had been publishing, and when they published their first educational paper;
- the distribution of the publications by document type including articles, conference papers, book chapters, books, and reviews;
- the percentage of publications which were educationally focussed;
- the number of citations on educational and non-educational publications;
- the author’s overall h-index, and that of their educational publications, and non-educational publications.

Results

Ratio of educational and non-educational publications per country

Country	Population (million)	Educational Publications	Non-educational Publications	Total Publications
Australia	26	1377	4924	6301
Denmark	6	318	663	981
Finland	6	334	1066	1400
Norway	5	98	307	405
Portugal	10	667	1690	2357
Spain	47	4479	15909	20388
Sweden	10	493	609	1102
Total		7766	25168	32934

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Table 2: The number of publications which are educationally focused and non-educationally focused, per country

Overall, authors from each country published more non-educational publications than educational publications (Table 2). While Sweden published slightly more non-educational publications compared to educational publications, some other countries had published over 3 times as many non-educational publications (Australia, Finland, Norway, Spain) as educational publications.

Average author percentage of publications which are of each document type

Country	Number of Authors	Type of Document	Article	Book	Chapter (Book)	Conference Paper	Review	Total
Australia	111	Educational	28.2%	0.1%	2.1%	15.8%	1.5%	47.7%
		Non-educational	27.5%	0.2%	1.5%	21.3%	1.7%	52.3%
Denmark	23	Educational	27.9%	0.3%	5.7%	24.8%	0.9%	59.7%
		Non-educational	24.0%	0.1%	6.2%	7.1%	2.9%	40.3%
Finland	23	Educational	32.9%	0.0%	0.8%	29.4%	0.1%	63.2%
		Non-educational	14.9%	0.0%	2.4%	18.7%	0.8%	36.8%
Norway	9	Educational	21.9%	0.0%	4.6%	11.3%	0.8%	38.6%
		Non-educational	22.8%	0.0%	2.9%	35.2%	0.5%	61.4%
Portugal	58	Educational	18.8%	0.0%	1.2%	19.8%	8.7%	48.4%
		Non-educational	29.1%	0.1%	2.6%	18.5%	1.4%	51.6%
Spain	397	Educational	24.1%	0.0%	0.6%	9.3%	0.3%	34.3%
		Non-educational	43.4%	0.0%	1.6%	18.9%	1.7%	65.7%
Sweden	30	Educational	29.2%	0.6%	1.4%	34.0%	0.6%	65.7%
		Non-educational	18.5%	0.0%	0.7%	14.0%	1.1%	34.3%

Table 3: The mean percentage of authors' publications which are educationally focused for each document type, per country

Table 3 shows that authors from Denmark, Finland and Sweden publish on average more educational papers at 59.7%, 63.2%, and 65.7% of their overall total, respectively. Conversely, authors from Australia, Norway, Portugal and Spain publish less educational papers at 47.7%, 38.6%, 48.4% and 34.3% of their overall total on average, respectively.

h-index

For each country, the h-index of non-educational publications is higher than the h-index of educational publications (Figure 1). While the difference between mean values is relatively large for Australia, Denmark, Norway, Portugal and Spain, it is closer for Finland and Sweden. The differences between h-index of non-educational publications and h-index of educational publications for each country was evaluated for statistical significance using the paired samples t-test with IBM SPSS 26. It was found that there was a statistically significant difference for Australia ($t=-4.244$, $df=110$, $p<0.001$), Norway ($t=-2.468$, $df=8$, $p=0.039$), Portugal ($t=-3.553$, $df=57$, $p<0.01$), and Spain ($t=-13.221$, $df=396$, $p<0.001$), but not Denmark, Finland, or Sweden. Considering all 651 authors, while the h-index of educational

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publications was significantly correlated with the overall h-index (Pearson Correlation=0.196, p<0.001), the h-index of non-educational publications was a lot more strongly correlated with the overall h-index (Pearson Correlation=0.956, p<0.001).

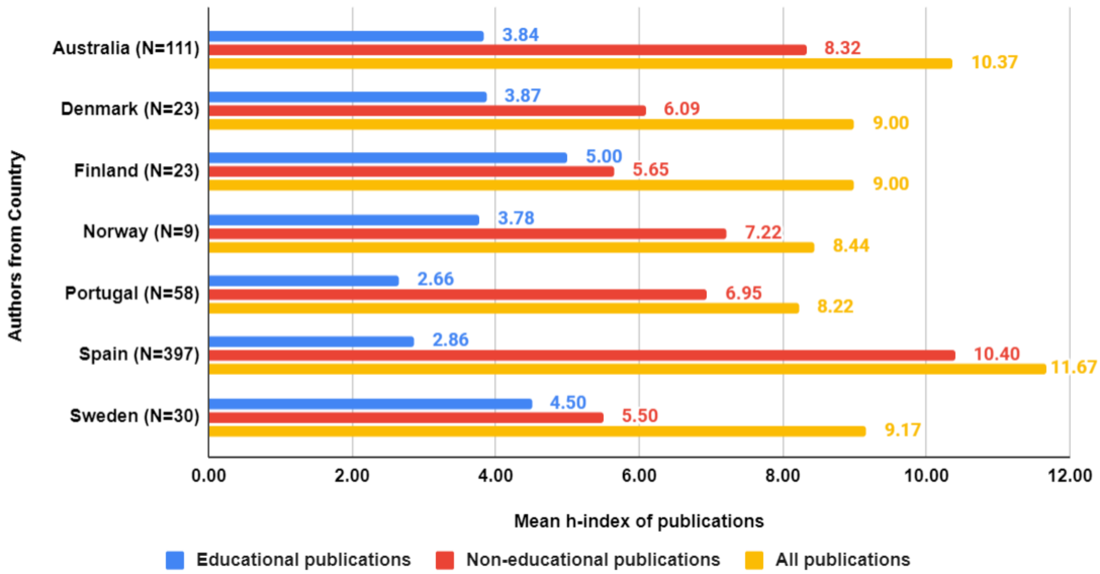

Figure 1: Mean h-index for each author per country for (i) all publications, (ii) educational publications, and (iii) non-educational publications

Evolution of Publication Careers

Years into Career Until First Educational Publication	Australia (N=111)	Denmark (N=16)	Finland (N=21)	Norway (N=9)	Portugal (N=58)	Spain (N=397)	Sweden (N=30)	Total
0	43	13	15	2	18	119	13	223
1-5	17	4	3	5	9	79	4	121
6-10	19	3	2	2	8	59	4	97
11-15	16	1	1	0	11	57	5	91
16-20	9	0	1	0	7	44	2	63
21+	7	2	1	0	5	39	2	56

Table 4: Mean number of years into a researcher's career before an educational publication is published (counting from the date of their first research publication) (N is number of authors)

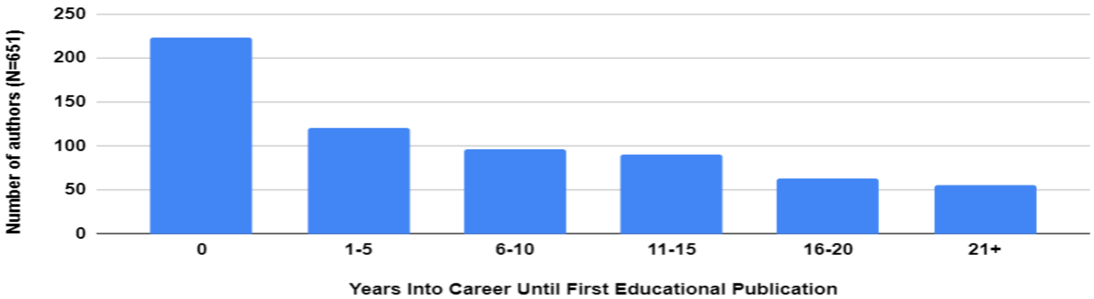

Figure 1: Mean number of years into a researcher's career before an educational publication is published (counting from the date of their first research publication)

Table 4 and Figure 1 demonstrate that many authors begin their careers publishing educational research, while others commence educational research at a later time during their career. Figure 2 shows the mean of years which authors from each country take until publishing their first educational publication, while Table 5 also shows the median number of years. Median values of 0 may be attributed to the small sample sizes of these countries.

Number of years until educational publication	Australia (N=111)	Denmark (N=16)	Finland (N=21)	Norway (N=9)	Portugal (N=58)	Spain (N=397)	Sweden (N=30)
Mean	6.44	4.26	3.43	3.56	8.26	8.17	7.60
Median	4.00	0.00	0.00	2.00	6.00	6.00	4.00

Table 5: Number of years into a researcher's career before an educational publication is published (N is number of authors)

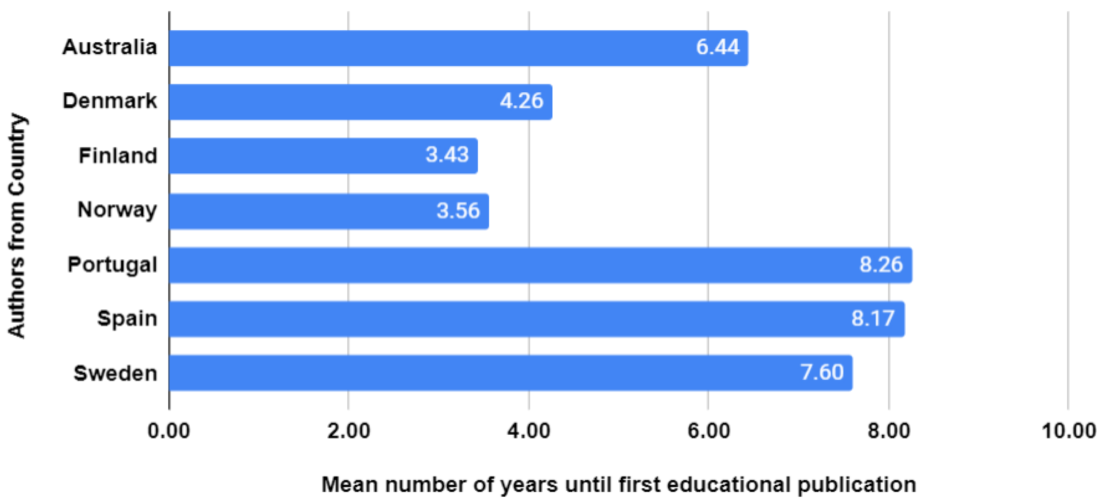

Figure 2: Mean number of years into a researcher's career before an educational publication is published

Limitations

Although we believe these data provide a valuable snapshot that allows us to compare the publishing patterns in these countries, as the number of authors is relatively small in some

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cases this can reduce the generalisability of the findings. We note for example that whereas Valentine and Williams, 2021b studied data from 12 EER journals, for analysis in this paper we added a further journal (Education for Chemical Engineers) to provide a larger sample; while this led to similar overall findings there are some minor differences between the results here and those of the smaller sample.

Conclusions

With regard to the ratio of education focused and non-education focused publications (Table 3), there is considerable variation between the 7 countries: authors from Denmark, Finland and Sweden on average publish more educational papers whereas those from Norway and Spain publish significantly more non-educational. In the case of Australia and Portugal, there is a small preponderance of non-educational publications. These data help us begin to characterise the current research culture in each country viz a viz research publication by engineering educators.

Taking population differences into account, output from Australian EER scholars is broadly similar to that of the other 5 EU countries. Globally, Spain appears to be something of an outlier, even taking into account the fact it has the largest population: it publishes a large number of journal articles, almost exclusively in two technically focussed journals, while conference publications from Spain are rather lower than those of the other countries. This is probably due to a nationally defined career progression system there that strongly privileges journal publications in both educational and non-educational fields (Valentine and Williams, 2021a).

The above publication patterns in turn affect the h-index of the 651 authors included in our study. In addition, our data suggest that non-educational publications play more of a role in determining the h-index than educational ones as they tend to acquire more citations. This reflects a generalized phenomenon that was noted in the 1970s by citation analysis pioneer Ernest Garfield – founder of the ISI system and credited with being the initiator of the journal impact factor concept – when he observed that “citation potential can vary significantly from one field to another.” (Garfield, 1979). In general engineering education articles tend to have much lower citation rates than those in specialized engineering fields. This can be seen in the impact factor of journals: for example, the most cited journal in the field of EER, Journal of Engineering Education, has a 2020 impact factor of 3.146 while those of the three highest ranked in the field of Mechanical Engineering are Nature Materials 43.84, Materials Science and Engineering: R: Reports 36.21 and Advanced Materials 30.85.

The mean number of years until educational publication is in the range 6 to 8.5 years for Australia, Portugal, Spain and Sweden while engineering educators in Denmark, Finland and Norway on average begin earlier in their academic careers. This may be due to the increasing number of PhD programs in engineering and STEM education provided in these countries: the Engineering/STEM Education Graduate Programs online resource curated by the University of Arizona lists 4 programs in Sweden and one in Denmark but none for the other countries. These results merit further study.

To conclude, scientometric findings acquired through analysis of large bodies of data, as in this study, can have a valuable role in informing institutional and national policy decisions regarding support for engineering education research and can also help individual engineering educators in planning their own research career.

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Implementation of a Virtual Mechanics Laboratory for a first year undergraduate engineering subject using MATLAB App Designer

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ABSTRACT

CONTEXT

In wake of the COVID-19 situation in 2020, when universities were faced with the transition from face-to-face learning to online delivery, many educators found themselves tasked with having to convert previously classroom-based teaching material to an equivalent online adaption. The transition was particularly challenging in a first-year engineering subject where hands-on laboratory experiments play an important part in the learning of basic mechanics principles as a foundation in engineering. Adaptation of physical hands-on experiments into the form of interactive virtual simulations was necessary to ensure students had an equally comprehensive laboratory experience in the online delivery mode.

PURPOSE

This paper describes the development and implementation of a virtual laboratory for a set of mechanics experiments as an alternative to the physical hands-on laboratory. The interactive simulation application replicates the procedures of a physical mass-spring system investigation that applies two fundamental mechanics concepts, resultant forces and principle of moments.

APPROACH

The virtual laboratory application is a user-friendly graphical user interface (GUI) integrated with a program code that models a physical spring system, developed in MATLAB App Designer. Key features of the application include animated outputs and virtual measurement tools that emulates the procedures of the actual experiment and MATLAB modelling that takes into account inconsistencies that may arise in real measurements. For deployment purposes, the simulation program in App Designer was compiled into a standalone executable and run using the MATLAB runtime environment.

OUTCOMES

The virtual laboratory activity was successfully conducted during the online workshop classes in the first-year engineering subject at the University of Melbourne across a cohort of over 600 students. The simulation application in the virtual setting achieved similar learning outcomes as the experiments in the physical setting, but the activity was completed in significantly shorter times as compared to the expected physical hands-on.

CONCLUSIONS AND RECOMMENDATIONS

The virtual experiments offered efficiencies over physical experiments in terms of minimising experimental procedure delays and allowing more focus on concepts and theories but unavoidably compromising other hands-on experience such as equipment set-up, calibration, real-world experimental observation, and troubleshooting. For a more comprehensive virtual laboratory experience, future work to model the virtual environment more accurately to represent real world behaviour is recommended.

KEYWORDS

Virtual laboratory, MATLAB App Designer, simulation application.

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Introduction

In April 2020, when movement restrictions came into effect during the COVID-19 pandemic in Victoria, Australia, the majority of courses offered by the University of Melbourne were forced to transition from face-to-face learning to online delivery at short notice. Educators suddenly found themselves faced with the challenging task of having to convert previously classroom-based teaching material to an equivalent online adaption within a limited time frame. Whilst lectures could be offered online in the form of recorded or streamed videos, hands-on laboratory experience was more difficult to transition over. The transition was particularly challenging in a first-year engineering subject where hands-on laboratory experiments play an important part in the learning of basic mechanics principles as a foundation in engineering. This paper documents the adaptation of three physical hands-on experiments in a first year engineering subject into virtual laboratory experiments, with the aim to provide students an equally comprehensive laboratory experience in the online delivery mode.

Within the process of transitioning to online delivery mode, various forms of virtual laboratory substitutes were considered, including video pre-recordings of the laboratory experiments where students observe experimental procedures and record measurements and data from it. Laboratory video recordings have thus far been shown to be effective as pre-laboratory preparation, for example in studies by Schmidt-McCormack,et al. (2017) and Rodgers, et al. (2020), but not so much about their use as a complete substitute for physical laboratories. For the author's primary purpose of transitioning hands-on laboratory to a virtual equivalent, an interactive simulation application that replicates the actual experimental process was favoured over video pre-recordings.

The inspiration behind the development of the interactive simulation application stemmed from the commercially available Physics Education Technology (PhET) Interactive Simulations project (PhET Interactive Simulations, 2020). Although simulations available within the PhET collection could be used to demonstrate the engineering principles of interest, they were insufficient to replicate the existing physical laboratory experiments that had to be transitioned online. This shortfall led to the author's development of a suite of experiments within a custom simulation application that has been specially designed to meet the needs of the university's first year engineering subject in demonstrating specific mechanics principles.

The simulation application was set up to allow students to essentially perform the experiment procedures as they would in the actual physical version. MATLAB App Designer, a graphical user interface development environment (Mathworks, 2020) was the tool chosen for the development of the application.

Modelling and Analysis

The basic mechanics principles of resultant force and moments are covered as part of the context in a first-year engineering subject at the University of Melbourne. To enhance the theoretical learning of these concepts, students perform a laboratory experiment applying knowledge of spring force, resultant force and the principle of moments to estimate the weight of an object.

To provide some perspective on the laboratory activities in the original classroom setting, students perform a suite of three experiments, first the Hooke's Law experiment followed by two experiments using a set of custom designed wooden spring scales.

In the Hooke's Law study, students perform the standard experimental procedures to determine the characteristics of a simple spring from the force versus extension graph governed by the linear spring equation below (Loyd, 2008),

$$F = kx + c \tag{1}$$

where F is the applied force, x is the spring extension with the applied force, k is the slope of the graph, that represents the spring constant, and c is the y-intersect of the graph.

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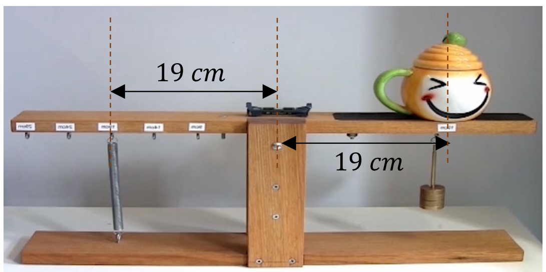
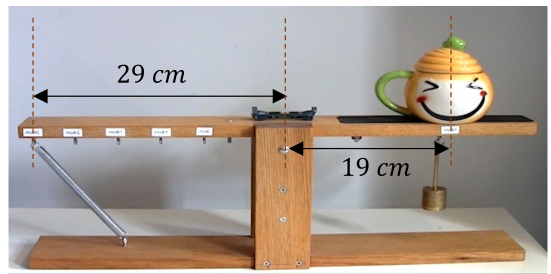
Following that, the spring is placed on one end of a wooden balancing scale that acts like a see-saw to balance the combined weights of an unknown weighted object (a container filled with sand) and known brass weights, as shown in the layouts (a) and (b) in Figure 1. The two configurations of spring placement in two separate experiments will apply different mechanics principles, namely:

(a) equating resultant forces – spring and weights placed at opposite ends at an equal distance (of 19 cm) from the centre of balancing scale.

(b) a combination of resolving forces and equating moments – spring attached with an inclination at a distance of 29 cm from the centre of the balancing scale while the weights remain at 19 cm.

Note that the unknown weights for spring scales configurations (a) and (b) will be different as they are two separate experiments.





(a) (b)

Figure 1: Two configurations of the Spring Scales experimental set-up

To illustrate the mechanics principles behind the spring scales experiments, the following section will derive the governing equations of the two spring configurations based on the virtual simulation application, which is modelled after the actual physical laboratory set-up.

In the virtual set-up for configuration (a) as shown in Figure 2, with the scales in the balanced position, the spring force on one end balances the weight of the unknown object and the known (brass) weights on the opposite end, resulting in the equation

$$F_{spring} = F_{unknown} + F_{known\ weights} \tag{2}$$

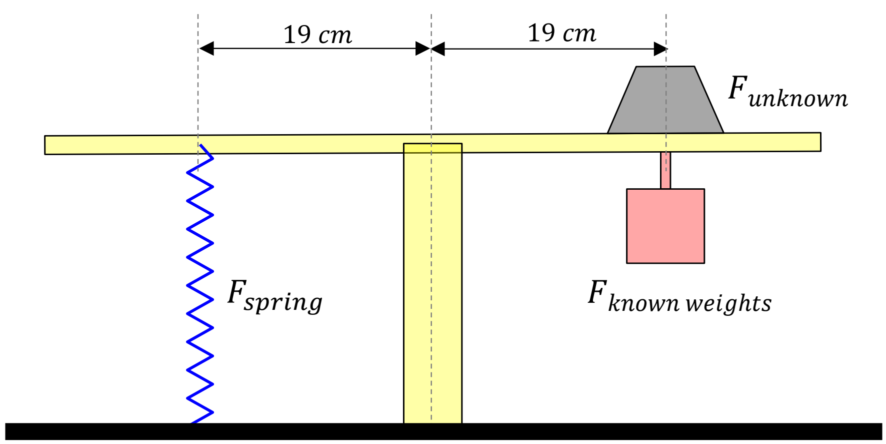


Figure 2: Virtual laboratory set-up for spring configuration (a)

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For spring configuration (b) as shown in Figure 3, with the introduction of spring inclination and a distance factor, applying the slightly more complex principle of equating clockwise moments to counter-clockwise moments along with resolution of forces results in the following equation when the scale is balanced,

$$F_{spring} sin\theta \times 0.29 = (F_{unknown} + F_{known\ weights}) \times 0.19 \quad (3)$$

where θ is the measured angle between the spring axis and the horizontal platform of the spring scales.

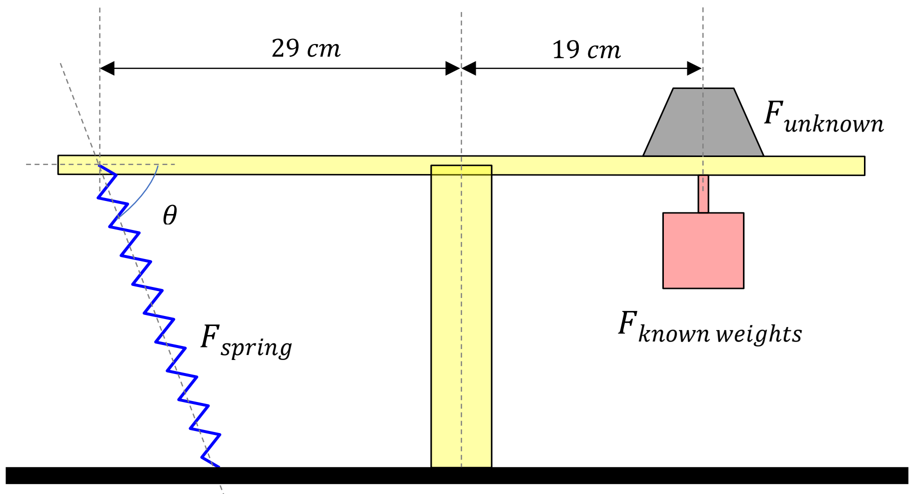

Figure 3: Virtual laboratory set-up for spring configuration (b)

The known spring characteristics from the Hooke's Law experiment, the known brass weights added to balance the spring scales and other measured parameters such as distance and spring angle allow the unknown object's weight to be calculated from the governing equations.

Design Considerations

The main intention behind the development of the virtual laboratory was to provide an environment where students can experience a virtual equivalent of the practical procedures of the physical laboratory, covering 3 key elements, experimental execution, measurement methods and real world non-ideal behaviours. In the virtual laboratory application, these considerations were realised through an interactive graphical user interface (GUI) front that combined animated response sequences with virtual measurement tools and background system modelling that incorporated random fluctuations to take into account inconsistencies that may arise in real measurements.

An important aspect of the virtual laboratory that the author took special care in designing was the user interface in accordance to recommended usability requirements (Cooper, 2005). According to Cooper, the user interface needs to enable the student to carry out all the tasks and make all the observations that are necessary to achieve the learning objectives of the experiment. It is important that students focus on performing the activity rather than on the use of the software. For this reason, the virtual laboratory interface was designed using mainly click buttons and drop-down menus to offer simple and straightforward operation.

Final considerations for the virtual laboratory were the scalability and the accessibility aspects of the application, for deployment to a large cohort of over 600 students within the subject. The way a remote experiment is designed will govern its accessibility to nearly all users irrespective of any disability (Cooper, 2005). For this reason, a stand-one executable application was

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deemed the best option as all students are provided access to the university's remote desktop server that contains the necessary software to run MATLAB executable files.

Software Description

The layout of the virtual laboratory's GUI was created using the set of interactive user interface (UI) components available in MATLAB App Designer (version R2019b). The GUI development environment allowed the integration of mathematical models that governed the behaviour of the spring and balance scales systems developed in MATLAB code for control of the simulation.

The default interface upon loading the virtual laboratory application is the Hooke's Law Experiment tab, as shown in Figure 4. In the experiment, users are provided with a selection of 6 mass values in a dropdown menu to load the spring with.

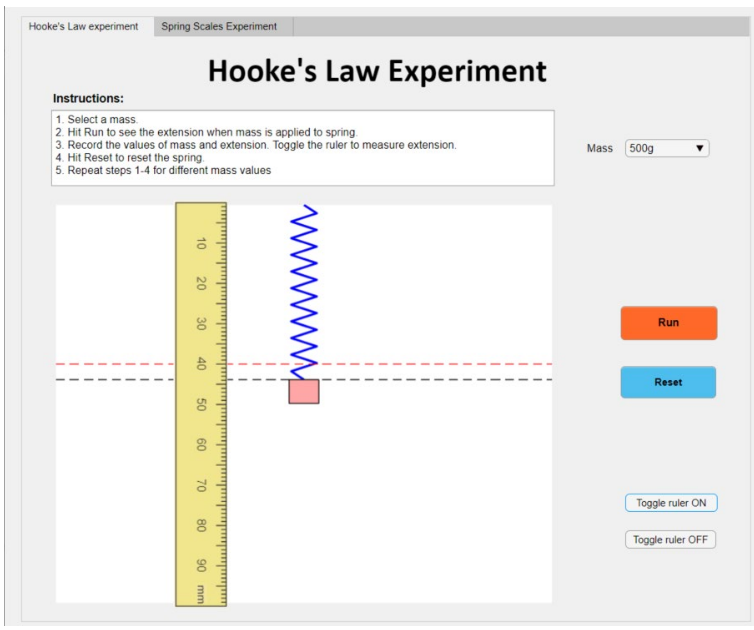


Figure 4: Hooke's Law Experiment tab

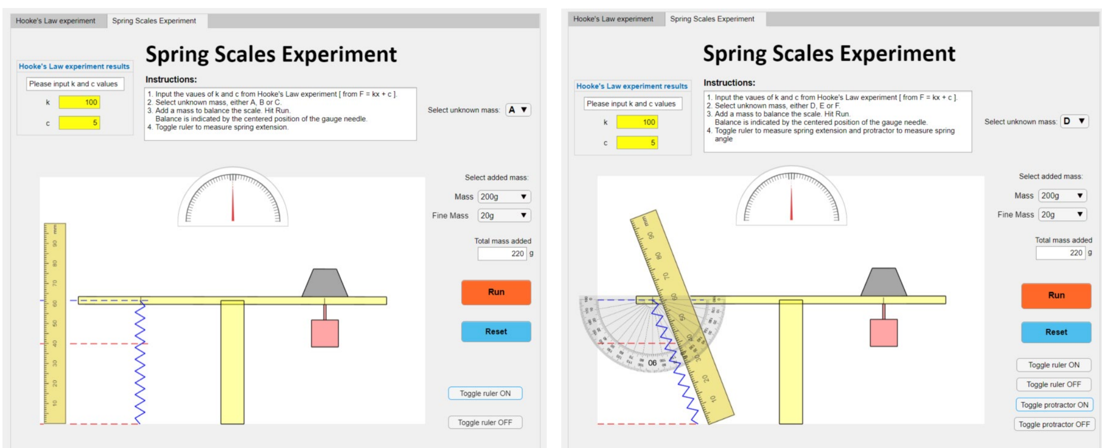
Whenever the user clicks on the Run button in the GUI, a background MATLAB function is invoked to process the applied mass and perform the necessary calculations to produce the appropriate animated spring extension response. The MATLAB code modelling the animated spring behaviour was adapted from Morales's spring algorithm to plot and animate a 2D-spring (Morales, 2020), consistent with the linear spring behaviour described in equation (1) to generate the value of spring extension for each respective applied mass. A random noise factor of between 0.8 and 0.9 was introduced into the c value of the equation to generate non-ideal behaviour in the linear spring, as a way of incorporating real-world measurement inconsistencies, shown in the equation below.

$$x = \frac{F - (c \times \boldsymbol{random\ factor})}{k} \tag{4}$$

A virtual ruler that toggles ON and OFF then allows for the measurement of spring extension, x, when the respective load, F, is applied. The set of 6 measurements of F and x from the GUI is used to plot a best fit linear force versus extension, $F - x$, graph to estimate the spring characteristics, k and c, as described in equation (1). To provide some variant within the experiment, 4 different springs were programmed into the simulation, of which one will be randomly loaded each time the application is run. The spring characteristics, k and c, obtained here will subsequently be used to calculate the spring force, F_{spring} in the spring scales experiments.

Following the completion of the Hooke's Law experiment, a second tab within the virtual laboratory application provides the interface to the spring scales experiments as shown in Figure 5. For each of the spring configurations (a) and (b) respectively, users choose one of three different objects of unknown weight to measure. Additional known mass values to balance the scale are provided in a dropdown menu. When the user clicks the Run button, the animated spring scales will tilt at an angle controlled by the magnitude of the forces applied at opposite ends of the scale platform. In order to achieve balance, loading at both ends must be equal, and this is visually indicated by the red gauge needle pointing at the centre position.

For configuration (a), a ruler that toggles ON and OFF is provided for the measurement of the extension of the stretched spring when the scale is balanced, whose value when applied to the calculation of F_{spring} in Equation (2), will yield the value of the unknown weight. Whereas for configuration (b), two toggle ON/OFF measurement tools, a ruler and protractor for measurement of the spring extension and inclination angle, θ, respectively, are necessary for the calculation of the unknown weight according to Equation (3).



(a) (b)

Figure 5: Spring Scales Experiment tab

For deployment to students, the application source code in App Designer was compiled with the MATLAB Application Compiler into a standalone executable and run using the MATLAB runtime environment (Ver 9.7 Windows 64-bit) in the online workshop classes.

Outcomes and discussion

The virtual mechanics laboratory activity was successfully conducted during the online workshop classes across the 2020, Semester 2 cohort of over 600 students, working in groups of 3. Within a workshop class, students are allocated 90 minutes to complete the tasks in each of the experiment configurations (a) and (b), which are to determine the spring characteristics of a random spring and to predict the unknown weight of an object.

Table 1 summarises the outcomes from the 220 student groups within the cohort.

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Table 1: Summary of outcomes from students conducting the virtual laboratory

Spring Scales Experiment	Outcomes	Average time taken to complete experiment
Configuration (a)	All 220 groups (100%) obtained spring characteristics within the acceptable tolerance of ±15% and predicated the weight of an unknown object within the acceptable tolerance of ±20g.	65 minutes
Configuration (b)	218 groups (99%) obtained spring characteristics within the acceptable tolerance of ±15% and predicated the weight of an unknown object within the acceptable tolerance of ±30g.	75 minutes

In successfully completing the two sets of virtual laboratory experiments, students have demonstrated their ability to:

- record a spring characteristic data set by applying varying load to a spring and taking measurement readings,
- plot a measured data set, determine a best fit line, and apply Hooke's Law principle to obtain the parameters that characterise a spring,
- set up a balanced spring scale, take the necessary measurement readings and apply either the mechanics principle of resultant force or resultant moment to predict the unknown mass of an object.

The learning objectives achieved from the virtual laboratory has tracked closely to the objectives of the original hands-on laboratory, thus validating that the virtual laboratory was equally effective in providing conceptual understanding of the relevant mechanics principles as the original physical laboratory previously. This is supported by studies from Triona and Klahr, (2003 and 2007) that suggest replacing physical laboratories with virtual laboratories does not affect the acquiring of conceptual knowledge.

From Table 1, a slightly higher percentage of groups produced results within expected tolerances for experiment configuration (a) and within a shorter completion time as compared to that of configuration (b). This observation is attributed to the additional angle measurement step and higher level complexity mechanics concepts required for the analysis tasks in configuration (b), which saw the increased average completion time and 2 groups failing to produce results within the time period allowed.

Overall observation on the time taken by students to complete the virtual laboratory experiments revealed that average completion time is shorter as compared to the equivalent physical experiments, which averages 90 minutes in previous semesters. To understand where the time discrepancies lie, the different natures of tasks performed in both the virtual and physical experiments are split into two distinct categories:

- Tasks that require performing an action - applying load and taking measurement readings
- Tasks that are analytical in nature - entering data, plotting graph, finding the best fit line, applying equations, and performing calculations.

In the author's opinion, the time taken to complete the analytical tasks in the virtual setting would not significantly differ from that of the physical setting due to the nature of these tasks that are not dependent on hardware or equipment, suggesting that the action tasks are the main factors for the shorter completion time in the virtual experiments. This is consistent with observations that measurements could be made with the click of a button in the virtual interactive GUI as opposed to the time required to set up and fine-tune or calibrate equipment in the physical setting. The virtual laboratory provided the environment for students to

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experience all the procedures in conducting the mechanics experiments but was unable to offer hands-on laboratory skills such as planning equipment set-up, calibration, real-world experimental observation, and troubleshooting. This is where the affordances of virtual laboratory versus physical laboratory can be argued. Virtual laboratories offer efficiencies over physical experiment by providing more focus on the testing procedures and concepts without the unnecessary delays of experimental set up. (Ibrahim, 2011; Ton, Linn, & Zacharia, 2013; Klahr, Triona, & Williams, 2007). Additionally, it provides an environment for students to explore both practical and theoretical concepts with a wider selection of materials and specimen sizes, an example being the introduction of 4 different springs for use in experiments as opposed to the original 1 used in the classroom setting.

In terms of the usability, scalability and accessibility aspects that was part of the initial design considerations, all cohort groups managed to access and run the executable application within university resources without requiring additional external software or support during their respective workshop classes. The MATLAB Runtime environment to run the standalone executable was provided by the University's remote server, hence there was no need for students to download and install a separate software. It is worth noting that the virtual mechanics laboratory was subject to a series of usability testing by 10 tutors prior to its use in the online workshop classes. This was in accordance with Cooper's (2005) recommendation of usability testing prior to deployment to provide insights into the way in which users will interact with the software and the experiment, which cannot be foreseen by developers. Feedback from the pre-workshop testing exercise has proven valuable in improvement and fine-tuning efforts towards the successful end product.

The final consideration is how accurate the virtual experiments were in modelling after the physical ones. Whilst the ideal system behaviour was easily modelled using standard equations, real world experimental inconsistencies were not so easily replicated. Although the simplified random noise factor that was incorporated in the simulation may not the best representation of actual behaviour, it serves as an introduction to non-ideal behaviour and was a practical option under the given circumstances. This is an area that could benefit from more in-depth investigations.

Concluding remarks and recommendations

Given the limited time allowed for the transition from face-to-face classroom learning to online delivery, the virtual mechanics laboratory was a viable alternative that has provided first-year engineering students the opportunity to experience experimental procedures that demonstrated the intended mechanics principles. The virtual experiments offered efficiencies over physical experiments in terms of minimising experimental procedure delays and allowing more focus on concepts and theories but unavoidably compromising other hands-on experience such as equipment set-up, calibration, and real world behaviour.

For a more comprehensive virtual laboratory experience, future work should be considered in areas relating to real world practicalities such as:

- modelling a more accurate physical environment within the virtual laboratory to represent real world behaviour, to include physical modelling of spring dynamics to replace the simplified random noise factor and introduction of modelled frictional losses at the pivot joint of the spring scales.
- incorporating additional tasks or assessments in the virtual laboratory associated with awareness and appreciation of real world practicalities. With the excess time remaining from completing the prescribed experimental tasks, students could be provided with a video recording and empirical data from physical experiments for comparison studies.

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Evaluation of H5P interactive videos in enhanced e-learning of an environmental engineering course during COVID-19 pandemic

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ABSTRACT

CONTEXT

In the autumn session of 2020, COVID-19 outbreak forced the transition of teaching and learning from face-to-face mode into remote delivery in Australian universities. Over this unplanned, unprepared, and rapid move to remote delivery for lecturers and online learning for students, many strategies, designs, and technologies were applied to replace conventional classes, tutorials, laboratory classes, project assignments, and assessments.

PURPOSE OR GOAL

This study investigated the design, use and impact of videos for lectures, tutorials, and laboratory experiments for a combined undergraduate and postgraduate Environmental Engineering course during the COVID-19 pandemic in 2020. The course was delivered through both face-to-face and online delivery modes, which we employed conventional video recordings and H5P interactive videos to support e-learning on the Moodle platform.

APPROACH OR METHODOLOGY/METHODS

H5P interactive videos, slides and quizzes were also used to design the pre-lab and recorded lab experiments, as our labs were closed due to social distancing requirements. Students' performance was evaluated through their marks of weekly quizzes; and their engagement was analyzed using Moodle activity logs and anonymous surveys through teacher evaluation and polling in Zoom meetings.

ACTUAL OR ANTICIPATED OUTCOMES

The attendance to online Zoom lecture and tutorials ranged from 70-87%. These data collectively demonstrate a high level of student engagement and satisfaction under the COVID-19 impacted teaching and learning environment compared to rate of lecture attendance at traditional lectures. H5P interactive videos helped students to achieve higher marks, compared to conventional videos. Student has watched the video more than once to obtain enough information to write the lab class report.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

It was shown that H5P interactive videos had higher views than conventional videos, which subsequently led to higher marks in weekly quizzes. The tutorials were delivered using Zoom meetings, supplemented with pre-recorded videos which supported students who could not attend the tutorial or for their revisions. The virtual laboratory experiments enabled with H5P provided adequate data and information for students to write their lab reports comparable to the requirements of a real-life lab class. Different approaches of video design and their limitations and improvements are discussed for the future development of e-learning in the post-COVID era.

KEYWORDS

H5P; interactive video; online delivery; e-learning

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1 Introduction

In the autumn session of 2020, COVID-19 outbreak forced the transition of teaching and learning from face-to-face mode into remote delivery in Australian universities. The transition was unexpected and quick, and many lecturers and students were unprepared to go down the path of complete e-learning. On the bright side, nearly everyone used internet and video conferences for their studies, work, and daily life long before the COVID-19 pandemic. Based on existing technologies, it became possible to deliver university subjects remotely. Over this unplanned, unprepared, and rapid move to remote delivery for lecturers and online learning for students, many strategies, designs, and technologies were applied to replace, within a short period, conventional classes, tutorials, laboratory classes, project assignments, and assessments (Dietrich et al., 2020).

Online learning and using multimedia have been widely reported for the engineering education in universities (K. Martin, Cupples, & Taherzadeh, 2020; Vial, Nikolic, Ros, Stirling, & Doulai, 2015; Xiao, Cai, Su, & Shen, 2020). Especially, video-based e-learning has been regarded as a formidable frontier of education, offering many benefits to teachers, students, and educational administrators. However, most current university subjects are still delivered in conventional face-to-face mode with supplementary online e-learning to enhance teaching and learning experience. It is due to COVID-19 that forced nearly all teaching and learning into online delivery mode; therefore, it offers a unique opportunity to investigate students' satisfaction, benefits, and the usefulness of different online delivery approaches.

This paper will provide a detailed evaluation of the design and outcome of the remote delivery of a core subject for the Environmental Engineering degrees at the University of Wollongong, Australia. The subject (Membrane Science & Technology) contents were delivered using lectures, tutorials, laboratory experiments, and a design project. The students' performance is assessed through weekly online quizzes, tutorial participation quizzes, assignment reports, mid-session and final exams. In the 2020 autumn session, this subject was initially delivered through face-to-face teaching for the first three weeks. Following the COVID-19 outbreak in Australia, the subject was switched to online delivery for the rest of the teaching session. This provided an opportunity to compare the different teaching modes, based on student engagement, experience, and achievements for the same subject in the same teaching session. Video-based learning is believed to offer sensory learning environment with a touch of face-to-face human texture that can support students to understand more and recall information better (Fern, Givan, & Siskind, 2011). Thus, for online delivery, we adopted conventional video recordings and H5P interactive video clips for both lectures and tutorials in different weeks. A comparison of these two different approaches was also conducted to understand how remote delivery can be carried out to achieve satisfactory learning outcomes. For lab classes during the COVID-19, it was impossible to conduct in-person experiments due to social distancing restrictions. H5P was used to establish a pre-lab and interactive pre-recorded videos of different experiments.

2 Research methods

2.1 Student cohorts

Two classes of students, one undergraduate and one postgraduate class, taught by the same lecturers and tutors in the same session (2020 autumn) were involved in this study. The students were studying this subject towards their Bachelor or Master of Environmental Engineering degrees. Students had in-person teaching of lectures, tutorials, lab classes and group design projects, and access to online resources organized on a subject Moodle site. The teaching lasted 13 weeks and included a lecture and a tutorial (each of two hours duration) each week, in addition to separate weeks for lab classes and field trip. The first three weeks were delivered in the normal face-to-face teaching mode, followed by online delivery for the rest of the session.

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2.2 Moodle subject site structure

The Moodle site for this Environmental Engineering subject is divided into different sections, including subject outlines, lecture notes, tutorials, lab classes, field trips, group design assignment and online examination. This site structure on the Moodle has been developed and evolved from previous teaching sessions before the COVID-19 pandemic. When remote delivery was implemented, a few key changes were implemented. The subject outline section was supplemented with a remote delivery guideline (details in Section 2.3), which was developed to give clear instructions to students how lectures and tutorials would be delivered online. We also gave some technical step-by-step instructions, including how to create PDF using mobile phone and attend Zoom meetings. In addition, two video sections were added to provide pre-recorded videos for lectures and tutorials, respectively. A few Zoom meeting links were created for recurring online lecture and tutorials. Most importantly, an online examination section was created for the mid-session and final exams.

2.3 Design of the remote delivery of the subject

Some previous studies showed e-learning can achieve similar or better learning outcomes than face-to-face teaching (Anwar, Lindsay, & Sarukkalige, 2011; Park, Kim, Cha, & Nam, 2014; Willis, Kestell, Grainger, & Missingham, 2013). This encouraged the transition to remote delivery. Prerecorded videos of lectures, either in the format of simple videos or as H5P enabled interactive videos, were made available weekly, four days in advance of the scheduled lecture. Students were expected to view the videos, answer the quizzes (embedded in the H5P interactive videos, mostly non-compulsory) and take necessary notes. During the normal weekly lecture time on the timetable, the lecture became a ZOOM meeting with all students, through a link available on the Moodle site. During the Zoom lecture time, the lecturer provided discussions on the weekly lecture contents based on student queries, and quizzes embedded in video lectures. Also, there were ample opportunities for Q & A related to the teaching materials of that week. It has been shown that a conversational style is better than a formal style for learning (Mayer, 2001) so the Zoom Lecture Q and A sessions were well received by students.

For tutorials, questions were made available weekly, four days in advance of the scheduled tutorial. Students were expected to attempt the tutorial questions for preparedness. Tutors were holding tutorials (for the entire class) via Zoom. Opportunities were created using Zoom breakout rooms for students to work in groups (like the design assignment in Week 9). Prerecorded video tutorials were provided after the live online tutorials to assist self-paced learning. For the tutorial participation quizzes, students needed to download the participation quiz question from Moodle and complete the quiz within 30 minutes using A4 size papers and in handwriting. They then uploaded the completed quiz after scanning into a PDF file.

2.4 H5P interactive lecture videos

The first three weeks of the subject was delivered in the face-to-face mode. We then divide the following typical teaching weeks (lecture + tutorial) into three weeks of teaching based on conventional prerecorded videos and three weeks based on H5P interactive videos. The videos were cut into clips from full-length lecture videos. The different teaching approaches allow a comprehensive evaluation of the experience and performance of e-learning in comparison to face-to-face learning.

Each 2-hour lecture is divided into 6-8 sections according to the teaching contents so that each section can be recorded in a single video clip which is usually less than 15 min. The lecture video was recorded using Microsoft PowerPoint with a small window of the lecturer overlapped on the slides. The “talking head” lectures (images of the lecturer’s face and shoulders) can add a sense of in-person communication to the video(Young & Asensio, 2002). Research shows that all learning requires both visual and auditory stimulus to promote the cognitive processing. We adopted the multimedia principle, contiguity principle,

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modality principle, and signaling principle by Mayer (2001) when designing the PPT slides and recording the lecture videos. Pictures, sketches, flow charts, animations, and technical videos were incorporated with text on the PPT slides.

For each H5P interactive lecture video clip, we added some H5P interactions including single- or multiple-choice questions, true/false questions, fill-in-the-blanks questions, drag and drop questions etc., as well as a summary task at the end of the video (Fig. 1). The embedded questions can be displayed as a push button or poster on top of the video, thus having the flexibility to make questions compulsory or voluntary for students, in combination to the option to pause the video for those interactions. The interactions allow students to digest parts of the lecture and quickly identify what they may not have understood. The H5P interactions on the Moodle site allow the answers of students being recorded in the Grader report (not accounted in the final grade), where the lecturer can review the answers and monitor the learning outcome. Carefully designed interactions can further divide the video clips into smaller durations, thus allow better concentration and enhanced learning.

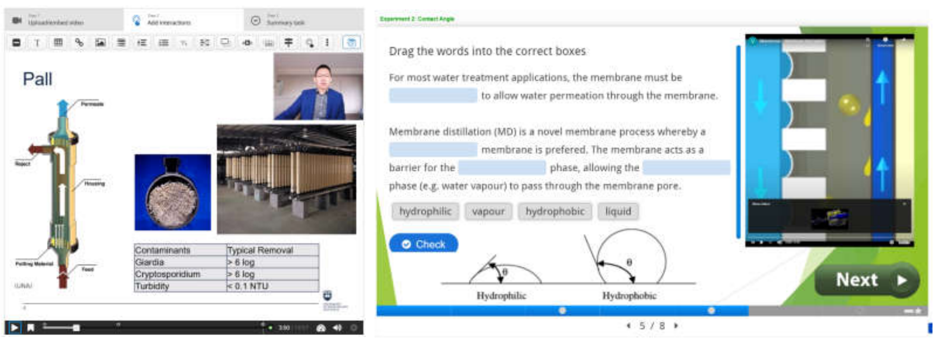

Figure 1. Moodle interface of editing a H5P interactive video (left); Pre-lab slides using embedded video and drag-and-drop questions, compiled with H5P on Moodle (right).

2.5 H5P laboratory classes

The subject has four experiments that need to be completed in one teaching week. To deliver the laboratory classes online, we provided an experimental step-by-step manual, H5P enabled slides as a pre-laboratory and finally, prerecorded videos of experiments with H5P interactions. It is important that students start the experiments as prepared as possible to maximise their learning potential. It was reported that students who watch the pre-laboratory videos increase their preparedness and also increase their assessment mark (Rodgers et al., 2020). The pre-laboratory H5P slides shown below (Fig. 1) combine videos (local or linked from YouTube or Vimeo etc.) and other interactions as discussed in section 2.3. The purpose is to prepare students with more in-depth knowledge and theory related to the four experiments, that would enable them to understand most observations of those experiments.

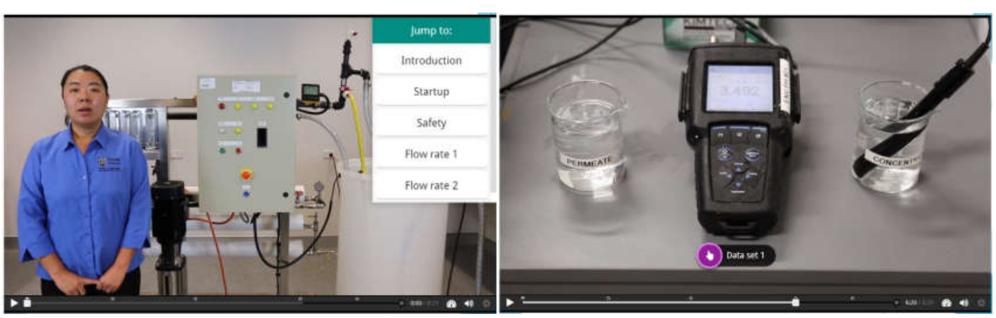

Figure 2. The navigation menu embedded in the video (left and push buttons reminding students to take readings for experiments (right.

The pre-recorded videos of experiments have a navigation menu which was designed according to the experimental manual so students can easily locate and revisit specific parts of videos. There are some push buttons embedded in the video, which serve as a reminder to students for noting down the equipment readings. Those numbers are essential for them to write up the lab class report. The students were required to watch the video, answer the questions (some are compulsory for the video to continue) and record observations and datasets from the video. Students then undertook relevant calculations, plotted graphs, answered questions and wrote a typed laboratory report. Interactivity and engagement were the principles at the forefront of the design process of these videos. However, these virtual experiments have inherent limitations and may only be used as an auxiliary of real-life experiments in the future.

2.6 Data sources and limitations

The online delivery was conducted on the Moodle platform, which has comprehensive activity logs and study analytics. Ethics approval (protocol number 2020/439 at University of Wollongong) was granted for the use of the Moodle log files and grades of all students enrolled in the subject in 2020 Autumn session. The primary data on the number of video views were extracted from the Moodle activity logs. A limitation of the research is that the video access logs do not show if students quitted in the middle or finished the whole video. The H5P interactive videos have checkpoints like submission and summary pages so it would allow checking the engagement with videos from the answers submitted by students.

3 Results and discussion

3.1 Overall subject feedback

The subject Moodle site provides a combination of traditional learning materials (PowerPoint slides, tutorial questions and solutions in PDF format) and interactive items like online quizzes, discussion forum and H5P videos. The well-structured learning materials and delivery ensured an overall good student achievement and satisfaction. The average final mark and pass rate were comparable to previous years. At the end of the teaching session, the lecturer conducted a formal teacher evaluation through the university teaching evaluation unit to collect feedback from the students.

In total, 18 out of 30 students responded to the teacher evaluation survey. Some students also took the opportunity and provided optional comments. A few students commented that the subject was “extremely well organized, delivers information clearly”, “teaches at a good pace” and “concise learning material provided is quite helpful”. Specifically, one comment pointed out that “I enjoyed the interactive prerecorded lectures put up by the teacher, the questions within the lecture helped with learning and understanding the material”. The comment also resonates with the in-class polling results using Zoom, which shows that 84% of students have watched the lecture videos before the summary lecture, and 42% watched all videos of that week. Among them, 74% of students have tried the embedded interactions and quizzes in H5P lecture videos and they found it helpful and like them. The Moodle log files show a range of 63-83% engagement with interactive lecture videos. The attendance to online Zoom lecture and tutorials ranged from 70-87%. These data collectively demonstrate a high level of student engagement and satisfaction under the COVID-19 impacted teaching and learning environment compared to rate of lecture attendance at traditional lectures (Purcell, 2007).

3.2 Lecture video views and weekly quiz marks

When the student achievement was assessed by the weekly quizzes, face-to-face teaching led to the highest mark (Fig. 4A). In comparison, remote delivery weeks using either conventional or H5P interactive video achieved lower marks, for both undergraduate and postgraduate students. However, H5P interactive videos helped students to achieve higher

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marks, compared to conventional videos. This is likely due to the higher views of the lecture videos with H5P interactions (Fig. 4B). It is also interesting to note that undergraduate students tend to prefer the H5P lecture videos than postgraduate students, evidenced by 1.0 vs 0.6 views/video per student. The conventional lecture videos received around 0.34 views/video per student, which is much lower than the H5P lecture videos. It is clear that H5P lecture videos can greatly enhance the student engagement during remote delivery, which subsequently led to higher student achievements. Postgraduate students were less promoted by H5P interactive lecture videos, from 0.33 to 0.6 views/video per student. This implies that some more advanced interactions (different sets of quiz questions designed specifically for PG students) might be needed to enhance their interests in using lecture videos.

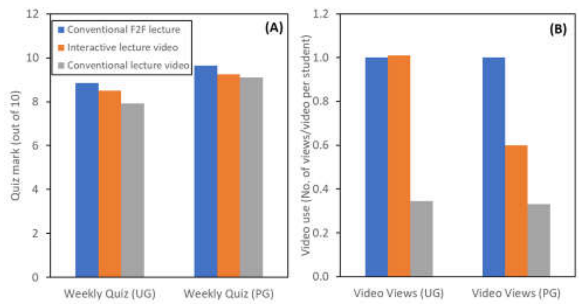

Figure 3. The marks of weekly quizzes for different weeks delivered through face-to-face lectures, H5P interactive lecture videos or conventional lecture videos (A); and the video use comparison for undergraduate and postgraduate students (B).

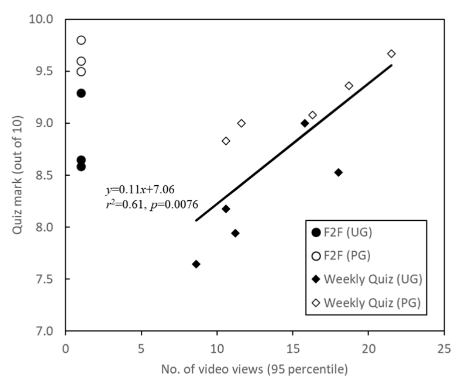

Figure 4. The correlation between the video views and marks of weekly quizzes.

There is a strong correlation (correlation coefficient *r*=0.8388) between the 95% of views of lecture videos and marks of weekly quizzes. This positive correlation, as shown in Fig. 5, indicates that increased video views can increase the student performance. Those students who had high video views achieved comparable quiz marks to face-to-face teaching. This correlation shows the importance to enhance the student engagement with lecture videos. The use of H5P interactions is obviously one way to increase the video views.

To further understand how the increase of video views influenced quiz mark, the students were divided into different groups according to the percentile of video views, i.e., low (<40%), medium (40-70%), and high (>70%), as shown in Fig. 6. This demonstrates that for UG students, the improvement mainly happens for those with medium video views, with slight improvements for students with high or low video views. In combination with above observations, H5P interactive video attracts mainly those students have relatively good levels of engagement. For students already actively engaged, its room of improvement is very limited. Also, for those students with very low engagement level (at risk students), other measures should be taken to identify the actual issue. Through contacting students at risk, it

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was found those students missed the first few weeks and was not motivated to follow the teaching schedule. For PG students, the improvement is consistent across all the range of video view groups and the overall engagement is higher than UG students.

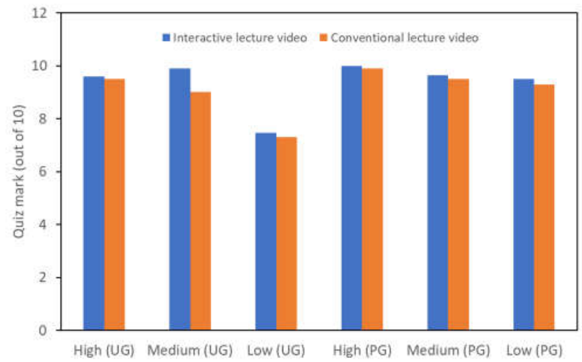

Figure 5. The improvement on weekly quiz mark for different group of students who had low, medium and high video views.

With the ubiquitous video recording capacity nowadays, there is no doubt that university lecturers can easily develop video-based digital teaching materials (Gillie, Dahli, Saunders, & Gibson, 2017). Some studies have found that in conventional teaching and learning, lecture or tutorial videos were mainly used by students for revision or supplementary to face-to-face lectures. Students tend to like short, focused videos more than longer ones (Gillie et al., 2017). However, video-based learning is not always attractive, as it is well-known that linear video may become a passive experience due to superficial learning and insufficient viability of the learning effect, what is called the "couch-potato-attitude"(Ertelt, Renkl, & Spada, 2006). Therefore, there has been a sharp increase of research in employing interactive video for learning in recent years (Palaigeorgiou, Papadopoulou, & Kazanidis, 2019). With interactive videos, students can answer questions, click on interactive items or regions of the video, choose how the video story develops, click on external links, access extra information, etc. It is clear that the functional and cognitive interactivity of educational interactive videos can greatly enhance the learning effectiveness through improved engagement.

3.3 Tutorial and laboratory class videos

For the tutorial classes, PDF documents of tutorial questions and solutions were provided on the Moodle site. The views of solution document were 3.2-3.6 per student. Although a short demonstration video was provided, the views were only 0.4-0.6 per student. This indicates that students tend to use the written document to help them in understanding the solution. It appears that only on rare occasions, they would turn to the demonstration videos for help. Overall, the tutorial videos still find some use likely for those difficult questions. Previous studies also reported the use of video tutorials to improve student learning experiences and student satisfaction (Anwar et al., 2011; Turan & Cetintas, 2020; Wong, Oladinrin, Ho, Guilbert, & Kam, 2018). In the future, maybe we can choose to only provide key problem videos to enhance its use (P. A. Martin, 2016).

Laboratory classes are an essential part of the education of undergraduate and postgraduate engineering students. Laboratories provide the opportunity to acquire a range of hands-on technical skills, active learning experiences and practical knowledge that are not available through other avenues (Feisel & Rosa, 2005; Restivo, de Fátima Chouzal, Abreu, & Zvacek, 2019). Some previous studies have explored different ways of delivering laboratory classes using online mode. Live internet-based bench-top shake-table experiments were developed using real-time video monitoring, control, and execution systems (Elgamal, Fraser, & Zonta, 2005). Another study reported an electronic experiment using real hardware and under real test conditions that can be remotely conducted by engineering students and other interested

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individuals in the world via the Internet and with the capability of live video streaming from the test site (Axaopoulos, Moutsopoulos, & Theodoridis, 2012). However, this type of remote labs or experiments would need time and effort to achieve the design and transformation. For the remote delivery of this subject, we opted to use pre-recorded video-based virtual experiments considering the short transition time due to the COVID-19 pandemic.

There were four laboratory class experiments, which were delivered using H5P interactive videos. Each video had some compulsory questions to ensure students record datasets by carefully reading numbers on equipment in the video. The average views per laboratory class video was 2.2 per student. It indicates student has watched the video more than once to obtain enough information to write the lab class report. Also, the H5P prelab videos and quizzes provide background knowledge for the discussion in lab reports.

4 Conclusions

The COVID-19 pandemic has created unprecedented challenges to the teaching and learning in universities, but also offer an opportunity to pursue changes that possibly have enduring effects to future higher education. This study demonstrated that H5P lecture videos obtained higher views than conventional videos, which enhanced student performance in understanding the teaching information. Students achieved similar marks in comparison to face-to-face teaching. H5P was also employed in delivering the laboratory classes using prerecorded videos. Short, focused and interactive video clips are more appealing and functional to students. Overall, the student gave positive feedback on the learning experiences in this subject.

This study shows that interactivity in teaching and learning is essential to maintain the much-needed engagement during the remote delivery over the COVID-19 pandemic period. Although current technology allows high definition of videos being adopted in developing a replacement of face-to-face teaching, interactivity and engagement should be the key principles at the forefront of the subject design and delivery process. Plain videos should be avoided as it lacks the ability to provide an engaging and active watching experience.

The investment in H5P interactive videos would be higher than plain videos. There is about 50% increase of the preparation time. Extra workload of lecturers in preparing interactive contents need to be recognized properly. However, H5P interactions can be reused so it also provides sustainability for the future. It must also be realized that prerecorded videos, being interactive or not, must be accompanied by live online lectures, consultation, or a certain percentage of face-to-face teaching when COVID-19 pandemic restrictions are relaxed.

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Hybrid Mode: A New Norm for Electrical Engineering Laboratory Education?

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ABSTRACT

CONTEXT

The COVID-19 pandemic has created an incredibly challenging period in which to deliver engineering laboratory exercises. Utilising available digital technologies, the authors converted traditional hands-on laboratory exercises to virtual labs and remote labs. Commencing in Semester 2, 2020, the authors' School has offered a hybrid teaching model which simultaneously delivers laboratory content to an on-campus cohort (who participate in traditional hands-on labs) and a remote-learning cohort (who participate via virtual and/or remote labs). While trying to ensure that the learning experience of both on-campus and remote-learning students were similar, and that teaching outcomes were maintained, the authors observed that the success in adaptation of existing course content to the hybrid teaching model differs between Units of Study (UoS). There is a challenge to understand the basis for these differences and how to optimally design teaching material and manage classes to achieve the best learning outcomes.

PURPOSE

The authors manage and coordinate operation and teaching across six electrical engineering teaching laboratories. This paper aims to report the degree of success of introducing hybrid laboratory education across twelve UoS. Specifically, based on student responses to a survey undertaken in Semester 1, 2021, the authors evaluate the effectiveness of the hybrid model by seeking to answer two questions: (1) Could the students be satisfied with the new hybrid model? (2) Could on-campus and remote-learning students have similar learning experiences?

METHODS

The study covers the School's teaching laboratory programs that span three broad teaching disciplines: power/energy, communications/photonics, and computer/digital electronics. They are organised in either mixed mode (both on-campus and remote cohorts undertake the same exercises) or parallel mode (cohorts complete different exercises that have common learning outcomes). Student survey data across twelve UoS are available, including responses about learning experience, tutor teaching, and additional comments. The method is mainly quantitatively statistical analysis, supplemented by qualitative study.

OUTCOMES

Overall, the hybrid lab program results in a satisfactory learning experience for students. This means that implementing electrical engineering laboratory teaching using a hybrid model is found to be both practical and applicable. However, students on-campus in the mixed mode and both cohorts in the parallel mode tended to adapt more successfully to the hybrid model than those remote students in the mixed mode. It prompts the educators to fine-tune the hybrid program to better accommodate the remote mixed mode students.

CONCLUSIONS

While the hybrid model can deliver effective laboratory education, the degree of success and student experience was found to vary between different cohorts. Further study is warranted to understand the factors behind these differences and to then explore more effective approaches to maximise the students' learning experience. This paper serves as a starting point for the community to discuss the new norm for engineering laboratory education. The pandemic has already had a transformational impact on the delivery of engineering education, and hybrid education may not be transient but instead a future steady state.

KEYWORDS

Engineering Laboratory Education, Hybrid Labs.

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Introduction

The COVID-19 pandemic has created an incredibly challenging period in which to deliver electrical engineering laboratory exercises which are heavily based on acquiring and demonstrating practical skills. At the authors' University, all practical laboratory classes resumed from Semester 2, 2020. However, a considerable percentage (~40%) of the students could only study remotely due to either personal considerations or travel restrictions resulting from the closure of international borders. To continue quality education for the students, the University decided to introduce a hybrid learning model, which allows students flexibility to enrol into either an on-campus stream or a remote-learning stream, depending on their individual circumstances.

The authors manage operations and teaching across six electrical engineering teaching laboratories that span three broad teaching disciplines: power/energy, communications/photonics, and computer/digital electronics (EIE Labs, 2021). To implement the new hybrid learning model for delivery of laboratory education, the authors utilised available digital technologies. They proposed developing new virtual and remote labs that could be as effective as the traditional hands-on labs, as computer-mediated experiments have effectively blurred boundaries between hands-on, virtual and remote laboratories (Ma & Nickerson, 2006). In virtual labs, students use software which mimics the appearance and operation of physical lab equipment or software which performs numerical simulations of circuits or systems. In remote labs, students gain remote access to view and control hardware that is physically located on-campus (Balamuralithara & Woods, 2009; de Jong, Linn, & Zacharia, 2013; Potkonjak et al., 2016). While trying to ensure that the learning experience of both on-campus and remote-learning students were similar, and that teaching outcomes were maintained, the authors observed that success in adaptation of existing course content to the hybrid teaching model differed between Units of Study (UoS). There is a challenge to understand the factors behind these differences and how to best design teaching material and manage classes to achieve the best outcomes.

While there have been many articles appear in the literature which report on aspects of delivering laboratory education during the pandemic (Gamage et al., 2020; Ozadowicz, 2020), to the authors' best knowledge there was no systematic evaluation of students' perception of the new hybrid lab program at a macro (School's) level. To evaluate the effectiveness of the hybrid laboratory program, the authors conducted a joint Teaching Laboratories Survey across twelve UoS at the end of Semester 1, 2021. Those Units were spread across junior years (2 Units), intermediate years (5 Units) and senior years (5 Units). They share the common characteristic of having significant hands-on components which were conducted purely face-to-face in the labs before the pandemic. In this article, the authors first describe their hybrid lab program in detail and then analyse the survey results to evaluate the effectiveness of the hybrid model implemented in their Electrical Engineering laboratories and mainly investigate students' perception of their learning. The research questions to be answered from this study are:

1. Could the students be satisfied with the new hybrid laboratory learning model?
2. Could on-campus and remote-learning students perceive similar learning experiences?

The approach to investigating these results is mainly quantitatively statistical analysis, supplemented by qualitative study.

Hybrid Labs

The School's laboratory programs span three broad teaching disciplines: power/energy, communications/photonics, and computer/digital electronics. Under the hybrid labs model, students elected to enrol into a UoS in either the on-campus cohort or remote-learning cohort. Depending on the course-specific content, the hybrid labs were delivered in either mixed-mode or parallel-mode.

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(a) Mixed-mode

Considering that modern Electrical Engineering lab equipment can be mediated by computers, physical colocation of students and equipment becomes less critical. Most of our modern instruments had an in-built interface that computers could control. This meant that as long as the remote-learning students could remotely access the lab computers and the lab could provide a video/web camera, these students could effectively work on experiments with the computers as their "hands" and the cameras as their "eyes" and obtain a similar learning experience as if they were on campus. So, the lab instructors provided one camera for each workbench and used Zoom Remote Control to enable online students to access on-campus computers (therefore instruments). Another hurdle was that some operations still required physical adjustments to be made to hardware (i.e. changing component placement on a breadboard circuit). To overcome this limitation, the authors paired remote and on-campus students, often in groups of 2-5, and structured the activities so that students were required to work on the lab tasks together. On-campus students can operate it physically, while remote-learning students could access them by remote-controlling the computers that connect the hardware. In addition, this approach also provided an opportunity to promote collaboration between on-campus and remote-learning students and to provide the remote-learning students with a sense of connection to the classroom. The mixed-mode arrangement is illustrated as shown in Fig. 1.

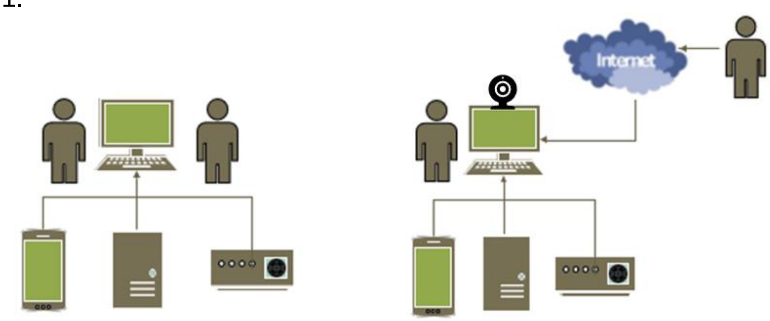

Figure 1: Lab arrangement (Left) the purely on-campus mode arrangement in 2019 before the pandemic and (Right) Mixed-mode collaboration from 2020.

(b) Parallel-mode

In the parallel mode, the authors have designed two sets of lab activities for both on-campus and remote students. On-campus students work in the traditional hands-on labs, while remote-learning students attended virtual simulation labs with learning outcomes derived from the hands-on labs. The classes were conducted simultaneously. The University has implemented UniConnect Cloud (UniConnect, 2017), in which the laboratory simulation software can be moved from the University physical computers to the Cloud. Students can access them through any web browser, making virtual labs accessible to anyone, anytime.

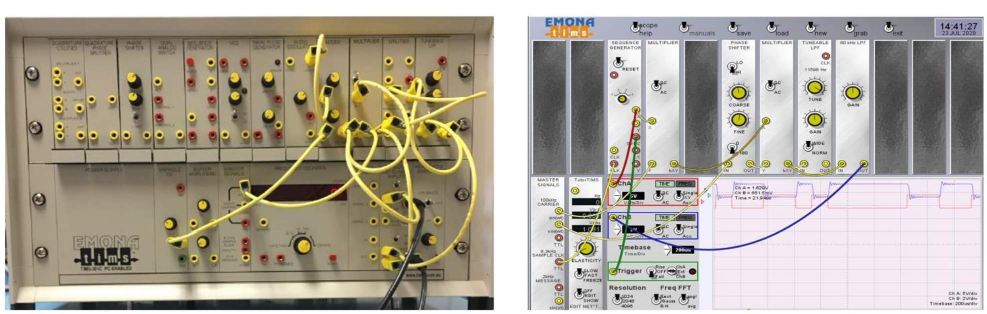

Figure 2: Lab arrangement (Left) TIMS physical setup on campus and (Right) TutorTims Virtual Lab on Uniconnect Cloud.

In the example shown in Fig. 2, Telecommunication Instructional Modelling System (TIMS) labs are set up and conducted using the physical TIMS equipment for students on campus

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(EMONA TIMS, 2021), while corresponding virtual simulation labs using TutorTIMS software are hosted on Uniconnect Cloud for remote-learning students to complete lab exercises. These two options are considered to be nearly identical in delivering the same learning outcomes. Students can choose either approach to complete the lab tasks/exercises through either hardware or software interfaces. This mode provided more flexibility and independence to students, however it also required more resources to prepare and support the classes.

Methods

(A) Participation

The setting of this study was undergraduate and postgraduate coursework students who enrolled in a UoS which was delivered under a hybrid lab program in Semester 1 2021. To evaluate the effectiveness of hybrid laboratory education, the authors conducted a Teaching Laboratories Survey across 12 UoS at the end of Semester 1 2021. Those Units have significant hands-on components that were conducted face-to-face in the labs before the pandemic, and they were distributed across junior years (2 Units), intermediate years (5 Units) and senior years (5 Units). The underlying population size of the survey exercise was 1300 in total. Among them, 775 students were on-campus students, while 525 students chose the remote-learning option. In another dimension, among the entire population, 952 students were enrolled in Units delivered using the mixed mode of the hybrid labs, while 348 were in Units delivered using the parallel mode. Based on the above two hybrid strategies, students studied in one of the following four learning environments: i.e.

- On-campus students, delivered in Parallel mode
- On-campus students, delivered in Mixed mode
- Remote-learning students, delivered in Parallel mode
- Remote-learning students, delivered in Mixed mode

(B) Data Collection

Data collection started in Week 13 (final week) of Semester 1, with the survey setup using Microsoft Forms. The specific questions of interest that were asked in the survey are provided in the Appendix. The exercise was entirely voluntary and anonymous as personally identifying information were not required. An announcement was sent through the digital learning system, Canvas, to the students enrolled in these 12 Units to request their participation in the survey. This initial request was reinforced by tutors via in-class announcements. The survey ran for two weeks before it closed. It returned a total of 272 responses (n = 272), i.e. 21% of the underlying population size. The overview of the survey and its response is summarised in Table 1. Among the entire population, 22% of on-campus students responded to the survey, while 20% of the remote students did. On another dimension, 19% of mixed-mode students responded, and 26% of parallel-mode students did. In addition to the ranking-style questions, the returned responses also included 110 specific student comments that were used for the qualitative analysis.

Table 1: Overview of the collected survey data

# (and %) of the student responding to the survey	Mixed Mode	Parallel Mode	Total
On-campus students	122 (21%)	47 (23%)	169 (22%)
Remote-learning students	59 (16%)	44 (30%)	103 (20%)
Total	181 (19%)	91(26%)	n = 272 (21%)

(C) Descriptive Statistics

First, the authors studied the entire dataset of samples by computing means, medians and standard deviations for three indicators: learning activities (Q3), tutors' teaching (Q4), and the effectiveness of the mixed group (Q5). All three indicators were rated out of 5, indicating the level of satisfaction (refer to the Appendix for more detail). These results are summarised in

Table 2. Overall, the ratings for both learning activities and tutor's teaching are greater than 4 out of 5, indicating some level of satisfaction at the macro level. In contrast, the ratings of mixed group effectiveness are only 3.16 (note that only mixed-mode student samples were used to calculate this number). This means students did not perceive any significant benefit of collaborating virtually, indicating that remote-learning and on-campus students were not related very well in this type of group arrangement. As for Q6-whether to keep the hybrid lab in the future, surveyed students had a split view with 116 of Yes, 68 of Maybe and 88 of No, indicating no clear advantage of the hybrid lab perceived by students to traditional on-campus labs.

Table 2: Basic statistics from samples (indicators rated out of 5)

	Mean	**Median**	**SD**
Learning Activities	4.06	4.00	1.01
Tutors' Support	4.24	5.00	1.02
Mixed Group Effectiveness	3.16	3	1.41

The authors then computed the correlations among key indicators, as shown in Table 3. Learning activities, tutor teaching and mixed group effectiveness are highly correlated. E.g. of those students who rated 5 for lab learning activities, 92% also rated 5 for tutors' teaching. It is clear that students' perceptions of both were correlated. Therefore, to simplify the analysis that follows, the authors will focus on the ratings of Lab Learning Activities as the leading indicator in the rest of the paper.

Table 3: Correlation between indicators

	Learning Activities	**Tutors' Teaching**	**Mixed Group**
Learning Activities	1.00	0.67	0.55
Tutors' Teaching		1.00	0.45
Mixed Group			1.00

The authors further investigated the samples between on-campus and remote-learning students and data between mixed-mode and parallel-mode students. In addition, the entire samples can be divided into four subgroups: i.e. on-campus mixed-mode, on-campus parallel-mode, remote mixed-mode, and remote parallel-mode, and four broad categories: i.e. between on-campus and remote-learning, between parallel and mixed modes. The results were computed and illustrated in Table 4. The data shows that the sample means of Learning Activities Ratings between on-campus (4.08) and remote-learning students (4.02) are close. However, parallel mode (4.51) scores 15% higher than mixed-mode (3.83). In particular, the subgroup of remote mixed-mode (3.63) scored significantly lower than the rest of the subgroups. This observation has prompted the authors to plan improvement strategies for this subgroup in the future.

Table 4: Sample Mean of Learning Activities Ratings across groups, categories and overall

	Mixed mode	**Parallel mode**	**Category (on-campus or remote-learning)**
On-campus students	3.93	4.47	4.08
Remote-learning students	3.63	4.55	4.02
Category (mixed or parallel)	3.83	4.51	**Overall:** 4.06

(D) Hypothesis Test – Satisfaction and Experience Gap

Given the unknown mean and variance of the entire population, Hypothesis tests with t-statistic are used to evaluate the significance of the results (Gravetter & Wallnau, 2007). The sample

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data from the underlying population would answer the two key research questions outlined in the Introduction section.

The first null hypothesis is that, on average, students from the entire population, as well as each underlying sub-category, are satisfied with the hybrid lab model (i.e. the mean of the rating for the lab learning activity is above the benchmark value of 4.10). This benchmark score of 4.10 was derived by averaging Unit of Study Survey results across four semesters before 2020. In that sense, the satisfaction is being determined relative to pre-pandemic levels. Mathematically, the first null hypothesis can be expressed as below:

$$H_o\colon \mu_{lab\_act} \geq 4.10$$

The alternative hypothesis would state that, on average, students are not satisfied with the lab learning activities in the hybrid model. The significant level of these tests is set as 0.05 for one tail. Degree of freedom equals the respective number of samples (from Table 1) minus 1. The authors perform this hypothesis test for the entire population and each category, respectively. The calculated t-statistics and t-cutoff are presented in Table 5. When t-statistic is less than the t-cutoff, this implies that the null hypothesis is to be rejected. Otherwise, the hypothesis is to be accepted. According to Table 5, on average, the entire population is satisfied with the hybrid lab model, statistically. As for the categories, on-campus students, remote-learning students, and parallel mode students are also satisfied with the labs. However, mixed-mode students have t-statistic in the rejection region, indicating dissatisfaction with their learning mode.

Table 5: Hypothesis testing using t-statistics of the entire population, on-campus, remote-learning, mixed and parallel students (the level of significance α at 0.05 for one tail)

	df	**t-stats**	**t-cutoff**
Entire population	271	-0.69	-1.65
On-campus students	168	-0.30	-1.65
Remote-learning students	102	-0.78	-1.66
Mixed-mode students	180	-3.56	-1.65
Parallel-mode students	90	4.68	-1.66

The second null hypothesis is that, on average, students from on-campus and remote learning perceive the same lab learning experience under the hybrid model. (i.e. the difference in means of lab learning activity between on-campus and remote-learning students is zero), Mathematically, it can be expressed as below:

$$H_o\colon \mu_{campus-}\mu_{remote} = 0$$

The alternative hypothesis would state that, on average, there is a perceived satisfaction gap between on-campus and remote-learning students. T-test: two-sample assuming unequal variances are performed, and the significance level of these tests is set as 0.05 for two tails. Again, the authors calculate the t-statistics and t-cutoff for the overall population, mixed-mode and parallel-mode students, respectively, as presented in Table 6. When the absolute value is less than the t-cutoff, the t-statistic is in the acceptance region, and the null hypothesis is accepted. Otherwise, the hypothesis is to be rejected. According to Table 6, on average, students between on-campus and remote learning statistically had the same satisfaction level under the hybrid model in Semester 1 2021, across the entire population, mixed-mode and parallel-mode students, respectively.

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Table 6: Hypothesis testing - difference in the mean using t-statistics (the level of significance α at 0.05 for two tails)

	df	t-stats	t-cutoff
Entire population	201	0.44	1.97
Mixed-mode students	106	1.79	1.98
Parallel-mode students	89	-0.44	1.99

Findings

Two key goals of developing a hybrid lab program are (1) to expand course enrolment options to accommodate remote-learning students while continuing to deliver quality lab education that students are satisfied with and (2) to provide the same learning experience between on-campus and remote-learning students. Overall, the hybrid lab program as implemented has been successful so far. Statistically, the entire population of students, both remote and on-campus students, had no less satisfaction rating than the traditional lab program delivered before the pandemic. In addition, on-campus and remote learning students had close satisfaction level under the hybrid model. However, when assessing subgroups, the authors observed that students in the parallel-mode rated lab learning activities 15% higher than those enrolled in the mixed-mode.

Qualitative detail of the survey can get lost in analysis of the statistics alone, and so it is equally valuable to consider students' comments to get a picture of how the students experienced the program. Comments from parallel-mode students (both online and on-campus) were, in general, positive and it was encouraging to see that they supported the findings from the quantitative data. In contrast, we observed that the most negative comments were from mixed-mode students – from both on-campus and remote-learning cohorts - with some criticisms such as:

> "*Don't combine online students with campus students. Communication is hard, especially with different time zones and language barriers*."
>
> "*Combining remote and on-campus students is a bad idea. Maybe just give remote students a slightly different Lab 6 project that can be done online*?"
>
> "*Mixing online and in-person learning makes interactions and tasks difficult - I would mostly prefer to keep the modes separate.*"

Those comments were effectively reflected in the poor survey ratings for learning activities (Q3), tutors' teaching (Q4), and the effectiveness of the mixed group (Q5). Finally, the authors observed comments from remote-learning students that they would prefer to enrol in the on-campus cohort if a choice could be given. This is interesting as, despite both on-campus and remote-learning students having close satisfaction level under the hybrid model, there is a perception amongst some remote-learning students that on-campus learning is preferable.

Finally, the survey data was compared across years (junior, intermediate, senior) and Unit-by-Unit at a micro level. The authors observed that senior-year students studying Units with labs consisting of system-level experiments reported a much better experience. It is believed that this outcome is due to being able to mediate system-level processes almost wholly using digital technologies, thus making those Units more successfully adapted to the hybrid mode. In contrast, many first-year Units have fundamental labs consisting of hands-on component-level experiments which are more difficult to adapt.

Discussion

In response to challenges presented by the pandemic, many educators have been driven to innovate alternative ways to deliver lab education which they have traditionally conducted on-campus. Overall, the hybrid lab program resulted in a satisfactory learning experience for students. This means that implementing electrical engineering in hybrid mode is both practical and applicable. While trying to ensure that the learning experience of both on-campus and

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remote-learning students were similar, and that teaching outcomes were maintained, the authors observed that success in adaptation to the hybrid teaching model differed between the mixed and parallel modes of the hybrid program. This study provides a window of opportunity to further study the program systematically at a macro level. It is now understood that the student cohort in the remote learning hybrid mode reported poor experience among other modes. This finding can guide educators where to direct more attention when fine-tuning its program, as both qualitatively and quantitative data point to the challenge faced by this cohort of students.

To motivate students in the laboratory, the educators need to have a lab program which meets students' psychological needs as well as their technical needs. To successfully implement the hybrid mode, the authors believe that the challenge is not purely technical, as digital technologies have removed the boundary between on-campus and remote learning. Niemiec and Ryan (2009) outlined some evidence from their studies that meeting students' three psychological needs (autonomy, competence and relatedness) would facilitate the learning experience and academic performance. The Nobel Prize-winning Physicist R. Feynman once said, "imagine how much harder physics would be if electrons had feelings". This study now shifts the authors' focus from purely technical aspects to psychological readiness. The authors now realise that all three psychological factors described by Niemiec and Ryan (2009) might not be well addressed, particularly for remote-learning students in the mixed mode. For example, before the study, the authors did not sufficiently consider the fundamental shifts in interactions between students, teachers and apparatus in the new environment. Among those negative comments, the criticisms tended to be directed towards the collaboration issues instead of technical content.

In the parallel mode, on-campus students would take the traditional physical labs, while online students would do corresponding simulation labs instead. Both cohorts have rated the learning activities highly, as evidenced in the lab survey (average 4.47 for on-campus students and 4.55 for remote-learning students). On-campus students effectively worked in a pre-pandemic environment, while remote-learning students would most likely feel more confident working with simulation models (which are not restrained by on-campus hardware, network latency or group member dynamics) than remote-lab activities. However, some specific learning outcomes can only be achieved through hardware-facing labs (either physically or by remotely interacting with the hardware) and there continues to be a challenge to design lab activities which effectively meet the related learning outcomes.

This study had incorporated one semester of data. Different UoS will be offered in Semester 2, 2021 and the authors intend to continue the study to include these Units, so that a full year of the course program can be investigated.

Conclusions

The pandemic has already had a transformational impact on engineering education. Commencing in Semester 2, 2020, the authors' School has offered a hybrid teaching model which simultaneously delivers laboratory content to both on-campus and remote-learning cohorts. While the hybrid model can successfully deliver engineering laboratory education, the degree of success and student experience varies between the different cohorts and UoS. This preliminary study found that overall, the hybrid lab program resulted in a satisfactory learning experience for students. However, this paper serves as the starting point for the community to discuss the new norm for engineering laboratory education. Hybrid education may not be transient. Instead, it is an excellent opportunity for reform and innovations.

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Appendix – Survey Questions

2021 S1 Teaching Laboratories Survey

1. Which Unit of Study are you enrolled in?
2. Are you enrolled as an on-campus student or remote-learning student?
3. How would you rate Lab Learning Activities? (5-star is the highest rating, and 1-star is the lowest rating)
4. How would you rate Lab Tutors? (5-star is the highest rating, and 1-star is the lowest rating)
5. Many UoS combined on-campus and remote students into groups. How would you rate the effectiveness of working with your group members under this arrangement? (5-star is the highest rating, and 1-star is the lowest rating)
6. In Semester 1 2021, we are running most labs in hybrid mode: on-campus labs and remote learning labs. After Covid-19 is resolved, do you still want us to keep both options in the future? Yes, No or Maybe.
7. Any other comments/suggestions?

Note that for the rating scale (Q3,Q4,Q5)

- 5-star means Strongly Agree/Satisfy
- 4-star means Agree/Satisfy
- 3-star means Neutral
- 2-star means Disagree/Dissatisfy
- 1-star means Strongly Disagree/Dissatisfy

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Online Versus In-person Teamwork: A Program-Wide Study

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CONTEXT

Teamwork is one of the important graduate competencies expected of Engineering graduates by Engineers Australia. Engineering courses tend to teach teamwork in less structured ways, although in-person teamwork is systematically studied and implemented across a few programs. The transition to online learning during COVID-19 has explored options for online teamwork.

PURPOSE OR GOAL

This study aims to investigate the development of teamwork skills in electrical engineering courses. The idea is to explore and compare the experiences of online versus in-person teamwork in courses at different levels. The questions that will be addressed in this study are: (i) How do in-person and online team dynamics differ regarding challenges and strategies? (ii) How does students' experience of teamwork and leadership skills differ in different levels and types of courses?

APPROACH

Three courses that have teamwork activities are selected for this study. These courses are a large first year undergraduate (UG) course with about 500 students, a final year UG design course with about 100 students and a postgraduate course with about 200 students. The characteristics of these courses are widely different in terms of diversity, group collaboration, the teamwork task, and its assessment. The study then discusses the various models of the teamwork in these courses, both during the in-person and the online offerings.

OUTCOMES

The outcome of this study includes a reflection and comparison of the in-person and online offerings of the teamwork models in each of these courses based on student surveys and course performance. Recommendations for implementing teamwork based on the observations from the analysis are outlined.

CONCLUSIONS

The results indicated that there is no single dominant model for how teamwork skills are developed within an engineering program. However, a consistent model for implementing teamwork skills within the entire program may prove beneficial for students to develop these skills systematically and strategically. This study has demonstrated that teamwork skills awareness and development should be supported and evaluated within a degree program. Such a program-wide outlook for online versus in-person teamwork would benefit in informing future blended/hybrid options, post pandemic.

KEYWORDS

Teamwork, Online, In-person

Introduction

The emergence of the digital revolution and Industry 4.0 has brought about several changes in the field of engineering. Engineers in the 21st century are not only expected to possess strong technical knowledge, critical thinking and problem-solving skills, but also expected to possess professional skills like teamwork, leadership and communication skills (Elayyan, 2021). Universities need to ensure students can operate in high performing teams to make them job ready after graduation. Engineers Australia is a professional body responsible for the accreditation of engineering degrees in Australia. Engineers Australia (EA) Stage 1 competencies require students to possess effective team membership and team leadership skills, as specified in the mandatory element 3.6 (Australia, 2017).

The importance of Teamwork and Leadership (T&L) skills have been identified since the past decade where a study conducted in Australia (Male, et al., 2011), surveyed industry professionals with varied experience and identified “leadership” and “working in diverse teams” to be in the top five skills required by the industry. It is therefore evident that universities and regulating bodies have recognised the importance of T&L skills and have created several teaching pedagogies to achieve them, but there is no consensus on a structured approach in teaching these skills at a program level (Chowdhury & Murzi, 2019). However, a program wide approach to teaching other professional skills has been successfully implemented in several universities. Colorado State University (Siller, et al., 2009) created a four-year program wide framework to develop professional skills that included communication, innovation and ethics. There were professional development workshops in addition to the courses that needed to be completed before the end of each year. This approach allows for the skills to be staged over the years depending on student’s maturity level and experience. However, these skills were developed through extracurricular activities rather than in mainstream courses. Griffith university has implemented a Professional Practice and Employability Skills Partner (PPESP) stream within their programs to improve the employability of students. This stream is designed for students to experience the PPESP courses at a regular interval using a staggered approach to expose students to professional practice and training throughout the program (Simon, et al., 2018). The University of Adelaide has introduced a range of professional communication skills into specifically modified courses in the school of mechanical engineering (Missingham, 2006). These courses are classified according to the levels and staggered throughout the undergraduate and postgraduate courses to reinforce the skills at regular intervals. The learning outcomes of the engineering courses were meshed with the ability of students to express their knowledge in various forms of communication.

The rise of online education during COVID 19 pandemic has introduced several challenges in effectively running teamwork activities (Wildman, et al., 2021). Universities have adapted to these changes and are now starting to implement both in-person and online delivery of teamwork activities. A selective Latin American university (Goñi, et al., 2020), investigated the difference in teamwork learning presented in online and in-person scenarios. However, the analysis was done for a single course and a program wide outlook with other courses from different levels was not considered.

Teamwork and leadership skills are taught in engineering courses by adapting team-based teaching pedagogies that suit the circumstances and type of the course. These skills are often the by-product of the outcome of the team project and the students are not guided on the teamwork process. A more structured and targeted approach to building these skills could be the key to prepare students for the workplace.

This paper analyses three case studies involving courses at undergraduate level 1 and level 4 and a postgraduate level in the UNSW Electrical Engineering program, having a varied approach and structure to teach teamwork. These courses were compared on the teamwork teaching methods, learning process, assessment methods, and performance in the online and in-person offerings. Level 2 and level 3 courses involving teamwork were not considered in

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this study as majority of these courses incorporate teamwork skills in standard assignments and labs without scaffolded development.

Program Wide Case Study

Case 1: First Year Undergraduate Course

Electrical Circuit Fundamentals is a first-year course which introduces fundamental electrical elements and circuits, as well as the technical skills to analyse and implement such circuits. The course is not only for Electrical Engineering students, but also for all other engineering disciplines across the Faculty of Engineering. This course has 1000+ students annually which are spread across two terms. The teamwork activity in the first offering of the course in 2021 had a mixture of online and in-person teams, depending on whether students attended in-person or online tutorials. There was a total of 139 teams (113 in-person teams and 26 online teams) with 3-4 students per team.

The teamwork task involved completing six online quizzes. Each quiz had to be solved individually out of class first, and then in groups. This gave students the opportunity to discuss those questions which they found particularly challenging when working individually. Group discussions were initiated in class, during tutorials, so that the tutor had an opportunity to monitor group discussions and teamwork. Discussions continued out of class in those cases where it was not possible for students to complete the group quiz in class. Once the group quiz was submitted, detailed feedback was released. The individual and group work were equally weighted. The overall mark for this assignment accounted for 15% of the total course mark.

The teamwork task in this course was intended to:

- Foster collaboration and build learning communities, something particularly relevant during the first year of study, where most students experience learning in isolation.
- Train students in the process of teamwork from the very first year of their program, to progressively build their capacity in dealing with different team-based situations.
- Provide regular and timely feedback, and help students consolidate their learning, build their knowledge, and make timely decisions concerning their studies.

For those students in in-person teams, groups were self-selected at the end of the first tutorial session. Students who did not attend the first tutorial were allocated randomly. For those students doing the course online, groups were randomly formed.

At the end of each tutorial session, students were given 30 minutes to work on the group quiz. Students attending in-person tutorials met in allocated rooms, whereas students attending the online tutorial met in pre-allocated break-out groups in Microsoft Teams. If students did not have time to finish the group quiz within the allocated 30 minutes, or were not able to attend the tutorial, they were given five days' time to organise alternative arrangements to finalise it.

Given that the main objective of the teamwork task was to foster collaboration and build learning communities, T&L skills were not specifically assessed, although the tutor encouraged and monitored effective communication and accountability.

Challenges

One of the main challenges, which affected in-person and online delivery equally, was the difficulty to have stable groups during the first four weeks (out of ten) of the term. The reason for this was the changing nature of enrolment until Week 4, which is the deadline for students to drop the course without financial and academic penalty. In some cases, enrolment changes involved dropping the course, whereas in others it involved changing the time of the tutorial session. Meeting the requirement of having a minimum of three, and a maximum of four team members in a group became challenging due to these changes, and continuous monitoring and re-structuring of the groups was necessary. Nevertheless, while desirable, having stable groups was not critical for this task, since students submitted their answers individually (even though answers were the same for all members of the same group).

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Another major challenge affecting both in-person and online delivery was the lack of an effective framework to properly introduce and evaluate T&L skills. While students were aware that the tutor monitored communication and accountability, these teamwork elements were not introduced in detail or evaluated, so students underestimated their importance. Also, a single tutor was not enough to formally evaluate the T&L skills in the short time available to work on the activity while in class (i.e., 30 minutes).

In the case of online delivery, an additional challenge was to keep students engaged in the task throughout the term. Given the much more limited interaction between students in the large online tutorial, online students were not as keen as in-person students to use the allocated 30 minutes to work in the group quiz. Instead, since all students were given five days to organise alternative arrangements and finalise the group quiz, most of them chose alternative ways to meet, so it was difficult to monitor teamwork, in contrast to in-person teams.

Outcomes

In the case of in-person delivery, tutorial attendance and participation in the task were very good (85.3% participation in group quiz on average, as per data in Table 1), since students found it more convenient to complete the group quizzes in-person during their tutorial times, rather than looking for a different time to meet. Also, as weeks passed, students felt more comfortable working together, so they did not only collaborate during the last part of the tutorial while doing the group quiz, but throughout the whole tutorial (as solving tutorial problems collaboratively was encouraged). In the case of online delivery, participation in the task was not severely affected (84% participation in group quiz on average), but tutorial attendance was considerably lower than the in-person tutorials, since students did not see any additional value in attending the tutorials to do the group quizzes, given the challenges explained before.

Table 1. Comparison of in-person and online teamwork task in the first-year course

	Quiz 1	Quiz 2	Quiz 3	Quiz 4	Quiz 5	Quiz 6
INDIVIDUAL QUIZ – In-person						
Average Mark (out of 50)	39.15	35.07	21.01	32.02	29.93	34.31
Number of participants (out of 348)	326	327	271	302	305	295
GROUP QUIZ – In-person						
Average Mark (out of 50)	41.93	36.25	25.33	32.11	30.15	34.60
Number of participants (out of 348)	336	324	274	295	275	277
INDIVIDUAL QUIZ – Online						
Average Mark (out of 50)	41.26	33.10	24.38	33.94	31.60	37.90
Number of participants (out of 81)	74	69	68	72	68	72
GROUP QUIZ – Online						
Average Mark (out of 50)	42.00	34.84	26.23	33.69	31.28	34.20
Number of participants (out of 81)	75	71	67	65	68	64

In terms of performance, according to the data in Table 1, group quizzes' performance (33.4/50 on average) was better than individual quizzes' performance (31.9/50 on average) for the in-person delivery. This improvement was expected, given that group quizzes are solved collaboratively; however, the improvement is not very noticeable as the platform used to create the quizzes randomises problem variables and there is no possibility to ensure that all students in a group get the same problem variables. This means that students could discuss the methods to solve the problems, but they still needed to re-do the working. This increases the chances to obtain a wrong response, which is something that does not usually happen when all students get the same problem variables and can check whether their answers match. In the case of online delivery, the performance was identical (33.7/50 on average for both individual and group quizzes), which suggests that the group interactions did not have a major effect in improving students' understanding.

The impact of the teamwork activity has also been assessed by comparing the results from the standardised evaluation tool before (Term 3, 2020) and after (Term 1, 2021) introducing the online quizzes. It is important to note that all course activities and pieces of assessment were identical in both terms, with the exception of the online quizzes, which were introduced for the first time in Term 1, 2021. Feedback provided for all assessment items was also identical, except for the additional feedback provided by the quizzes.

In terms of the first objective of the teamwork task (fostering collaboration and building learning communities), the task was clearly effective, as shown by students' answer to the question "I felt part of a learning community": 94.6% agreement in Term 1, 2021 versus 85.8% agreement in Term 3, 2020. In terms of the second objective (training students in the process of teamwork from the beginning of the program), the teamwork task helped to start building students' capacity in dealing with different team-based situations and made them aware of different behavioural attributes that lead to effective communication, accountability and trust, which were actively encouraged by the tutor. In terms of the third objective (providing regular and timely feedback, and help students consolidate their learning and build their knowledge), the teamwork task was also clearly effective, as shown by students' answer to the question "The feedback helped me learn": 92.8% agreement in Term 1, 2021 versus 86.4% agreement in Term 3, 2020. Specific comments shown below also support the effectiveness of the task in this regard:

"The quizzes helped consolidate content and it was easier to understand concepts."
"[…] this also created a friendly community of struggling students who were willing to help each other simply because we understood the sheer difficulty of the subject."
"The constant small assessments (weekly quizzes) meant that the coursework was ingested as it was presented."

Case 2: Fourth Year Undergraduate Design Course

Electrical Design Proficiency is a final year undergraduate design course with around 130 students. The course involves four separate design tasks with three core topics and one elective topic. This course was not offered online as it is heavily hands-on, but it has been considered in this study to assess the teamwork skills developed in a design-based course and compare them with those in non-design courses (Cases 1 and 3 in this study). It should be noted that in any design course there must be an element of teamwork in the conduct of the project and the assessment, as part of EA Competency Stage 1 (Australia, 2017).

In this course, the core design topics are done individually, but the elective topic, which is more comprehensive, is a teamwork design task. Each elective topic is presented with a description of the project and the objectives, a set of requirements that must be achieved along with constraints, as well as marking criteria. Each team member has a designated role, and all members are encouraged to work together throughout the laboratory time.

Team members have the authority to decide how the team should conduct the teamwork, as it is expected from final year engineering students. The course requirements do not enforce a specific approach to the way teams should operate. Students choose their own team members. In cases where some students are not able to find team members, the course coordinator forms the team with the remaining individual students. As this is a final year course, many students already know each other and are familiar with the strengths and capabilities of other students. Therefore, the teamwork dynamics would be more effective compared to randomly chosen teams. Also, due to the short duration of the elective task (~3 weeks), it makes sense to allow students to choose their team members themselves.

A dedicated mentor is assigned to each team. The mentor observes the teamwork and the interaction of team members in each laboratory session. The teams can discuss some of their design decisions with the mentor and receive feedback on their work from the mentor. The observations recorded are then used by the mentor to award the team performance mark. The weekly feedback from the mentor helps to improve the performance of each team.

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During the final assessment of the task, each team member is interviewed, and the team presents the results to their mentor and an assessor (both are laboratory demonstrators in the course). They must also write a team report outlining how the team assigned different sections of the project to team members, as well as a reflection activity outlining their experience and answering some reflective questions. The final mark is then divided into achieving the requirements (9%), team performance (3%), team report (7%) and understanding of the task (9%, assessed individually).

Challenges

Adapting the course and the teamwork activity to be run in online mode is the main challenge, due to the practical nature of the course. Maintaining the hands-on experience as a major learning outcome would mean that some form of at-home experimentation must be introduced for the online mode. This raises workplace health and safety issues that must be carefully looked at before expecting students to conduct any form of electronics experiment at home. Some realistic virtual experiment could be designed as an alternative for such circumstances where physical lab access may not be feasible.

Another challenge is ensuring a good trade-off between completing team-based design tasks and ensuring development of individual skills and knowledge. Teamwork activities must be meticulously designed to ensure that each team member carries their individual contribution in completing the project equally, as well as to reflect students' skills when working together towards achieving the requirements of the design tasks, so it is necessary to provide a well-structured set of instructions on how each team needs to use daily briefings, minutes taking, and task distribution amongst the members to build the teamwork skills and utilise them in completing the project.

Outcomes

The average teamwork-related marks obtained in this course for in-person delivery were 79.22% for team performance and 82% for team report, which demonstrate good engagement in the teamwork task. In addition to this, the standardised evaluation tool recorded a course satisfaction of 98%. Specific comments shown below further support the effectiveness of the teamwork task:

"The best things were the ability to work with peers to solve problems and being able to see the results in front of us"

"For the question on "I felt part of a learning community" – I normally just 'Agree'. This is the first course where I checked 'Strongly Agree'. […] the way in which it was delivered FAR exceeded my expectations."

As previously mentioned, due to the practical nature of the course, in-person delivery is highly encouraged whenever possible, as introducing online delivery negates the practical hands-on experience required.

Case 3: Postgraduate Course

Electrical Safety is a postgraduate elective course in the power engineering specialisation, with an enrolment of about 200 students. High calibre undergraduate students are allowed to enrol in this course via an approval process. 90% of the students in the course are international students. The teamwork task in this course is a project-based learning task that was introduced to enable students to critically analyse the course content and apply it by presenting solutions for real world scenarios which is best achieved via brainstorming within a team. The teamwork activity in this course requires students to investigate and analyse electrical safety incidents to propose engineering, administrative, related laws and standards and personal protective equipment solutions in the form of a presentation which is marked by industry experts. The course was in-person in 2019 and was modified to be offered completely online in 2020. Teams were assessed in both the offerings using the VALUE rubric (McConnell, et al., 2019). This task contributes 30% towards the course.

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In-person Teamwork

The 2019 offering of the course was designed to be run in collaborative learning spaces shared by multiple teams. There were 199 enrolments and teams of maximum 10 students were created. Teams were formed in random ensuring diversity based on the demographics and gender. This ensured that the prior knowledge of the students in the basics of electrical power engineering was broad enough to manage the teamwork activity, as the students had completed their undergraduate degree in different universities Worldwide. Each team met every week for 1.5 hours during the timetabled class hours, to discuss the teamwork activity. One mentor was allocated to four teams. The mentor acted as an observer and was able to walk around the teams in the collaborative learning space observing their participation and answering their queries. They also marked the individual students in the teams against the VALUE rubric and provided weekly feedback on their team performance. At the end of the term, the teams presented their analysis to industry experts, who marked their presentation and offered their live feedback. The other teams also attended these presentations and were required to provide peer assessment to at least three teams.

Online Teamwork

The 2020 offering of the course was completely run in an online mode. Team formation was done based on geographical location to accommodate people living in different time zones to be able to organise their weekly team meetings with the mentors. Some mentors were also overseas to better coordinate with time zones. An experiential learning approach was adopted with structured teamwork training modules created for every week simulating an industrial environment (Thite et al, 2020), following the Tuckman's model of teamwork development (Bonebright, 2010).

The structure of the team activity was changed in the following ways:

- There were smaller teams of five.
- The final presentation was replaced by a team video presenting the case study analysis which was marked by industry experts.
- Separate team meetings were scheduled exclusive to the class time. There were two weekly meetings of one hour each: (i) Team meeting with mentor and (ii) Team meeting without mentor.
- Team meetings with the mentor included the following aspects in different phases of team building: concept plan, role assignment and rotation, structured tasks and milestones, introduction to teamwork concepts, team building activities, and reflection activities.
- The teamwork topics introduced to students were communication, leadership, accountability and trust, and conflict management. The leadership role was carried out by every team member at least once throughout the term.
- Mentors marked the students weekly against the VALUE rubric. The marks of the teamwork task were then individualised based on this rubric.

Challenges

In the in-person teamwork, the main challenges were: (i) The size of each team (10 students), which made it difficult for mentors to provide personalised feedback to each team member and (ii) Exclusive team meetings among the students themselves were not mandated, so students felt less connected outside the classroom.

In the online implementation, the main challenges were: (i) The time needed for planning, as the team building activities which are usually face to face needed to be chosen and tailored to be able to run online; (ii) Handling and providing feedback to a large number of teams for their case study analysis – for example, in the 2019 offering there were 20 teams of 9-10 students each and hence 20 projects to mark, whereas in the 2021 offering, there were 36 teams of 4-5 students each, so more casual staff were needed to mentor all the teams; (iii) Students did not get the opportunity to meet with the industry experts, although they offered their feedback asynchronously; (iv) Students were not able to look at other teams' video, as there were no opportunities for a general showcase due to lack of time during the term; (v) Some students had challenges in giving their full participation due to poor internet connections.

Outcomes

In both modes, the teamwork assessment was rated as the most helpful learning activity in the course. Table 2 shows the comparison of the 2019 in-person and 2020 online offerings. From the table, it is clear that the online teamwork has produced similar results as the in-person mode in terms of course satisfaction, but students performed better (as indicated by the mean course grade and high distinctions). Additionally, the engagement and collaboration levels in the teams were noticed to have increased in the 2020 online version with an average of 22% improvement of teamwork marks in 76% of students, whereas this was only 12% in the 2019 in-person offering in 68% of students. Due to COVID in 2020, there were 23% of students taking this course online as the first course in the university from their respective countries. The teamwork activity helped them connect with their peers. The response rate on the standardised evaluation tool also drastically increased to 76.2% (highest among all courses in the school) for the online offering, which shows the improvement in engagement level in the course, attributed to the teamwork task.

Table 2. Comparison of in-person and online teamwork in the postgraduate course

Category	2019 in-person mode	2020 online mode
Enrolments	199	172
Course satisfaction	96.5%	96.2%
Response rate on survey	57.8%	76.2%
Course mean grade	69.5%	76.5%
High distinction	2.5%	4.7%

Team bonding and engagement is usually affected negatively in online teams. However, due to a structured approach which included team building activities, reflection activities, and weekly tasks and milestones, the team bonding was counterintuitively noticed to be consistently high for all the teams. This was also reflected in the quality of the final videos. Some other advantages were noted in terms of flexibility and improved work efficiency due to digital means like screen sharing and live documents.

Some specific comments by students in 2020 include:

“Structured weekly meetings with mentors in MS Teams helped us to collaborate well.”
“I enjoyed the online teamwork – a convenient and time-saving activity. Breaking our tasks down into smaller weekly tasks helped us accomplish the overall goal easily.”
“Since this is the first term of my postgraduate study, I loved the way I got connected to my peers.”

Conclusion

Three courses, with different expectations and motivations, have been considered to analyse how in-person and online team dynamics differ regarding strategies and challenges at different levels. The first-year course (Case 1) used online group quizzes to create a learning community, improve feedback, and serve as an introduction to teamwork. The main challenges identified were the difficulty to have stable groups at the beginning of the term due to enrolment changes, the lack of an effective framework to properly introduce and evaluate T&L skills, and the difficulty to keep online students engaged. The fourth-year design course (Case 2) used a teamwork design task to implement T&L skills in accordance with EA Stage 1 competencies. While the teamwork task was evaluated very positively by in-person students, maintaining the hands-on experience as a major learning outcome in an online delivery mode was identified as the main challenge. Finally, the postgraduate course (Case 3) used a project-based learning task to deepen student’s understanding while focusing on improving T&L skills in a more structured, industry-oriented manner. The main challenges identified in the online mode were increased number of teams for marking the task, lack of time in the term to help students watch and peer mark other teams’ videos and the limitations to interact with industry experts.

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In all three courses, students' perceptions of the effectiveness of team learning are shown to be positive, although there was mixed experience in terms of challenges and benefits of online teamwork. In Case 1, there was a drop in engagement during online activities whereas a more structured and scaffolded online instruction in Case 3 showcased improved engagement and bonding within the teams. A similar trend was noticed in the performance of students where Case 1 reported marginally better performance in the in-person mode whereas Case 3 reported an improved performance in the online mode.

Going forward, T&L skills' development requires a more structured and staggered plan for an undergraduate degree incorporating the four pillars of teamwork skills development: team formation, team building, team feedback and team performance. In the case of postgraduate courses, effectively incorporating T&L skills in a staggered manner is challenging, since most of the postgraduate students in Australia are international students, who have maximum two years to complete their degree, can choose their courses (mostly electives) in any order during the program, and have significantly different past T&L experience which is usually on the lower side. A more direct, broader, structured, and scaffolded approach is then required for postgraduate degrees that provides students insights into the expected skills of the Australian industrial work culture.

Overall, this study highlights the importance of supporting and evaluating awareness and development of T&L skills within a degree program, and proposes strategies to do so, highlighting the main challenges to overcome. Although the results indicate that there is no single dominant model for how teamwork skills are developed within an engineering program, such program-wide outlook for online versus in-person teamwork would benefit in informing future blended/hybrid options, post pandemic.

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Supervision and management practices of Final Year Engineering Projects: Impacts of COVID-19 Pandemic

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ABSTRACT

CONTEXT
It is essential that supervision and management practices of Final Year Engineering Projects (FYEPs) maintains the quality of education and achieves AQF Level 8 outcomes even during the unprecedented situation due to the COVID-19 pandemic. In this situation, students cannot attend face-to-face meetings with supervisors, cannot perform practical/laboratory-based research, and cannot use software labs for their modelling and simulation works (if applicable). To achieve learning outcomes at AQF Level 8, some strategies and alternative pathways were developed to overcome the impacts of COVID-19 for supervising and managing FYEPs.

PURPOSE OR GOAL
The goal of the paper is to assess the impacts of the COVID-19 pandemic on the supervision and management practices of FYEPs. The paper also discusses the effectiveness of the technology we used for supervision and management of FYEPs, and how the supervisor and student relationship and engagement can effectively be maintained during this COVID-19.

APPROACH OR METHODOLOGY/METHODS
The traditional modes of supervision and management of FYEPs (theses) such as face-to-face meetings, laboratory works, and use of simulation labs were changed to virtual/online operation only to provide essential feedback and directions to the students for their projects. The online communication and learning and teaching tools such as Zoom links, chat windows, outlook team, etc., were employed for maintaining weekly progress (planned tasks). A Google doc communication channel was also considered for each student to monitor their weekly progress.

ACTUAL OR ANTICIPATED OUTCOMES
The students' feedback suggests that students were generally happy with the new ways of student engagement in FYEPs/thesis supervision and management. More specifically, they indicated that they were very happy with the online presentations of mid-term progress and final presentations (direct zoom presentation or recorded video) which were less stressful as opposed to face-to-face presentations. They were able to concentrate more to achieve project outcomes without spending much time on travelling to university.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
Although there were a few challenges in adapting online supervision and management of FYEPs during COVID-19 pandemic environment, student feedback suggests that they are happy with the online system too.

KEYWORDS

COVID-19 pandemic environment, effectiveness of online engagement with the students, FYEPs online/virtual supervision and management.

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Introduction

It is required that Final Year Engineering Projects (FYEPs)/theses meet the requirements of educational standards and AQF Level 8 outcomes. AQF Level 8 outcomes indicate that the graduates should be able to demonstrate the knowledge and skills gained during their study into their future workplace, community involvement and further learning. AQF8 defines research as systematic experimental and theoretical work, the application and/or development of which results in an increase in the dimensions of knowledge (Australian Qualifications Framework Council, 2013, p. 100). Although in normal circumstances the supervision and management practices of FYEPs varies between universities, disciplines, and countries (Rasul et al., 2015a, 2015b, 2015c; Lawson et al., 2014; Ku and Goh, 2010; Schmid et al., 2012), currently, because of the COVID-19 pandemic, the supervision and management strategies needed to be adjusted to ensure the achievement of the requirements of AQF8 outcomes. Assessment criteria also vary from university to university (Rasul et al, 2015c).

The impact of COVID-19 on various disciplines (such as medical, engineering, science, etc.) are significant. The COVID-19 pandemic presents the biggest challenge on the people's life and day-by-day activities (Wang and Huang, 2021, Ghasem and Ghannam, 2021). A transition rapidly occurred from face-to-face, blended, and flipped classroom modes to distant or online modes (Iglesias-Pasad et al., 2021). This temporary shift of instructional delivery happened suddenly due to the pandemic situation. Various studies have been put forward to quantify the problems and challenges (Rafique et al., 2021). For example, a detailed survey on the impact of the COVID-19 pandemic on final year medical students in the United Kingdom was undertaken by Choi et al. (2020). They surveyed 440 students from medical schools throughout the UK and analysed the impact of COVID-19 on final year medical students' examinations and placements and how it might impact their confidence and preparedness for their foundation training (Choi et al., 2020). The University of Sheffield studied the impact of COVID-19 for Aerospace Engineering students (University of Sheffield, 2020). More information on effective teaching and examination strategies for undergraduate learning during COVID-19 school restrictions can be found in recent literature (George, 2020). A focus was made to study the student learning through remote teaching due to the COVID-19 pandemic (Iglesias-Pradas et al., 2021, Silva et al., 2021).

There are benefits and drawbacks of the COVID-19 pandemic. The face-to-face academic classes were transferred to online/remote classes which generates changes in teaching and engagement routines. Silva et al. (2021) concluded that the online classes tend to minimise the overall evaluated impacts. The authors proposed a hybrid student engagement model for their learning. As a result, they estimated that overall impacts could be minimised by 57% (Silva et al., 2021). Rafique et al. (2021) pointed out that the new pedagogy of teaching methods also inspired and motivated students to learn through computers and the internet. On the other hand, Ghasen and Ghannam (2021) concentrated on student interactions with their academics and articulated that limited student interaction occurred during online lectures. Generally, there were less than 20% attendance in lecture and tutorials. Hence there were problems for graduating students for their final year thesis as the students encountered problems in achieving effective technical discussions with their academic supervisors (Ghasen and Ghannam 2021).

With the diverse background of student cohorts (school leavers, mature age, and students from diverse cultural backgrounds in distance and multi-campus modes) at CQUniversity, it is important to ensure that the students meet the requirements of AQF8 learning outcomes and are also satisfied with the delivery, supervision and management practices of FYEPs. The main purpose of this paper is to assess and report the impact and effectiveness of recently adapted virtual/online supervision and management of FYEPs in the COVID-19 pandemic environment. The paper also reports how the supervisor and student's relationship, and engagement were effectively maintained at a distance during the COVID-19 situation. While

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the effectiveness of online supervision and management practices of FYEPs is still not clearly understood, this study is very important in that it gives us clear indication on how students were engaged and what was their overall satisfaction on FYEPs supervision and management.

Methodology

The traditional modes of teaching each FYEPs student includes face-to-face meetings, experimental/laboratory works, computer simulations using software labs, etc., to provide essential feedback and directions to the student for successful completion of their FYEPs. Given the recent/current COVID-19 pandemic situation, online learning, and teaching tools such as zoom links, chat windows, news, and discussion forum, Microsoft team, etc., were employed for weekly scheduled tasks. A Google doc communication channel was also created for each student to monitor their weekly progress. The effectiveness of online supervision and management practices of FYEPs is still not clearly understood. The data base linked to online supervision and management is still in its initial stages. As this practice has so far only occurred in 2020 – to date, both students and facilitators are yet to develop full protocols and procedures for online supervision and management. This study presents the methodology used for supervision and management of FYEPs and analyse the effectiveness of employing these practices based on feedback from 2020 at CQUniversity. One of the frameworks used for online supervision and management of FYEPs students can be represented in Figure 1.

The use of experimental facilities, software labs and face-to-face meetings with students are restricted during COVID-19 period. The progress meetings, student engagement, online demonstrations of simulations, etc., were done through the link between A and B in Figure 1. Both A and B are linked with C for progress presentations and final project presentations, again through zoom.

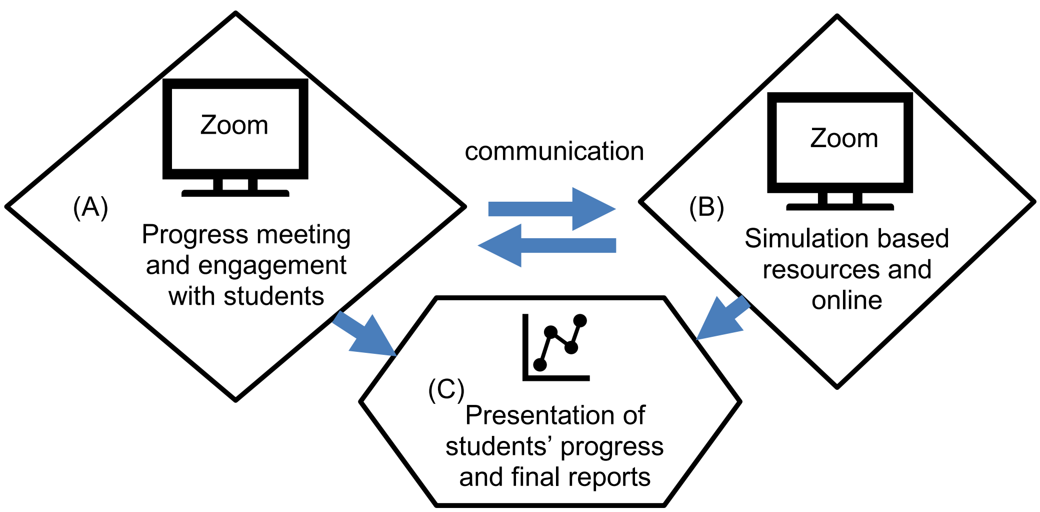

Figure 1: The supervision and management of FYEPs during COVID-19 Pandemic (modified from Mandal and Rasul, 2020)

In addition, using social networks such as Facebook, LinkedIn, Skype, Google, etc are also a trend for online supervision and management of FYEPs as all the information can be digitised in online perspectives which helps to convey knowledge to support student learning. Supervisors and students can talk virtually. Online and flexibility of communication can provide continuous feedback, irrespective of whether supervisors are away from the institution, in another geographic location or in any other situation. Frequent use of emails is also an essential media during COVID-19 pandemic, it has advantage of online learning via

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written correspondence. Email, skype, etc have their own advantages to communicate with the students for any update, difficulties, progress, etc.

Results and Discussion

The study investigated the effectiveness of zoom sessions for progress meetings, engagement with students, feedback to student's submissions, how to prepare good presentation slides, ongoing progress, and final presentations. These sessions were recorded for use after hours if they needed to refer to again for any information which were not clearly understood during zoom meetings. Within Term 1 2020, there was no consensus on matters of how to best supervise project students online, how regularly to meet and for how long with groups of students or individuals. As usual, the issues around quality of supervision were related to knowledge gained and students achieving quality learning outcomes as measured by their grades. There was some concern about variations in online supervision style between academics and teaching facilitator. Most of supervisors were quite methodical regarding checking progress of each agreed/scheduled item and taking notes/minutes during the meetings. Weekly meetings are more appropriate and effective, and most of the supervisors organised weekly meetings, 30 minutes to one hour. It can be noted that the research projects that were primarily based on laboratory work were most challenging and finally they were revised as computational and simulation-based projects during COVID-19. They did simulations using the relevant software (if freely available online) and validated their model using the data available in the literature. However, most of the students did not have access to a software lab because the CQUniversity campuses were closed.

What needs to be done or can be done to reduce the impact of COVID-19 for maintaining progress of research students should be correctly identified (Mackenzie, 2020). Scheduling regular meetings is simple and makes it easy to maintain contacts with supervisors while they are off campus. It was evident that the supervisory meetings and relationships at a distance should continue as much as possible, even during non-COVID time. This can be successfully done through developing tailored processes to avoid the impacts of the COVID-19 circumstances. Understanding each other's (i.e., students and supervisors) point of view through online/zoom meetings was important. Review of working practices were needed to settle on a mutual understanding of regular progress. Consideration should be given regarding how to arrange any variation on agreed weekly plans/tasks. In addition to the zoom/chat windows/outlook team meetings, emails and phone calls were/can also be used for maintaining scheduled progress and agreed plans. For zoom meeting, documents should be sent in advance of the meeting date so that participants can read and be fully prepared to talk about them. Screen sharing is a wonderful option for zoom meetings. Although all supervisory relationships are different, there are opportunities to create friendly/good will relationships with students through zoom meetings. Making notes/minutes during remote meetings is another key point during online conversations. There are no problems with joint supervision through zoom or any other form of virtual communication.

The students mentioned that weekly meetings with their supervisor cover weekly requirements and milestones including project scope, literature review, preliminary results, presentations, etc. Through zooms, students from various locations can communicate with the project advisors to sort out the templates and requirements of each required item confidently. As the COVID-19 problems have only recently occurred, detailed quantitative data are not available yet, rather the authors focussed on their own reflections and student feedback for modifying the processes of online supervision and management. It was realised that, although the students were not in the face-to-face mode, the communication and engagement was still at a high level. The authors noticed a gradual improvement on documentation focussing on the template and style of presentation covering the technical content of the set tasks. It was fruitful to ask students to present weekly progress through screen sharing and power point slides. Zoom recording was also another excellent option to

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revisit/navigate later what was discussed and agreed upon for maintaining regular progress before next meeting.

There were mostly positive comments provided in CQUniversity's students' evaluations. The online supervision of mature and working students was very attractive to them. The students indicated that, during weekly zoom sessions (by unit coordinator and individual supervisor) on various aspects of project supervision, feedback, and suggestions, it was very useful to listen to how other students were travelling with their projects. The weekly progress reports and meeting minutes submitted online in the same week of a meeting were a very useful exercise as it forced to prepare what will be the contents and quality of online progress submission. In their evaluation/feedback, students expressed that "Unit coordinator of the planning unit explained all the requirements of assessment tasks clearly in the lecture sessions conducted and precisely listed the requirements in unit's Moodle site. Question and answer sessions conducted by the unit coordinator were helpful for completing the assessment tasks. Academic advisor of my project responded to all my questions and pointed me in the right direction throughout planning phase of the project" (Term 1 2020, Thesis planning feedback). Some students from the thesis implementation unit indicated that they were happy to see some weekly videos covering what needed to be done. Generally, students liked the zoom final presentations and indicated that it was a less stressful way to give a presentation, as opposed to a face-to-face presentation which is very stressful for them, sometimes, some students become nerves. They indicated that they gave a better-quality presentation through zoom, compared to face-to-face.

Other important points stated by some individual students in their Term 1 2020 feedback are *It has been my pleasure to work under your guidance. You have been helping me throughout the planning and implementation phase of the project by providing your valuable guidance, report writing style, etc. I am very glad to work with you. I am thankful to you. I hope you stay safe and healthy (Student feedback 1)*. Another student feedback was *It is very helpful throughout the term. He arranged weekly meeting to solve the technical and non-technical issues regarding the project problems. He explained very well how to improve the presentation and thesis writing. He explained how to connect the figure with text, and which points I need to include in thesis to improve the quality of writing. Overall, the weekly meeting and feedback given by him was very helpful to improve the quality of writing and how to complete the task within the time frame (Student feedback 2)*. The student feedback 3 also provided some interesting comments – *It was very good, and we learned a lot, also you helped me to manage my deadlines and taught me how to improve my work day-by-day and the thing you did for us was very appreciable that you work on weekends to meet our deadlines during this critical time*.

Students and supervisors have freedom of ambiance and locations as they can be at any geographical location, only limited by internet access (Hamzah et al, 2017). During COVID-19, usefulness of supervision and management of FYEPs were scored about 4.5 out of 5 on things such as the increase in quality of work, more control over the work, get the things done faster, increases in productivity, support critical aspects, enhances effectiveness of thesis works, etc (Ismail et al, 2020). During COVID-19, technology/online media was a right medium for students and supervisors to share information, update project/thesis progress, project presentations, interaction with peers, etc. It could be more effective for those students and supervisors who have strong skills and up to date knowledge in using digital technologies. It is fair to say from student feedback and the authors own reflections that the students were generally happy with the online methods of student engagement, supervision, and management of FYEPs. The students' weekly communication and presentation on set tasks, and their progressive and improved content in Google doc indicated student learning was well evident. Social interaction through online media should not be neglected compared to face-to-face meeting and discussion (Ismail et al, 2020).

Innovation lies in the development of a 'virtual supervision' tool that enables both stakeholders (supervisors and students) communicate effectively at any time through the different digital technology/platform mentioned above. Outcome mentioned by Ismail et al. (2020) put an argument that online supervision improves quality of work, productivity, effectiveness on job and job performance, accomplishment of tasks more quickly etc. Earlier, Bender and Dykeman (2016) reported that both traditional and online supervision have same efficiency. These achievements and outcomes clearly satisfy the requirements of AQF8 learning outcomes which are defined by "graduates are expected to demonstrate knowledge and skills for initial work, community involvement and further learning" (AQF, 2013). Broadly, students achieve cognitive skills through synthesizing knowledge, identifying solutions to complex problems with intellectual independence; (ii) understanding a body of knowledge and theoretical concepts; (iii) exercising critical thinking and judgement in developing new understanding; (iv) designing and presenting research outcomes to a variety of audiences, and more mentioned in AQF learning outcomes. Some limitations such as technology/software faults (noise, presentation modes/recording, sudden WiFi loss, power supply, etc) which interrupt in efficiency in online supervisions can be noted.

The proper implementation of online supervision and management of FYEPs could develop students' ability and improve performances which could benefits both supervisors and student. Development of tools to compare different online technology individually to evaluate whether each technology can achieve AQF outcomes could be a topic for future research. Another interesting future research could be an assessment of effectiveness of mixed mode supervision i.e. combination of face-to-face and online supervision.

Conclusions and Recommendations

The paper presented and analysed the impact and effectiveness of introducing online supervision and management of FYEPs during the recent COVID-19 pandemic situation. Although there were a few challenges in adapting to online supervision, student feedback from Term 1 2020 suggests that they were generally happy with the ways we managed the projects and the strategies developed to avoid negative impacts on learning quality of FYEPs. The students said that they were able to concentrate more to achieve the learning outcomes of the projects instead of spending much time travelling to university. The supervision and management practices of FYEPs during this COVID-19 situation can ensure that universities are still able to meet the requirements of AQF8 outcomes. Despite the challenges now on how to incorporate supervisory inputs during COVID-19, this study indicates that the online technologies and social networks can improve students' productivity, effectiveness, and performance.

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A comparative analysis of student learning experience in face-to-face vs. fully-online

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ABSTRACT

CONTEXT

The last several years have witnessed both gradual and dramatic changes in the nature of learning and teaching delivery. In particular, online learning continues to gain momentum as it capitalises on evolving technology and provides the flexibility of place or distance. Whilst online and face to face learning share many fundamental aspects for both student and educator, there are significant differences which require carefully considered pedagogical design and approaches. For instance, with appropriate learning design, online learning provides new opportunity for learners to develop independence in their learning. Overcoming the challenges of designing and delivering learning activities for an online learning environment require planned and pedagogically sound intervention. The Melbourne Polytechnic Blended Learning Model (MPBLM) was developed to provide a quality learning experience for students across vocational and higher education programs where any form or degree of online learning delivery was included. The MPBLM sets standards for the curriculum design of a learner-centred approach to learning consistent with the Melbourne Polytechnic vision of developing the capabilities of students for industry readiness and to thrive in a rapidly changing world.

PURPOSE OR GOAL

Educational institutions need to understand the impact of changes to education delivery, especially where this has occurred at short notice due to exceptional circumstances. Student learning achievement review ensures whether quality outcomes are maintained. If student learning has been compromised, remediation may be necessary to ensure students' longer term educational goals. If student learning has been enhanced, identified practice improvements can be used to strengthen educational delivery going forward. The objective of the study is to establish, using already available quality indicators, whether the shift from essentially face-to-face delivery to fully online, at extremely short notice and in the context of a pandemic, impacts student learning achievement.

APPROACH OR METHODOLOGY/METHODS

Learning and teaching strategies and the resulting student learning achievement will be considered for two consecutive offerings of a third-year engineering unit which was first offered in essentially a fully face-to-face mode and later as fully online, necessitated by the recent lockdown in the following year. The two offerings of the same subject are contrasted according to their approach to and ability to meeting the MPBLM standards. The student learning achievement is also compared for each offering using a number of readily available standard indicators.

ACTUAL OR ANTICIPATED OUTCOMES

The results of the study show student learning achievement could be maintained in fully online learning delivery provided appropriate strategies were applied to facilitate the short notice pivoting from fully face to face delivery.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Our study contrasted two delivery approaches to the same subject using the standards for quality learning design provided the MPBLM. Student learning achievement for the face to face delivery and the fully online delivery were found to be comparable. The study results show student learning achievement can be maintained through a fully online learning delivery provided that appropriate strategies are used. The study provides a method for comparing subject delivery which utilises existing quality data and is therefore useful for establishing learning quality when unexpected subject delivery changes are necessary. Further research is warranted due to the limitations of the study around relative impacts of specific elements of delivery approach, the nature of the sample size and single cross-sectional data.

KEYWORDS - Blended learning model, online learning, comparative study

Introduction

The last several years have witnessed gradual and dramatic changes in the nature of learning and teaching delivery. In particular, online learning continues to gain momentum as it capitalises on evolving technology and provides the flexibility of place or distance. Whilst online and face to face learning share many fundamental aspects for both student and educator, there are significant differences which require carefully considered pedagogical design and approaches. Online learning can provide new opportunity for learners to increase interactions, communication, motivation and participation (Gedik et al., 2012) and develop particular educational leadership skills such as time management, reflective thinking and independence in their learning (Namyssova et al, 2019). Online learning is not about simply adding digital technologies to the traditional face-to-face curriculum (Vaughan et al, 2017) rather an online learning environment needs to overcome the challenges of designing and delivering learning activities on the online platform with the use of planned and pedagogically sound intervention.

The world was unprepared for the Covid-19 pandemic. In the face of major disruption, all sectors scrambled to find work arounds which meant they could continue to function as close to normally as possible. Education was no less impacted, as hitherto normal on-campus learning opportunities were moved fully online at short notice to accommodate lockdown requirements. The enabling capacity to immediately pivot to fully online delivery was welcome, however for many it was unanticipated, and so changes to students' learning experiences could understandably lead to changes in learning achievement. This paper gives consideration to understanding changes to the student learning experience arising from the move to fully online learning delivery and seeks to identify and apply a process to determine if learning achievement has been impacted by this move. The approach utilises readily available learning achievement and quality indicators, providing a model for a straightforward 'health check' of student learning which can be easily applied.

The paper is structured as follows: the next section presents some comparison of face-to-face vs. online learning approaches and impacts. This provides a theoretical basis for the two delivery approaches utilised in this study. That is followed by a description of the paper's methodology which introduces the Melbourne Polytechnic Blended Learning Model (MPBLM) as the set of standards for delivery which both delivery approaches aim to achieve and which provides a framework for comparing these. The application of the MPBLM in a subject offered to engineering students in two different delivery approaches is then presented. The paper concludes with a summary and an outline of areas for future research.

Face-to-face vs. Online Learning

Face-to-face classroom learning provided the primary method of learning and teaching over several centuries. A face-to-face instructional method provides a number of benefits not found in online learning (Xu and Jaggers, 2016). Face-to-face classroom instruction can be extremely dynamic providing real time interaction and stimulating innovative and scaffolding questions which respond directly to learner need. On the other hand, online learning provides benefits such as program choice and time efficiency (Wladis et al., 2015); the freedom to communicate with instructors, address classmates and complete assessment tasks from any internet accessible point quality education without sacrificing work time, family time and travel expense (Richardson and Swan, 20013) and flexible study hours (Lundberg et al., 2008). Combining both face-to-face and online learning, the University of Waterloo (2015) and the University of Queensland (2021) report significant success in flipped and blended learning at a number of institutions.

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Despite recent reports advocating online education, researchers still question its ability to provide desired learning outcomes. Research is still conducted on the effective use of the online learning platform. Financial viability, provision of pedagogically sound online learning, achieving a quality student learning experience and desired student academic performance and the gradual transformation of students from learners to professionals are now being carefully considered when determining whether online education is a sustainable and effective substitute for face-to-face learning. In this context, the current study aims to understand whether the pandemic mandated move to fully online learning delivery maintains learning outcome achievement.

Blended Learning Model

The Melbourne Polytechnic Blended Learning Model (MPBLM) was developed to reflect the breadth of ways for applying blended learning across vocational and higher education programs and to provide a quality learning experience for students. This blended learning model is intended to retain a learner-centred approach of learning and to support the Melbourne Polytechnic vision of developing the capabilities of students for industry readiness and to thrive in a rapidly changing world.

The MP definition of blended learning is: *"Blended Learning at Melbourne Polytechnic means that you will be connected to your learning and assessment through a combination of in-person and technologically enabled experiences. Your study will be supported by teachers and resources available to you through scheduled classes and workshops held on campus and online. Blended Learning offers the best mix of the flexibility of online learning with the benefits of the personal experience of face to face learning.''*

The MP blended learning model is underpinned by a set of standards to support a quality learning experience for MP students. These standards outline a student-centred approach achieved by the provision of: (i) A safe online learning environment; (ii) Flexible access to learning materials that are current, aligned and engaging (fully developed, comprehensive, consistently presented to a high standard); (iii) Assessment tasks that are aligned and relevant; (iv) Regular and relevant communication from their teachers; (v) Opportunities to interact and collaborate with peers; (vi) Meaningful opportunities to have input into their learning (student voice); (vii) Learning experiences that (a) utilise a range of contemporary teaching and learning strategies, (b) include purposeful use of technology, (c) engage students to develop contemporary skills for life and work, (d) enable students to demonstrate higher order thinking skills; (viii) Opportunities to give and receive feedback (to & from teachers; to & from peers); (ix) Opportunities to use technologies to find, use and disseminate information; (x) Appropriate support in their learning journey, including support in the use of technology (Melbourne Polytechnic, 2020).

In practice, the MPBLM provides the flexibility of choosing appropriate synchronous (face-to-face or online real-time lecturer-led instruction) and asynchronous (self-paced) components for delivering a particular subject provided that the standard framework is maintained.

Methodological Approach

Learning and teaching strategies and the resulting student learning achievement were considered for two consecutive offerings of a fourth year engineering subject. The first of which was offered in essentially a face-to-face mode with some online components (pre-pandemic) with the second offered fully online, as necessitated by the pandemic related lockdown the following year.

The MPBLM standards are used as a framework to compare the delivery of the two offerings. The learning strategies used to address each standard are presented.

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The student learning achievement was compared for each offering using a number of readily available standard indicators. Similar to other research, grade distribution and student experience questionnaire results are compared (Johnson, Aragon, Shaik, 2000), although unlike Johnson et al., no specifically designed data collection was undertaken. Grade distribution comparison indicates educational outcomes achievement. Student experience questionnaire results indicate the extent to which students believe they achieved learning that was relevant and appropriately delivered in this study, however, assessment submission rates are also compared to round out an overall indication of student learning achievement. This provides an indication of learning achievement in relation to student participation.

Differences in student learning achievement and delivery approaches are reviewed and compared to other studies in order to assess the validity of the approach. A selection of the comparative data is then discussed in relation to possible impact on student learning achievement.

Results

The results below describe two deliveries (face to face and online) of a third-year engineering technology subject against the MPBLM standards (Table1).

The subject covers issues related to traffic flow and transport planning. This subject aims to equip students with necessary knowledge and skills to survey traffic distribution and flow patterns and to develop related traffic engineering or transport planning solutions. The subject is usually delivered face to face without a laboratory component over13 weeks. Both offerings of the course covered the same topics and the same instructor facilitated both modes of delivery. Approximately thirty students undertook each class, a large majority were international students, where English was their second language.

Table 2 shows the student mark distributions for the two modes of delivery. There are some variations in the grades obtained among different categories in these two modes of delivery, however, there is very minor difference in the average mark for the face-to-face class (67.1%) and the online class (68.7%).

Table 2: Distribution of student grades for two modes of delivery

Mark range	Face-to-Face (% of Class)	Online (% of Class)
80 – 100%	8	13
70 – 79%	33	35
60 – 69%	46	30
50 – 59%	13	22

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Table 1: The Blended Learning Model of selected Standards applied to two modes of delivery

MPMPBLM Standards	Face-to-face version	Fully online version
(i) A safe learning environment	Common to both: Allowing students to be openly expressive and celebrate student work in different ways.	
	Use of a list of classroom guidelines that are supposed to be followed by each participant.	*Use of a list of online protocols that are supposed to be followed by each participant.*
(ii) Flexible access to learning materials that are current, aligned and engaging	Common to both: All learning materials were approved as current and aligned. Subject guide, lecture notes, exercise sheets, some worked solutions, and references to web-based resources were available to student via the LMS.	
	Additional learning resources were available in hard copy via the library and as handouts in classroom settings.	*Additional synchronous class sessions (lectures, workshops and tutorials) were recorded and uploaded to the LMS.*
(iii) Assessment tasks that are aligned and relevant;	Relevant assessments were conducted both in-class and online submissions. All assessments were the same in each delivery excepting the exam with the following modifications.	
	Final exam - the weighting of MCQ to problem solving questions = 20:80.	*The structure of the online exam differed from the face to face version with a randomised MCQs order, so each student had a unique exam paper. Weighting of MCQ to problem solving changed to 50:50.*
(iv) Regular and relevant communication from their teachers	The main communication opportunity was provided during face-to-face class sessions and synchronous online sessions. This was supplemented by asynchronous means (such as emails).	
(v) Opportunities to interact and collaborate with peers	Common to both were in class (synchronous) whole-group discussions and small group discussions were featured and a key part of the learning approach. The face-to-face did this in the classroom, the online version used zoom whole group discussion and break-out rooms.	
(vi) Meaningful opportunities to have input into their learning (student voice)	Common to both were opportunities for students to provide input into their learning experience, during both face-to-face class sessions and synchronous online sessions and, also by asynchronous means via emails or LMS discussion forum in both delivery modes.	
(vii) Learning experiences	Common to both: Students were provided with - • explicit class learning intentions with success criteria • a well-planned lesson structure with appropriate sequencing of learning activities, • a learning process to build on and connect to existing knowledge *For online only: an asynchronous pre-introduction of selected content and a recorded synchronous lecture video for self-paced post review was made available*	
(viii) Opportunities to give and receive feedback (to & from teachers; to & from peers)	Common to both: • written feedback from the lecturer and comments from student peers • instant probing for learner understanding using thumbs up/down (online via zoom reaction tool).	
(ix) Opportunities to use technologies to find, use and disseminate information	Common to both were in-class small discussion groups to find, use and disseminate information. The face-to-face mode offered this in the classroom, the online version used zoom whole group discussion and break-out rooms.	
(x) Appropriate support in their learning journey	Common to both: students were encouraged to use library sessions to enhance their capability in the use of technology.	

Figure 1 presents the submission rates of the weekly assessment tasks for both modes of course delivery. The weekly submission rate was a few percentages higher for the MPBLM mode in comparison its face-to-face counterpart.

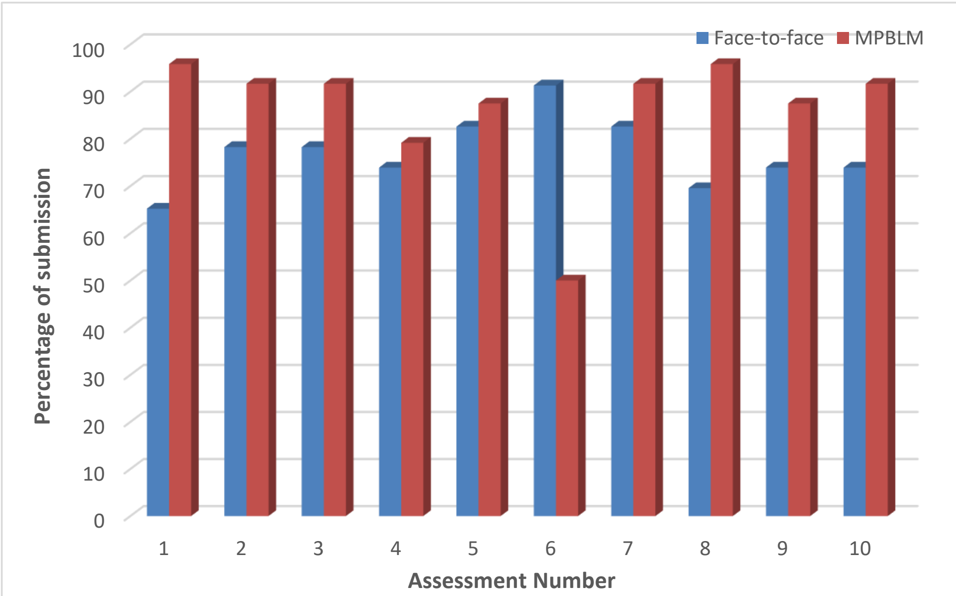

Figure 1: Submission rates of weekly assessment tasks

Table 3 shows the student opinion surveys for these two modes of delivery. The responses indicate that the online delivery has a slightly better response in comparison to face-to-face delivery, however, there is not significant difference between these two modes of delivery. The average changes from 4.28 (face-to-face) to 4.30 for online delivery.

Table 3: Subject evaluation questionnaires, each out of five

Mark range	**Face-to-Face Class**	**Online Class**
Achieve learning outcomes	4.27	4.30
Appropriate assessment	4.27	4.35
Helpful and timely feedback	4.27	4.35
Manageable workload	4.18	4.20
Appropriate learning resources	4.27	4.20
Relevance to future career	4.36	4.35
Professionally relevant skills development	4.27	4.25
Learning stimulation	4.27	4.35
Overall well taught	4.36	4.30
Overall quality of subject	4.27	4.35
Average	4.28	4.30

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Discussion

Impact on Student Learning Achievement

All three of the selected measures (moderated grades, assessment submission and SEQ results) show no significant student learning achievement difference between the face-to-face and online deliveries. This finding is consistent with other studies comparing online and face-to-face delivery (Dell, Low, Wilker, 2010; Johnson, Aragon, Shaik, 2000), albeit, some different measures were used across these studies. These findings show student learning achievement was maintained and therefore suggests students were not disadvantaged by the change in delivery mode.

Comparison of Learning and Teaching Strategies

Appropriate learning design of a subject has greater impact on student learning achievement that the delivery mode, face-to-face or online (Dell et al., 2010). The learning and teaching strategies were selected and applied in this study in order to compensate for the move to online learning and to achieve best opportunity for student learning achievement suggests these appropriate choices.

Significant commonality of learning and teaching strategies across the delivery modes is shown in the MPBLM standards in Table 1. These commonalities include an asynchronous pre-introduction of selected contents, an explicit learning intentions with success criteria, a well-planned lesson structure with appropriate sequencing of learning activities, a learning process to build on and connect to existing knowledge, an encouraging learner participation environment to develop interest and curiosity, an alignment of the learning goal with the relevant assessment task and an instant probing for learner understanding with the provision of effective feedback.

Differences in learning and teaching strategies included a series of online protocols for safe learning environment, an asynchronous pre-introduction of selected content, pre-reading resources to allow substantial class time on discussion and active learning during synchronised online classes, an availability of recorded videos of online classes tin the course learning management system (Moodle) for post-review and a restructuring of examination format with changed ratio of MCQ to problem solving styled quesitons.

These differences seem to provide a mix of benefits and challenges to student learning in the online learning mode. Students will have benefitted from the increased availability of learning materials in the online mode. Recorded class sessions were available to be reviewed by students asynchronously. Capturing this discussion is especially valuable for students whose first language is not English. In contrast, students may have been disadvantaged by exam format changes. Where MCQs replaced some problem-solving questions, students may have missed out partial marks for their working. Further, designed activities for socially constructed learning may be less effective in an online environment. For instance, using breakout rooms can be more difficult for the lecturer to monitor and support group work and discussion.

Impact of Lockdown

The effect of a lockdown online delivery compared to a non-lockdown delivery is not possible to determine from the study, however, it is likely that lockdown influenced student learning achievement in addition to the shift to online. Kapasia et al. (2020) found negative impacts of lockdown on student learning associated with student wellbeing, whilst Aristovnik et al. (2020) found students suffered from uncertainty and impacts on personal circumstances, whilst students were still satisfied with their learning experiences. Thus, compensating effects may well have resulted in mediating the impact of student learning during lockdown.

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The shift to online learning may also offer this student cohort additional benefits. Online learning has been shown to set students up for stronger learning achievement in subsequent subjects (Burns et al., 2013).

Limitations and Learning Going Forward

This study aimed to show a straightforward method to indicate the shift to online learning due to lockdown did not disadvantage students. The method presented uses readily available measures. Other studies (for instance Dell et al., (2010) and Thompson (2000)) comparing online to face-to-face delivery include student demographic data and additional data collection on student assessments etc. This study has not undertaken this additional data collection, and this might be seen as a limitation. Nonetheless, the study results have been consistent with these other studies. This strong alignment in outcome of this study, despite these limitations, suggests the method provides an acceptable ‘health-check' of the delivery and validation of the teaching and learning ‘work-arounds’ implemented when pivoting learning delivery in a time of disruption.

Conclusions

The study presented the application of the MPBLM in a lecture-based face-to-face format with some online components and a fully-online version and compared student learning experiences between these two different modes of delivery. The MPBLM provides the flexibility of choosing synchronous (face-to-face or online real-time lecturer-led instruction) and asynchronous (self-paced) components to deliver a particular subject keeping the standard framework. The fully-online delivery strategies intended to, at a minimum, maintain and ideally enhance the learning engagement of engineering technology program students in the lockdown period. The study results show no significant difference in student experience between online and traditional classroom students outcomes, suggesting learner engagement can be maintained in fully-online delivery provided that appropriate strategies are used. The study suggests the application of fully-online version of the MPBLM means students were not disadvantaged by the mandated move to online learning arising from the pandemic lockdown. Significant commonality of learning and teaching strategies exit across the delivery modes.

This study presented a straightforward method, using readily available qualitative and quantitative indicators, to compare the two delivery modes. This study has not undertaken this additional data collection, and this might be seen as a limitation. Nonetheless, the study results have been consistent with these other studies. This strong alignment in outcome of this study, despite these limitations, suggests the method provides an acceptable ‘health-check' of the delivery and validation of the teaching and learning ‘work-arounds’ implemented when pivoting learning delivery in a time of disruption. However, further research is warranted due to the limitations of the study around the nature of the sample size and single cross-sectional data.

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Pandemic exacerbating Work Integrated Learning experience for International Students in Australia

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ABSTRACT

CONTEXT

The key purpose of Work Integrated Learning (WIL) is to offer domestic and international students the opportunity to explore and participate in real-life projects offered by industry or community integrating theory with practice. There are a variety of structured activities, for example, internships, field trips, industry guest speakers, and the industry or community projects. These activities are aligned with students' needs in gaining professional experience and enhancing their employability skills, as well as with engineering curriculum requirements. The literature presents numerous papers discussing students' WIL practices and students' expectations; however, it becomes more complex when international students need to be prepared for and made capable of understanding and navigating the cultural nuances and workplace differences. Previous studies (Jackson, 2017; Jackson, Rowbottom, Ferns, & McLaren, 2017; Kaider, Friederika; Suri, Harsh; Read, Wayne; Russell, Leoni; & Marlow, 2020) discussed the relevance of WIL program and the difficulties faced by the international students in Australia.

PURPOSE OR GOAL

In addition to providing equal opportunity to domestic and international students to gain hands-on skills and job readiness via WIL activities, the industrial experience component is compulsory for accreditation purposes in most engineering courses. This study aims to evaluate international students' experience and challenges faced by them in seeking local industry placements. Naturally, some strategies published previously do not address the COVID-19 situation and its effects on WIL. The pandemic has introduced significant challenges in effectively implementing WIL and industry placements. This paper observes and evaluates the current challenges faced by international students in gaining meaningful experiences. It also seeks to better understand students' perspectives and assess the effectiveness of the mitigation strategies put in place during the pandemic

APPROACH OR METHODOLOGY/METHODS

Exploratory research is the most suitable method to support the main objectives of this study. Desktop research covers recent journal and conference publications in the field, government statistics, and reports from Engineering Educational institutes. The questionnaire-based on the Likert scale will provide insights of student motivation level with industry placement, job readiness, and knowledge gain of local professional practice. The semi-structured interviews include questions focused on new technical and personal skills gained to enhance students' competitiveness to find a job in the engineering industry under the global pandemic scenario

ACTUAL OR ANTICIPATED OUTCOMES

It is ongoing research that will be completed in the coming months. Currently, international students require more support to overcome the challenging time due to COVID-19. The anticipated outcomes include the new challenges associated with work integrated learning programs posed by COVID-19 and the effectiveness of various measures in conquering the difficulty.

KEYWORDS

Industry placement, international students, work-integrated-learning.

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Introduction

Australia is one of the most popular destinations for international students. Recent data (2019–20) from the Australian Bureau of Statistics (ABS) show that international education contributed $37.4 billion to the Australian economy. Furthermore, Higher Education accounted for 68.1 % of international education export income in 2019–20, and 47.4 % of all overseas student enrolments in 2020 (APH,2021).

To ensure the stability of the Australian Education sector in attracting and retaining overseas students during the pandemic period, it is imperative to observe that international students desire a combination of qualifications from reputable institutions and local work experience to enhance their chances to succeed in their professional career.

Work Integrated Learning (WIL) is a superset that covers a variety of experiences aimed to expose students to work-related tasks and integrates academic learning with its practical implementation in the workplace. Engineers Australia is the national competent authority responsible for the accreditation of engineering education programs in Australia. In their guidelines for accreditation, exposure to engineering practice through various activities including work placement is strongly advocated by Engineers Australia (Engineers Australia, 2008). The demand for embedding WIL in Australian universities and institutes of higher education is driven by three distinct stakeholders: government, industry, and students. WIL is being considered as a means to address the national skill shortage and can also provide a head start to the fresh graduates in the relevant workplace (Edwards et al., 2015). It is reported that the graduating engineers have significant gaps between their capabilities and those mandated by their relevant engineering field of practice (Male, 2010). This is exacerbated by engineering science rather than practices and applications being the main focus of engineering education (Sheppard et al., 2009). Students tend to develop misperceptions about engineering practice and inconsistent professional identity as a result of a lack of in-built focus on hands-on practices (Fletcher, 2001). Furthermore, the expectation of learning theory without substantial exposure to the practices promotes confusion among the students as they cannot understand the context or relevance. The skill gap and skill shortage of Australian engineering graduates were identified and addressed in a 2008 report. The importance of exposure to engineering practice in undergraduate curricula was emphasized as an important strategy to address skill gap and skill shortage. Engagement with industry was one of the 6 recommendations made in the report to maintain Australia's engineering enterprise into the future (King, 2008). After identifying the on-going need to tackle skill-gap and skill-shortage in the engineering sector, another rigorous exercise of reviewing relevant literature, consulting Engineers Australia, consolidating survey results from 17 universities and interviews and focus groups with academics, industry members, and students was carried out and very detailed and informative guidelines for effective industry engagement in Australian engineering degrees were proposed as a part of a national project (Male and King, 2013).

Many Australian universities and institutes of higher education have opted to make the engineering students responsible for acquiring 12 weeks of industry placement in order to address mandated requirements of WIL by EA (Male and King, 2019).

Despite being instrumental in equipping new engineering graduates with the much-needed employability skills and bridging the skill gap, WIL comes with its own set of challenges. Several factors including privatisation of previously state-owned engineering infrastructure, engineering-based manufacturing moving offshore, and rise in contract-based engineering services require arduous efforts in availing traditional work experience placement (Male and King, 2019). This not only delays graduation but also fails to satisfy an ever-increasing demand of employable engineering graduates and ends up accentuating the skill shortage.

The following sections summarize such challenges from the universities and institutes of higher education point of view and also from the student point of view.

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Challenges experienced by the universities:

The key challenges in mainstreaming WIL at Australian universities and institutes of higher education include securing enough placements, fitting in with industry needs, skill and expertise of academic staff, embedding WIL in pedagogy, and resource intensiveness (Mclennan and Keating, 2008). Although WIL is considered as an important aspect for attracting international students, providing WIL opportunities to international students become more challenging for the universities and institutions of higher education as some employers see this as a limited return of the investment when international students are unlikely to stay in Australia after graduation (Gribble et al., 2015). The need for strong pedagogic practices, incorporating reflective practice as a part of WIL, the importance of measurable learning outcomes, and requirements for effective mentoring especially focusing on time management and autonomy were also identified as additional challenges (Jackson, 2014). The need for having a mix of evidence and involvement of workplace supervisor and academic supervisor in order to assess professional competence was also emphasized (McNamara, 2013).

Challenges experienced by the students:

Quite a few challenges experienced by international students discussed in various literature were summarized in a more recent article (Jackson, 2017). These included challenges like students not ready to start low, employers preferring domestic graduates who can easily integrate in the workplace, international students being forced to take up WIL in their own country and missing out on capturing valuable insight into Australian work practices. Lack of support from family while juggling work, study, and social commitment also hinders the performance during WIL. This is further aggravated by cultural differences and high expectations about communication skills. In a latest survey of 151 students, confidence along with workplace environment and relationships were identified to promote the sense of belonging among the students undertaking WIL (Rowe et al., 2021).

Methodology

In order to obtain and analyse information to accurately identify the impact of COVID-19 in the WIL activities and the main barriers encountered by international students, this study adopted the mixed method. This approach includes a combination of desktop research, interviews (online) and survey questionnaire (online).

Desktop research covers recent journal and conference publications in the field, government statistics, and reports from Engineering Educational institutes. The student interview is a vital technique and plays a critical role in the scholarship activities including work integrated learning experiences. The interviews were conducted with students to know how valuable these WIL activities were for them. The interview aimed to give students 8 (eight) open questions to evaluate their understand and motivation to gain industrial experience in Australia and how COVID-19 is impacting their journey to be placed in local companies.

Additionally, a semi-structured survey was distributed to the same group of students enrolled in their final year - industrial experience unit. The survey questionnaire used a variety of questions to gauge the perception, motivation, and preferences of the students who took part in this survey to participate in different activities of WIL program. The questions were designed to capture important aspects such as student diversity including their geographical locations and prior relevant industrial experiences in their fields of study.

The survey presented open questions and used the Likert scale from very unlikely to very likely. There were 7(seven) open questions in part I of the survey while part II contained 3 (three) close questions, 7(seven) questions with a Likert scale, and one reflection-based question. The open questions were aimed to obtain students' perceptions of the relevance of industrial experience and the COVID-19 impacting their engagement WIL activities during their Engineering courses. For example, " How has COVID-19 impacted your internship? If it is the case, please share your experience with blended work-integrated learning". The open questions were grouped to identify the similarities in the students' mindsets. The Likert scale questions were focused on the analyses of “Motivation to gain industrial experience via Work Integrated Learning (WIL) activities” and pandemic scenario influencing students' determination to gain hands-on experience in Australia.

Findings and Discussion

The interview and questionnaire were disseminated among 207 students; however, 30 students submitted their responses, showing a response rate of 15%. According to (Saleh and Bista, 2017) “a low response rate of online surveys has been a concern for many researchers in the last few years; the response rate for web surveys is estimated to be 11% lower than other survey modes (Yan & Fan, 2010)”. This study results demonstrate that the initial strategy disseminating the interview questions and the survey online need to be reviewed. Also, the low response rate probably reflects the lack of students' interest due the fact that the industrial experience units are zero credit unit, even though it is compulsory for students' graduation following the Engineers Australia requirements.

Figure and Figure 2 were plotted based on student responses to close questions (Q. 10 and Q.11) which were designed to gain to better understand of the survey participants. At EIT considering both online and on-campus modes, the predominance of international students is significant, the majority coming from African and Asian countries. This information enhances the need to provide these students with institutional support offering WIL programs ensuring their participation in hands-on activities and connecting them to the Australian industry.

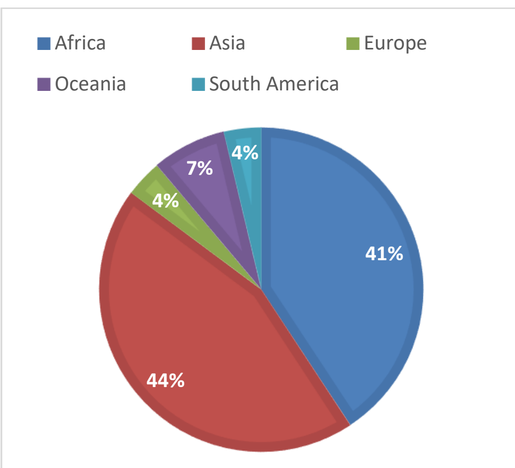

Figure 1 – Students' country

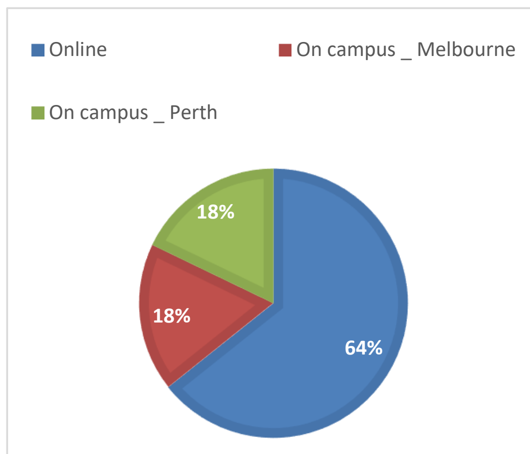

Figure 2 – Students per study mode

With the outbreak of the COVID-19 pandemic, students suddenly needed to consider the alternatives to gain industrial experience to meet the requirements for the completion of Engineering courses. International students require more attention and support from their education providers to secure an internship position due to the lack of networking skills, familiarity with industry demand, and cultural barriers among other challenges of studying overseas. The open question responses were gathered in two main groups:

Group 1 – Students' general perception of WIL program in Australia influencing their professional success as Engineering graduates.

Students' responses were consistent in pointing the importance of critical aspects to connect theory and real-world application:

“*Acquire real-world experience and build a professional network by putting what you've learned at university into practice in a professional setting (S22)”*

“Work integrated learning is essential because it will help to gain the real understanding for how to implement academic knowledge into real work scenario (S20)”

“It helps me to properly integrate my classroom knowledge with what is obtainable in the industry. It also gives me the opportunity to get the Australian industrial experience, thereby getting to know more about the Australian standards and code of practice (S14)

Additionally, some students reflected on the main differences and cultural barriers comparing the Australian versus overseas workplaces. Students’ responses mainly addressed the issues like cultural diversity, code of ethics and conduct, equal opportunities etc.:

“*Workplace in Australia is very good especially for women in engineering when compared to other countries I worked. Work culture is good and pay scale is high in Australia” (S5).*

“Getting adapted to the Australian work culture is a very challenging aspect. (S26)

Group 2 – Critical reflection on WIL and COVID impact

Students described several challenges faced since the pandemic outbreak. Usually, online students are more familiar with blended systems and with the need to work remotely. This observation is confirmed via some responses, for example:

“No… i have been working online” (S14); or “I am on the on-line programme. There have been no disturbances in my academic area (S17).

On the other hand, on-campus students reported different aspects of COVID-19 impact, such as a number of internships opportunities, delay in the start of some activities among others:

“As we all know, Covid-19 has impacted everyone in different ways. As for students they have adopted new experience with both on campus and online learning system. However, in case of internship the opportunities were decreased” (S19)

“Internships were impacted even more than full-time jobs by the COVID-19 pandemic. Many more have had their internships cancelled entirely. It enhanced my soft skills and advance my theoretical knowledge. Working to learn is learning to work. Work integrated learning allows me to gain a good grasp of basic work capabilities and a plethora of both soft and technical skills that I wouldn't necessarily develop without working in a professional setting(S8)”

Students were asked to share their perception and motivation to overcame the current challenges to gain practical experience when *in situ* placements decreased and virtual/remote activities appeared as promising alternatives. Figure 3 shows that international students are open to obtain the required WIL hours via online, hybrid, non-paid placement even through no-profit organisations. Also, the majority understands that mentoring plays an important role in preparing them to better fit the local enterprises. Additionally, it can be seen through the student responses that trying to find such WIL placements by themselves is very difficult. This agrees with well-documented previous studies (Jackson, 2017). It reflects the increase of students demanding institutional support to enable partnerships with industry and other organisations to connect students with local professionals enhancing their change to gain industrial experience and be better prepared to find a job after graduation.

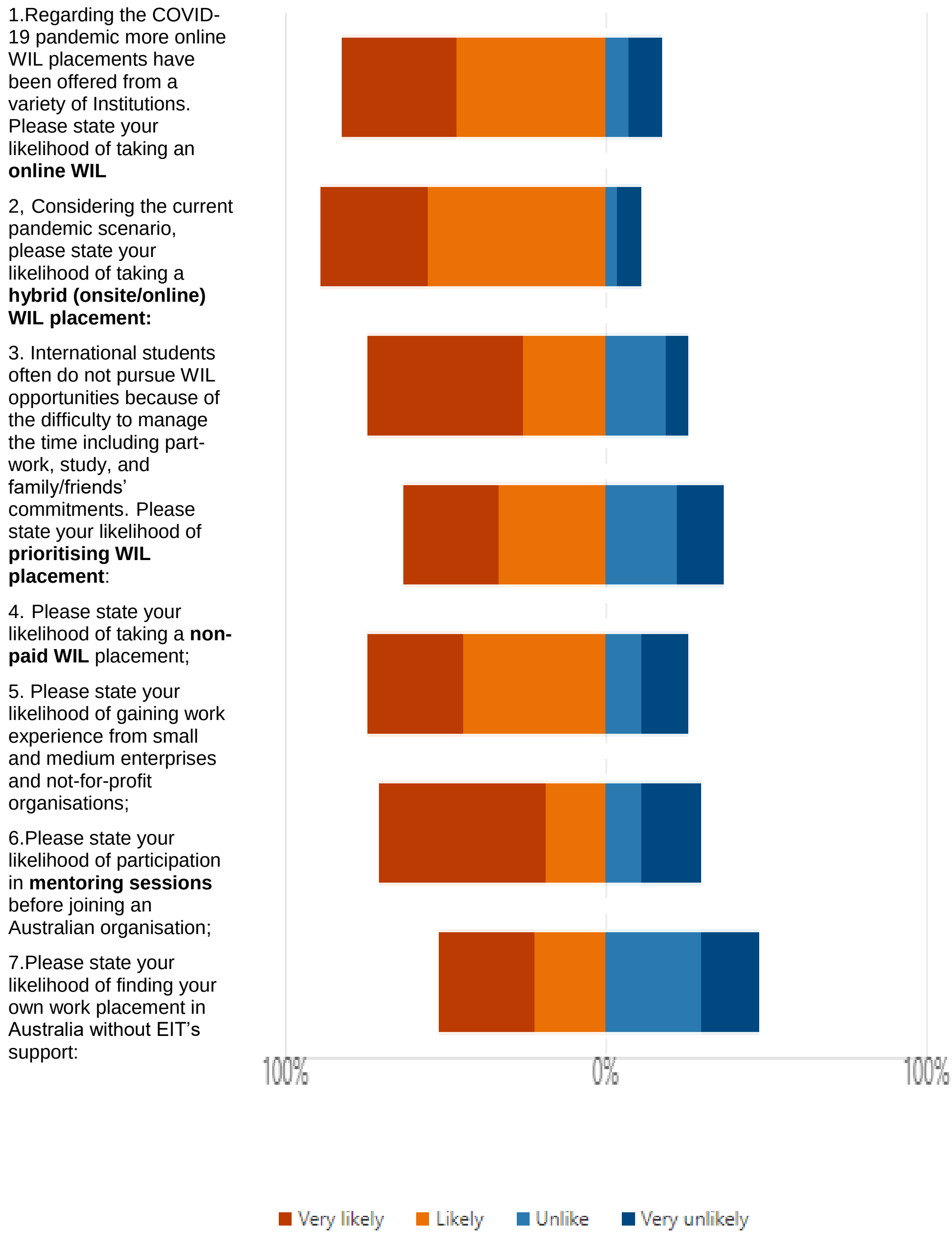

Figure 3 – Students motivation to embrace different WIL activities to gain local (Australia) experience during the pandemic scenario

Conclusion

Since COVID-19 outbreak, universities around the globe have been searching for feasible alternatives to continue offering the high-quality qualification. In order to achieve this main goal,

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there is no doubt that WIL programs are essential in enabling students to gain the skills and knowledge needed to succeed and to gain employment. Over the last years, organisations and universities focused on different forms of WIL including face-to-face, remote or simulation practices. These alternatives are aligned with e-Learning systems offering courses in several disciplines. However, even with students' familiarity with synchronous and asynchronous activities, the challenge to enhance university-industry collaboration to give international students the possibility to engage with local (Australian) enterprises had significant decrease.

Undoubtedly, the pandemic scenario disrupted WIL programs. This study aimed to better understand the students' motivation and attitude to overcame lockdown restrictions and personal concerns. International students are willing to take opportunities related to the virtual or hybrid internship, non-paid placement, and prioritise WIL experience managing time dedicated to family and friends. Although the ownership of completing WIL activities falls on the students, it is evident the special attention and additional support is critical. For example, narrowing the partnership with industry targeting not only tier 1 companies but SME business, promoting more network events, virtual/face to face competitions, and site visits. These opportunities need to be more often offered by their education provider in order to support international students coming to Australia to get the benefits interacting with local employees and become exposed to the Australian organizational policy and culture.

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Evaluation of Assessment Methods in Problem and Project-Based Learning

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ABSTRACT

CONTEXT

1801ENG,Introduction to Structures is a core course for first-year students in Bachelor of Architecture at Griffith University. A Problem and Project-based Learning (PPBL) approach with assortment of individual and teamwork activities and assessment items were used to deliver the course. The assessment methods and their alignment with learning outcomes were evaluated based on historical evidence of student performances and Student Experience of Course and Teaching surveys from 2016 to 2020. The evaluation helps in redesign of the assessment and learning activities for future offerings of the course with enhanced student learning outcomes.

PURPOSE OR GOAL

Non-Engineering students (such as Architects) normally do not perform well in courses that have engineering mechanics components. Instead of conventional theoretically demanding methods of teaching, a PPBL approach has been used to teach these courses. This study aims to understand and discuss the students' perception of the PPBL approach, and the assessment items involved in this approach.

APPROACH OR METHODOLOGY/METHODS

The students' performance and their evaluation of course and teaching surveys were analysed over five course offerings (in five consecutive years). A five-point Likert scale survey was conducted in 2020 from previous students enrolled in the course from 2016 to 2019. The survey aimed to find links between students' perception of the PPBL approach with the corresponding assessment items. Moreover, appropriateness of the assessment items and their alignment with the course and program level learning outcomes were also analysed using the survey.

ACTUAL OR ANTICIPATED OUTCOMES

Majority of students found PPBL engaging and motivating. The final design project and analytical report were ranked more favourite assessment items compared to written quizzes and laboratory tests. Students reported that the two former assessments are better aligned with the adopted PPBL approach. The current results agree with findings in literature that enforcing students to maintain a reflective journal (known as logbook herein) has positive impact on their retention of knowledge.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Adopting PPBL teaching approach shows positive impact on students' engagement and ability to integrate theory and practice. It is understood that, to achieve the intended PPBL outcomes, the assessment items should be designed to encourage critical thinking and problem-solving capacities in students. Furthermore, analysis of current results suggest that a combination of assessment items shall be provided to improve the learner's capacity to work independently as well as to give them a sense of connection.

KEYWORDS

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Introduction

The structure of a building significantly affects the architectural design and its construction. Hence, teaching structures is an essential part of Bachelor of Architecture worldwide (Estes & Baltimore, 2014), as well as at Griffith University through a common first-year course “1801ENG, *Introduction to Structures*” offered to multi-disciplinary group of students from architectural design, industrial design, construction management and engineering. Understanding a structure requires a sound knowledge of mathematics and fundamentals of engineering mechanics and strength of materials. Unlike engineering students, most architectural students either: (1) lack the basic knowledge of mathematics and physics (Salvadori, 1958), or (2) do not find the conventional engineering teaching methods engaging (Chiuini, 2006). Previous educators have used array of methods to overcome these obstacles in teaching structures to non-engineers. Most important are the works of: (Vrontissi, 2015) using analogy methods to relate examples from nature in teaching, (Ogielski, Pelczarski, & Tarczewski, 2015) by means of physical modelling to help learners shape the structural intuition, (Pedron, 2006) using interactive online Tools (*eQUILIBRIUM and Zometool*) to graphically illustrate statics concepts, as well as exploiting hands-on (Emami & Buelow, 2016) and multimedia tools (Vassigh, 2005). One of the most effective methods are known to be the project-based learning (PBL) and problem and project-based learning (PPBL), as outlined by (Atadero, Balgopal, Rambo-Hernandez, & Casper, 2014) teaching statics, (Muhsan & Albarody, 2019) teaching mechanics, (Dym, Agogino, Eris, Frey, & Leifer, 2005) teaching engineering design. Moreover, previous studies have proven the significant effect of assessments used in PBL methods on stakeholders satisfaction (Van den Bergh et al., 2006), creative thinking (Doppelt, 2005) improving generic professional skills (Hosseinzadeh & Hesamzadeh, 2012) and enhancing cognitive measures, reasoning and self-directed learning (Hmelo, Gotterer, & Bransford, 1997).

Hence, 1801ENG, *Introduction to Structures* was re-structured in 2016 and PPBL method was used to teach the course (Karampour, Gilbert, Guan, Gunalan, & Howell, 2016) to meet the needs of students from various backgrounds and different programs. An assortment of assessment items was incorporated to fulfil the learning outcomes of the PPBL approach. The main aims of introducing PPBL and design of assessment items in the re-structure were to: (1) make the Learning and Teaching (L&T) activities engaging by motivating students, giving them a sense of purpose and encouraging teamwork culture, and (2) improve knowledge retention by integrating theory and practice, enhancing critical thinking and problem-solving skills and improving their independent professional judgement. Moreover, change from a Quiz in week 4 to a problem-solving assignment aligned with the final project on student performance and participation rate is discussed.

This paper reviews the efficiency of the adopted strategies by analysing the students’ performances in the L&T activities and assessments and their feedbacks.

Learning and teaching activities and assessment items

The course introduces structural concepts to architecture students and enables them to apply the knowledge gained during the course to conduct preliminary design of their ideas which are structurally feasible, sustainable and structurally sound. A combination of weekly lectures and tutorial/workshops was implemented in teaching the course from 2016 to 2019 and since 2020, the course is offered in blended mode (online and face-to-face). In a 12-week trimester, the first four weeks are allocated to fundamentals of engineering mechanics and reinforcing the mathematics/physics background knowledge. During this period *problem-based learning* method is used and a series of hands-on activities is developed to help the students understand the fundamentals of static equilibrium through experiential learning (Gunalan, Gilbert, Guan, Karampour, & Crough, 2018). Snapshots of sample activities used to teach how to calculate reaction forces or deflections in beams are shown in Figures 1 and 2, respectively. Students are assigned in groups of 3 to 5 to conduct each activity according to stepwise instructions provided for each activity.

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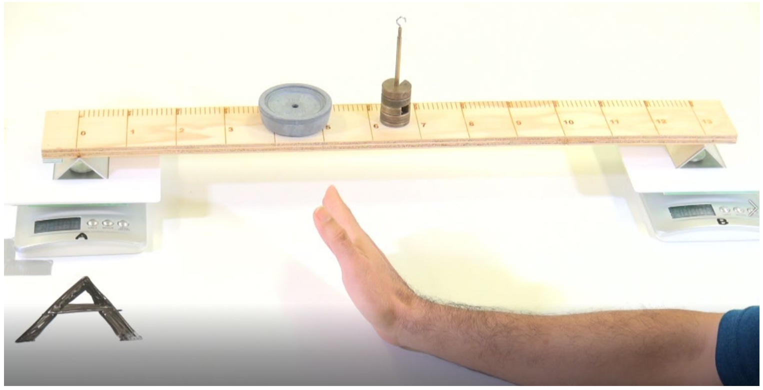

Figure 1: Snapshot of a sample hands-on activity to find beam support reactions.

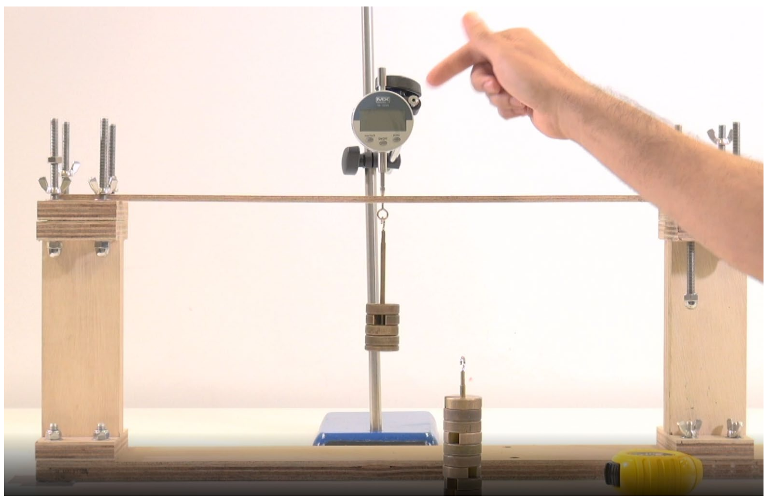

Figure 2: Snapshot of a sample hands-on activity to find beam deflections.

The L&T activities in the mid-trimester (weeks 5-9) are allocated to structural systems and their analyses, and final three weeks are dedicated to the final project, which is the preliminary design of a two-story house. During the final 3 weeks a *project-based learning approach* is adopted in which the theory is taught during the design process and feedback is provided in the tutorial sessions. The students are asked to reflect on their work by keeping a logbook of activities that is also a portfolio of their progress and achievements towards the final project. The learning outcomes of the course are: (1) State and describe structural engineering principles and terminologies at a basic level, (2) Calculate, interpret and solve introductory structural engineering problems, (3) Recognise, define and explain principles, behaviour and limitations associated with a range of structural materials and systems and how they might work together, (4) Identify the structural/stability components in existing structures and describe their role in the structural system, (5) Select, justify and evaluate appropriate structural systems in a preliminary design, and (6) Practice group work and evaluate work of others.

The assessment items and co-relation with learning outcome (LOs) are:

1. Problem-solving assignment (2020-) with a 10% weighting, replacing the previous Mechanics Quiz (2016-2019), is due end of week 4. Students' understanding of equilibrium and statics is assessed (LO 1,2);

2. Online Written Quiz (2020-) with a 20% weighting, replacing the previous in-person one (2016-2019), is due end of week 6 to assess students learning of beam theory from the hands-on activities (LO 2,3);
3. Analytical report with a 20% weighting due end of week 9, helps students to develop a sense of structural design by observing and analysing the role of individual elements in real-life structural systems (LO 3,4);
4. Final design project, due end of trimester, is a group work and weighs 45%. A conclusive report of the architectural design and drawings and structural design and supportive calculations are assessed (LO 1,2,3,4,5,6);
5. Individual reflective journal (logbook), which weighs 5%, is checked twice in the trimester to provide constructive feedback on students' reflection (LO 1,2,3,4,5,6);.

Analysis

In 2020, 60 participants from (2016-2019) cohorts were asked to participate in an anonymous online survey of 1801ENG, *Introduction to Structures*. Out of the participants, 8.5%, 28.8%, 27.1% and 35.6% were from cohorts of 2016, 2017, 2018 and 2019, respectively. Using a 5-point Likert scale questionnaire, responders were asked to specify their level of agreement to statements about learning and assessment activities. Moreover, students were asked to write any plus, minus or interesting aspects of the course. A total of 37 participants (61.7%) provided written comments. The results are represented in Table 1 and are discussed in the next section to evaluate the PPBL method and assessment items.

Table 1: Results of the anonymous online survey of students from different cohorts 2016-2019

Question	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
(Q1) Did you find the project-based learning and teaching activities of the course engaging?	36.7%	58.3%	5.0%	0%	0%
(Q2) Did the course motivate you and gave you a sense of purpose?	33.4%	43.%	21.7%	0%	1.6%
(Q3) In your opinion, did the final project integrate theory and practice?	45%	50%	3.3%	1.7%	0%
(Q4) Did the analytical report help you enhance your critical thinking and problem-solving skills?	45%	46.7%	6.7%	0%	1.6%
(Q5) Did the course help you improve your independent professional judgement?	25%	53.3%	20%	1.7%	0%
(Q6) Did the individual assessments of the course and maintaining the logbook help you improve your capacity to work independently?	23.3%	50%	21.7%	3.3%	1.7%
(Q7) Did the team-work activities help you strengthen your sense of connection, effective working relationship and friendship?	26.7%	36.7%	26.7%	8.3%	1.7%

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Most important outcomes of the survey are given below which provide evidence of impact of adopted active learning PPBL approach:

Learning Outcomes: Over 76% of the participants believed that the course motivated them and gave them a sense of purpose. 95% of the students agreed (45% strongly agreed) that the final design project successfully integrated theory and practice. This is a very promising result, given that the alignment between theory and practice is a major goal in PPBL learning. More than 90% of the students found the analytical report helpful in enhancing their critical thinking and problem-solving skills. Positive comments demonstrate that the PPBL approach has influenced, motivated and inspired students to learn:

> *"Challenging quizzes for non-engineering students however once we've grasped the concepts it became easier. I liked the final assessment. It was challenging but very interesting and learned a lot especially working in a group."*
>
> *"Lectures were engaging for this course (even on a Friday afternoon). Assessment helped to guide students through the coursework. Assistance was provided wherever needed for students struggling to grasp concepts. Overall, one of the most engaging courses completed in my Architectural Design degree."*

Engagement: More than 95% of the students found the PPBL learning and teaching activities of the course engaging. About 80% of students agreed that L&T activities and assessment items improved their independent professional judgement and their capacity to work independently. More than 62% believed that team-work activities strengthened their effective working relationship and friendship. Students also found the hands-on activities and the real-life final design project meaningful. These outcomes suggest that the adopted PPBL has made the course engaging and relevant to students from various backgrounds and different programs, as is evident in students' comments:

> *"The most memorable part was going out and applying/investigating what we were learning in real life situations and projects. Being able to see how what were learning about works and where it is utilised was incredibly helpful and by doing so ourselves we gained a greater understanding of how these structural systems work. I think it would be good to continue sending students out and having them see for themselves how these structural systems work and where they are applied, it provides you with a realistic skill and understanding as opposed to a theoretical one. This is something we can actually use later, after university."*

In order to encourage the students to reflect on their peers' work, group PPBL activities were developed. These collaborative and cooperative activities were successful in improving the students' sense of connection and effective working relationship as is evident in the positive responses to Q7 of the survey in Table 1.

Knowledge retention: The effect of PPBL approach on improving students' knowledge retention, and the relation between the learners' background and their performances in different types of learning activities and assessments have been statistically investigated from two consecutive offerings of 2014 & 2015 (Karampour et al., 2016). Retention of knowledge during the trimester (or semester) and its relation to the assessment items and L&T activities was evaluated from years 2016 to 2020. This was conducted by monitoring students attendance and performance in individual and group activities. It has been found that the performance of school leavers in a problem-solving written exam was greatly enhanced by encouraging them to participate in group hands-on activity, actively supervised by the teaching team. The PPBL approach also proved to have significant effect on improving students' retention rate. In 2014-2015, the failure/non-completion (Grade<4) rate was around 20%. This ratio reduced to 9.1% in 2016, and has been below 10%, since.

Assessments:

<u>Assessment item 1</u>: From 2016 to 2019, this item was run as a traditional paper-and-pencil test. In 2020, this assessment was changed to a problem-solving assignment that included

appropriate items to measure students' understanding and level of skills required for the project-based learning. Table 2 presents the students' (a) participation rate and (b) performance in assessment 1 over the studied period and shows that the re-design in 2020 has improved both.

Table 2: Assessment 1, traditional (2016-2019) vs. re-design in 2020

	2016	2017	2018	2019	2020
Participation rate, excluding deferred attempt (enrolment)	73.9% (131)	67.8% (119)	71.3% (138)	66.7% (163)	80.1% (158)
Average mark	65.0%	64.8%	57.6%	60.1%	78.8%

Assessment item 2: The closed book Multiple Choice quiz was changed to an open book online MC quiz in 2020. The questions were slightly different from previous years and were more in line with the learning outcomes of the PPBL approach. As represented in Table 3, a change from closed book in-person quiz to online open book exam significantly improved the participation rate without major change in the overall average mark.

Table 3: Assessment 2, traditional (2016-2019) vs. re-design in 2020

	2016	2017	2018	2019	2020
Participation rate, excluding deferred attempt (enrolment)	69.9% (131)	68.2% (119)	60.0% (138)	66.1% (163)	79.7% (158)
Average mark	60.0%	55.1%	50.6%	50.8%	46.8%

Assessment item 3: As evident in Q4 of the survey (Table 1), over 90% of the students agreed (45% strongly agreed) that the analytical report improved their critical thinking and problem-solving skills.

Assessment item 4: Based on the learners' response to Q3 (Table 1) of the survey, 90% of the students agreed (45% strongly agreed) that the final design project achieved its goal and integrated theory and practice.

Assessment item 5: In order to inspire students to reflect on their work, each student was asked to keep a logbook of weekly activities and progress. The logbooks were marked twice in the trimester, first time in week 6 (prior to the Quiz) and second time in week 12 (before submission of the final design project). As represented in responses to Q6 in Table 1, over 83% of the students agreed that maintaining the logbook helped improve their capacity to work independently.

Conclusions and recommendation

- The PPBL approach combined with the variety of individual and group assessment items have proven to foster student learning and engagement by linking theoretical knowledge to real-world problems, evidenced by the survey data and the students' qualitative responses.
- Survey results showed that, the most favourite assessment items are the real-life final design project (50% of the votes) and the analytical report (38% of the votes), compared to the written quiz (12% of the votes). This shows that students prefer assessments that are more reflective of a career-based scenario.

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- Current results confirm that in PPBL learning, performance-based assessment and portfolio assessment are more appropriate than traditional paper-and-pencil tests. The former methods not only are better measures of the level of understanding and analytical/design skills in a PPBL learning method, but also boost students' participation in the assessment.
- Requiring students to document their information, feelings, experience, reflection and conclusions in a reflective journal can enhance their learning process and outcomes.
- In future, the first two assessment items should be accompanied by L&T activities that are aligned with a problem-based learning approach. These assessments should be properly linked to assessment items 3 and 4 to close the loop of the PPBL method.
- The PPBL method may also be extended to other similar engineering courses that offered to multi-disciplinary group of students from different programs.

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An active laboratory learning experience for chemical engineering students facilitated by hypothesis testing

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ABSTRACT

CONTEXT

The ability to think critically and to be self-directed learners are recognised as pivotal to university graduates in the evolving context of the engineering profession. Lab practices are important learning experiences in undergraduate engineering programs and are generally viewed as main occasions to develop such skills. The use of enquiry-based learning approaches in lab practices supports the development of the graduate attributes of critical thinking and independent learning.

PURPOSE

A traditional approach in engineering educational laboratories is expecting students to achieve pre-determined results by following instructions given, for example, in a laboratory manual. It is recognised that such approach is ineffective in engaging learners in critical thinking or in making design decisions, for example when dealing with multiple objectives and constraints. Holistic approaches emphasizing the use of hypothesis forming and evaluation and design of experiment (DOE) in laboratory practicals are perceived to be conducive to improved learning outcomes. An "open-ended" learning activity has been designed and implemented to foster student's engagement and deep learning. The activity includes an assessment scheme that allows an evaluation of the transformative effect on student learning approach, specifically engagement in critical thinking, and an observation of the metacognitive awareness in the learning process. The laboratory practice covers separation unit operations that are ubiquitous in several industries, nominally continuous distillation.

APPROACH

The approach adopted is rooted in inquiry-based pedagogy. Students are given the task of optimising the operation of a distillation column. Responding to the proposed problem, requires students to model the distillation system, determine optimal operating conditions by simulation, identify the most influential process variables, and design an experimental plan to validate modelling and simulation work. The use of a critical approach is encouraged by the assessment design associated to the laboratory project: students individually submit their hypothesis about the expected outcomes of the experimental practice and a reflection on it considering the results subsequently obtained. Overall, the learning activity proposed is structured to encourage learners to engage critically and, to a certain extent, independently. The use of hypothesis testing, reflections, conceptual questions in assessment, and surveys allows the collection of learning analytics suitable to evaluate learning approaches.

ANTICIPATED OUTCOMES

The proposed activity engages students in a six-steps learning process: modelling of a separation process, hypothesis forming and prediction, process optimization through simulation, design of experiment, results evaluation, and reflection on the original hypothesis. The need to verbalize predictions is expected to improve engagement in the task. It is expected that the sequence of activities encourages students to derive logical conclusions from multiple inputs, question their findings and justify their conclusions. The assessment design allows a longitudinal evaluation of critical thinking and of metacognitive awareness. The combination of students' reflections, summative assessment results (laboratory reports, mid-session exam),

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and observations from the teaching team allow for evaluation of dept of learning and skills development.
SUMMARY

An enquiry-based approach has been implemented in a 2nd year chemical engineering laboratory. Such open-ended approach is a closer representation of real-world engineering work that often lack pre-determined solutions. The activity is designed to boost students' engagement with the practical activity and support critical thinking and deep learning. The assessment scheme is an integral part of the learning activity and allows for the observation of students' learning approaches over the duration of the activity and of the knowledge and skills developed.
KEYWORDS

Hypothesis forming, design of experiment, active learning, critical thinking, Chemical Engineering education.

Introduction

Enquiry-based learning and hands-on experimentation provide students with an opportunity to actively construct, process, and communicate their own understanding leading to effective conveyance of concepts (Huet, 2018). Meyers et al. (2009) suggested five principles for effective curriculum design to ensure the attainment of learning outcomes, one of which is to employ authentic, relevant, and real-world teaching and learning resources. It is postulated that students engage more with course content when they feel it is relevant to current real-world practice and necessary to improve their employability. This is particularly true when it comes to engineering students with pragmatic attitude towards knowledge. As such, incorporating unit operations laboratory in chemical engineering curriculum is perceived to be an effective way in exposing students to the real-world application of the theoretical concepts.

Traditional approach in unit operations laboratories is to direct students to carefully follow a laboratory manual to obtain pre-determined and "desired" results (Chandra, 1991; Young et al., 2006). Such an approach fails to inspire students to develop and demonstrate critical thinking, and to make design decisions when dealing with multiple objectives and constraints, the latter being a required graduate attribute by accreditation bodies such as The Institution of Chemical Engineers. Holistic approaches emphasizing the use of design of experiment (DOE) technique and statistical tools in laboratory practicals have been identified as conducive to improved learning outcomes (Doskocil, 2003; Jimenez et al., 2002; Narang et al., 2012; Young et al., 2006). Design of experiment is widely-used in industry to minimise the cost related to experimentation necessary to reach a conclusion while generating results with appropriate levels of accuracy (Doskocil, 2003). Concomitantly, computer simulation and process modelling are being increasingly viewed as safe and cost-effective alternatives to pilot-scale experimentation in chemical industries (Williams et al., 2003). Several educational institutions have applied advancements of information technology to develop virtual laboratories to partially or completely replace bench-scale or pilot-scale unit operations practicals (Brault et al., 2007; Rafael et al., 2007; White et al., 1999; Williams et al., 2003),however, the findings of White and Bodner (1999) suggest that practical laboratory experience is integral to chemical engineering education.

There have been numerous studies suggesting the contribution of hypothesis testing and predictions to active learning and enhancing the students' learning experience (Bertram, 2002; Codella, 2002; Dantas et al., 2008; Modell et al., 2004; Rivers, 2002; Yoder et al., 2005). In a study by Modell et al. (2004) on the effectiveness of hypothesis forming in a physiology laboratory, it was found that students performed better when asked to verbalize their prediction of the outcomes prior to attending the laboratory. This was partly attributed to the fact that students were more likely to engage with the learning task when they had committed to a prediction. However, the literature is limited on the evaluation of the effectiveness of integrated

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active learning practical labs in promoting critical thinking and independent learning. The latter will be investigated focussing on evidence of metacognition in students' output.

Context of study

The learning and teaching activities included in this study have been designed as part of the educational offer of the Separation Processes courses at School of Chemical and Biomolecular Engineering, University of Sydney. The courses cover the design of separation unit operations commonly used in chemical industries including distillation columns and are offered to second year undergraduate students and to Master of Professional Engineering students. An inquiry-based pedagogy has been adopted articulated in the following main steps: modelling of a separation process, hypothesis forming and prediction, process optimization through simulation, design of experiment (DOE), results evaluation, and reflection on the original hypothesis. Figure 1 presents an overview of the activities.

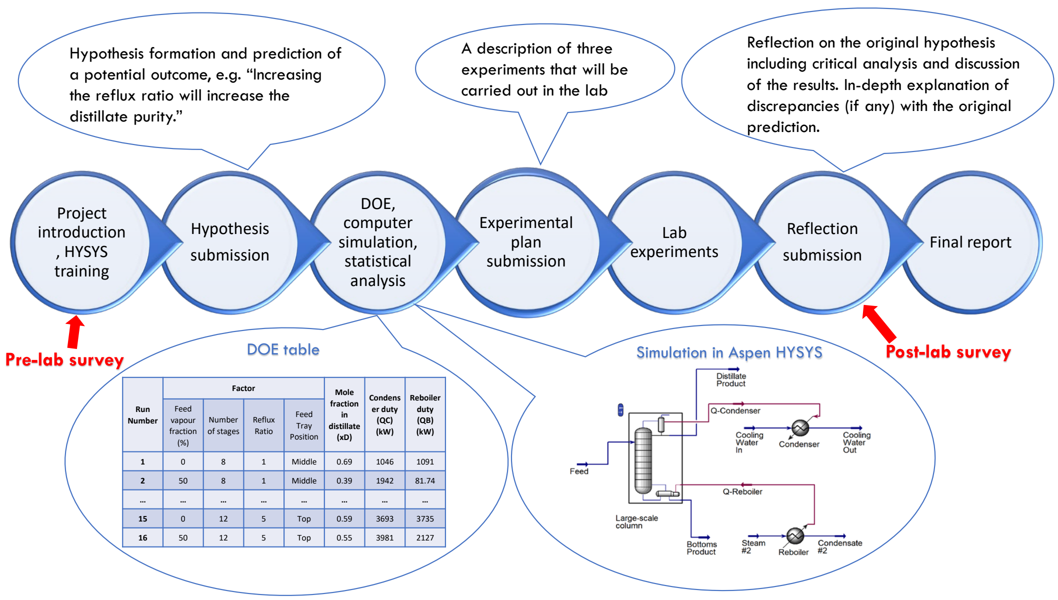

Figure 1. Overview of the teaching and learning activities associated to the distillation laboratory practical.

The hypothesis and reflection submissions are individual tasks and allow for the qualitative longitudinal observation of the students' approach to learning and metacognitive awareness. The assessment scheme of the courses comprises a mid-session individual test that includes conceptual questions. Responses to individual tasks allow an evaluation of student approach with particular attention to evidence of critical thinking and, potentially, to the transformative impact of the intervention.

Students work at the other tasks of the activity in groups of 3 to 4. The activity sets a realistic work scenario in which students are asked to work as chemical engineers in a consulting firm. An ideal client tasks the consulting form to optimise the operation of an industrial-scale distillation column with a specified diameter for the continuous separation of ethanol-water mixtures. The design objective set by the client is to maximise the purity of the distillate with the minimum operating costs: the cost of steam and cooling water consumption in the reboiler and condenser, respectively. The client specifies the pressure at which steam is available. Additional design constrains are that a water-cooled total condenser is used in this column with the cooling water entering the condenser at 30°C and returning to the cooling tower strictly below 40°C. The bottoms from this column are used elsewhere as "process water" and thus cannot contain more than 2 (mole) % ethanol. The client requires the estimation of the total

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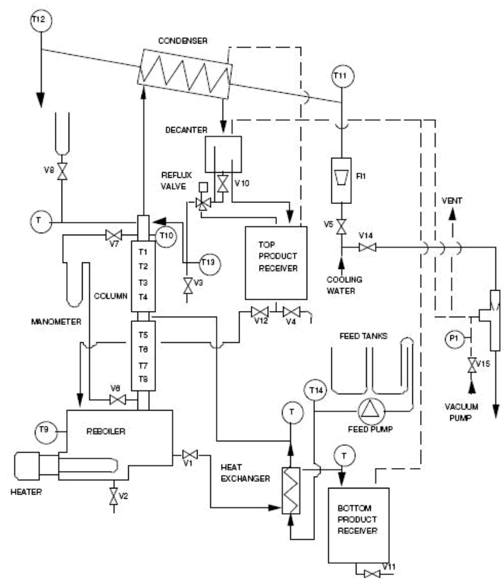
number of sieve trays before proceeding with the procurement and installation of the column internals.

Students carry out a comprehensive experimental study to find optimum operating conditions such as feed temperature, feed tray position, number of theoretical plates, reflux ratio, and reboiler duty using HYSYS. Design of experiment is required to find the minimum number of experiments that maximise the number of variables that could be investigated. Students notice that even after a well-planned DOE, it is unpractical to conduct the experimental study on the industrial-scale column. Hence, the concepts of pilot-scale experimentation and scale-up to large-scale plants is presented, introducing students to a common practice in chemical industries. The distillation equipment available for the practical is a 50 mm diameter sieve plate glass distillation column (UOP3CC, Armfield Limited) containing eight sieve plates. A photograph and a schematic diagram of the equipment are presented in Figure 2. Students are presented with the additional constraint that the session time in the laboratory is sufficient to carry out only three experiments. This leads to the use of simulations to execute the experimental design and investigate the effect of different process variables. The simulation is conducted using Aspen HYSYS simulation software. Subsequently, students perform a statistical analysis of the results and determine the variables that have the most significant impacts on the process. The results inform the selection of the operating variables to be investigated in the practical session when students use the lab-scale experiments to selectively validate the computer simulation data. Students need to estimate the efficiency of the industrial-scale sieve trays to be able to calculate the actual number of sieve trays. This is done by evaluating the tray efficiency in lab-scale column and scaling up the results for large-scale column.



A **B**

Figure 2. A: photograph of experimental rig. B: Schematic diagram of experimental rig

Research Methodology

Enquiry-based pedagogy has been adopted to engage students with the learning process as active learners. Contrary to traditional laboratory approaches that encourage passive learning through prescribing laboratory procedures, the proposed approach provides students with the autonomy to design their own experiments and be actively involved in the learning process. “Autonomy” defined as the willingness to spend time and energy to study is one of the three

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psychological needs contributing to students' intrinsic motivation towards learning according to Self Determination Theory (SDT) (Niemiec et al., 2009; Trenshaw et al., 2016). Autonomy-supportive teaching practice provides students with the voice and choice in the learning activities thereby increasing their interest in self-learning (Niemiec & Ryan, 2009). The activities start by introducing the project scopes and overview of the tasks. A training session on Aspen HYSYS will be given to prepare students for the process simulation activity. Students are then asked to form a hypothesis and make a prediction of the potential outcome of the optimisation task. For example, they may hypothesis that "increasing the reflux ratio will increase the distillate purity". This gives students the chance to develop an understanding of the theory before entering the laboratory and hence have a better appreciation of the distillation theory in practice. Committing to a prediction, students are more likely to be actively engaged with the activity as suggested by Modell et al. (2004). Students will complete the pre-lab survey (Figure 3) and answer few questions about their attitude to self-directed learning and ability to think critically.

Pre-lab survey

Q1. If you were stranded in a canyon, what would your first move be?

Free text response

Q2. Consider the following skill list.

T - Team work

C - Critical thinking

S - Sourcing information

D - Data analysis

P - Data presentation

Which of these skills are your strong points?

Rank these (TCSDP) from 1 (strongest) to 5 (less strong). You should not have two skills ranked in the same way.

Q3. Experiments should be designed by (please tick the option/s you agree with)

The teaching team

The students

Other (please specify)

Figure 3. Pre-lab survey questions to evaluate students' perceptions of their critical thinking skill and self-directed learning.

To evaluate the validity of their hypothesis, students undertake an experimental campaign including DOE, HYSYS simulation, and statistical analysis of the simulation results to find the most significant factors and their optimum values. Lab-scale experimentation is used to validate the simulation data and estimate the real tray efficiency for scale up purposes. Students commit to three distillation experiments of their choice as part of their experimental plan to be carried out on the lab-scale distillation column. Students individually articulate their predictions of the laboratory and reflect on the assumptions they made considering the experimental results of the lab practicals. Finally, each team submits a laboratory report including recommendations for the ideal client. Students will be asked to answer the post-lab survey questions shown in Figure 4.

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Post-test (available any time from the laboratory sessions to the end of the semester)

Please rank the following from 1 (Strongly disagree) to 4 (Strongly agree) or Not Applicable

1. My team decided the scope of the lab practical on our own
2. My team worked out the interpretation of the practical outcomes independently
3. I thought carefully about my predictions
4. I looked at relevant information to interpret the results
5. I thought about what assumptions I made during the project
6. The simulation work and the lab practical together supported my learning
7. I found the project interesting

Each question will also have a free form entry box with the guidance "Please explain your response".

Figure 4. Post-lab survey questions

The overall experience is designed to support student learning and to provide the opportunity to evaluate student approach to learning at the start of the activity by examining responses to the survey, the hypothesis submission, and the DOE proposed. The first two items are individual and offer the opportunity to evaluate the effectiveness of the experience to shift students learning behaviour toward a more critical approach as opposed to focussing on searching for pre-existing solution algorithms or a memorisation-based approach. This can be achieved by analysing and comparing students' outputs in the early stages of the experience (pre-lab survey, hypothesis submission, DOE) to outputs generated in later stages of the experience (post-lab survey, reflection, response to conceptual questions in mid-session test). Such evaluation of the effectiveness of active learning in chemical engineering labs is novel and the results are likely to be transferable to other contexts in engineering education applying a similar design. The effectiveness of the intervention on the performance of the general cohort will be evaluated based on the examination of the laboratory reports and of the observations of the teaching team that will be collected by semi-structured interviews.

In general, critical thinking is revealed by indicators, for example:

1- Evidence of evaluation
2- Draw of logical conclusions considering all available data
3- Presentation of arguments
4- Practice of critical reflection
5- Evidence of data analysis
6- Suggestion of alternatives
7- Question credibility and accuracy of information and supporting evidence
8- Justification of procedures/recommendations
9- Accurate self-evaluations

Following are some examples of observations from students' outputs indicating a critical approach to the specific activities proposed here.

- Use the temperature profile from the HYSYS model and lab-scale column to estimate the composition of ethanol in the top and bottom products using the theoretical T-xy diagram. Compare differences between the temperature profiles. Discuss possible reasons behind the discrepancies (if any).
- Test the accuracy of the thermodynamic property package used in the HYSYS model by comparing the produced phase equilibria data (T-xy diagram) with literature data.
- Scale up from lab-scale to large-scale column and present conclusion on the real number of plates taking into consideration the column efficiency calculated in lab experiments.

Examples of metacognition can emerge from students' submissions as indications that students identify their abilities in relation to the requirements of the activity and use strategies

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in response to it. For instance, upon recognising that they cannot explain the results of the experiment, student identifies that linking theory to experimental outcomes is their limiting step and seeks help to improve this skill.

The sample evaluations presented in this work, show that the activities are collectively suitable to highlight the aspects of student learning targeted by this educational intervention. The next iteration will include a larger number of participants and will introduce semi-structured interviews. Both aspects will arguably allow for a more systematic evaluation of the intended outcomes.

Conclusions

To support student learning and experience, enquiry-based pedagogy has been applied in the design of the learning and teaching activities in a chemical engineering laboratory. In particular, the approach aims to support critical thinking and independent learning. Both abilities are recognised as pivotal for university graduates to succeed in the evolving context of the engineering profession. The approach is articulated in multiple steps: design of experiments, computer simulation, hypothesis forming and prediction, results evaluation, and reflection. The study investigates the effectiveness of the approach through analysis of student outputs at different stages of the experience integrated with pre-lab and post lab student surveys and interviews of the teaching team. Results from the work are likely to be transferable to other teaching laboratories in engineering as the approach proposed in generalizable. Moreover, the work contributes a readily applicable framework within engineering practical labs to evaluate critical thinking and the effectiveness of interventions directed to support such skills.

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Response to Student Feedback for 1st Year Mechanics Subject at Swinburne University of Technology

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ABSTRACT

CONTEXT

The subject ENG10003 Mechanics of Structures is common to all Engineering degree courses at Swinburne University of Technology. In the 2020 COVID year, the course was delivered fully online. Student feedback from the Subject Assessment Surveys for 2020 largely uncovered the limitations they perceived in the online delivery of the subject for its first time. A particular inference made, was that some students claimed they gained little additional benefit from the online delivery of the subject than from going through presentation of the theory and example solved/worked problems in textbooks.

PURPOSE OR GOAL

In reviewing the content of the delivery, student comments were vindicated in places as some material was based on inclusion of its electronic form of treatment with worked examples made available by the publishers of the recommended textbook. Some of the more positive feedback from students related to the screening of the videoed performance of the two experiments and their results presented in Weeks 7 and 10 of the online delivery. Students were required to perform analysis of the measurements made available to obtain key results and then to compare these against their theoretical counterparts in a report forming part of their assessment for the subject. The inclusion of experiment-based evidence on topics treated in other weeks of the subject delivery was therefore seen as a positive step towards increasing value to students of the online delivery of subject ENG10003 in 2021.

APPROACH OR METHODOLOGY/METHODS

The content of the online delivery of ENG10003 in every alternate week of Semester1 2021, was therefore supplemented by excerpts of experiment-based material drawn from www.Mechanics-Lab.com and made available by Strucomp P/L as a trial. The trial was anticipated to provide an opportunity to judge the efficacy of inclusion of experiment-based evidence as an enhancement to the learning of topics relevant to the subject. In addition, relaxing of COVID restrictions during the latter part of Semester 1, allowed students optional attendance of two "Open Sessions" where they could perform the TechnoLab™-based experiments used in the online delivery of ENG10003, hands-on for themselves.

ACTUAL OR ANTICIPATED OUTCOMES

Informal student feedback has been quite positive. Results from a purpose-specific quiz and the Subject Assessment Learning Survey for the subject, also show favourable responses for the inclusion of experiment-based verification of topics in the delivery of ENG10003.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Whilst hands-on performance of experimentation on physical models for obtaining experiment-based evidence supporting the understanding and acceptance of basic principles and analysis/modelling techniques treated in ENG10003 has been acknowledged by students as superior to online delivery of such material, these students still feel it worthwhile to include videos of experiment-based evidence of topics in the online delivery of the subject.

KEYWORDS

Hands-on experiments; experiment-based evidence; validation of theory

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Introduction

The waxing and waning of the severity of the COVID pandemic restrictions over the past two years has disrupted the normal operation of practically all industries and businesses in Australia, including the Tertiary Education Sector (TES) in Engineering.

Complete campus shutdowns on several occasions with odd stints in-between of a few weeks of return to short periods on campus have occurred during this time. When not in complete shutdown, limits on staff level presence and on room capacities on campuses were imposed by State and Federal governments that in the most required fully online delivery of under-graduate and post-graduate degree courses in Engineering.

The preparedness of universities to going fully online for delivery of courses varied from subject to subject, largely dependent upon the extent and ready availability of suitable material in electronic form, for all topics covered. In addition, in-house experience for online delivery and the resources needed to do so effectively, varied from university to university. Whatever the situation for a quality online delivery of its engineering subjects of any university, it has generally been accepted by academics, and their students alike, that this would fall very short of an on-campus experience of a subject delivery.

Specific areas that online delivery would not be able to adequately provide a substitute/ equivalence to on-campus delivery would be reasonably obvious: face-to-face interaction with academic staff and fellow students, both academically and socially; activities that are organised for students working in groups; and access to learning facilities such as physical laboratories and engineering workshops.

Arguably, the most academically important area in this list, especially when it comes to the learning of fundamentals in Engineering, is the performance of physical experiments to verify basic principles and/or modelling/analysis techniques in Statics and Mechanics of Solids/ Structures/Materials. These are the subjects that the majority, if not all, of first and second year level students undertake in Engineering courses at Australian Universities and which underpin later year subjects that deal with the analysis and design of structures (buildings and general infrastructure; mechanical and aerospace structures).

In recognition of the importance that hands-on performed experiments has on students in consolidating and reinforcing their understanding of topics associated with these experiments, (Tsang et al, 2019; Lewis and Williams, 1994; Bonwell and Eison, 1991; Haritos, 2018; Finkel and King, 2013; Kolb et al, 1999; Khamar, 2015), the delivery of the subject ENG10003 Mechanics of Structures at Swinburne University of Technology for the first time in online form in Semester 2, 2020, included presentation material of the two experiments students in this subject would have otherwise performed hands-on in pairs on classroom bundled sets of TechnoLab™ experiment test rigs.

Video/photographic recording was purpose-arranged of these experiments performed hands-on by a student actor in such a way as to intimately capture all key features and results. The strategy here was to provide as immersive an experience as possible so that student viewers felt as if they were present, actively witnessing the experiment performance and the associated results.

Feedback from Questionnaires & Student Learning Assessment Survey in Semester 2 2020

The two experiments from TechnoLab™ that were video/photographically captured and presented in the online delivery of ENG10003 were: Experiment T3 – *7-bar Warren Truss* (see Fig. 1a) and Experiment F8 – *Shear Force and Bending Moment in a Simply-supported Beam*, (see Fig. 1b). These experiments were the only two performed by students hands-on (in pairs) in Subject ENG10003 and for which they wrote up a structured report that formed part of their subject assessment, prior to the advent of COVID.

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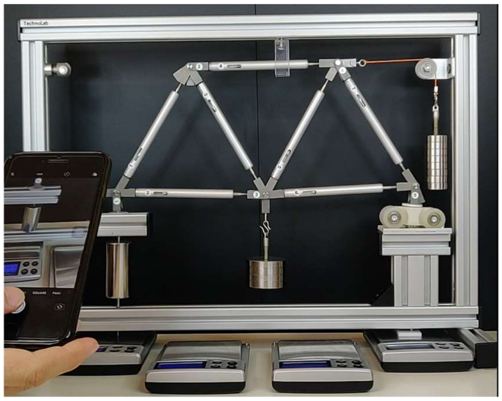

Figure 1a: Experiment T3 - 7-bar Warren Truss test rig (combined load case)

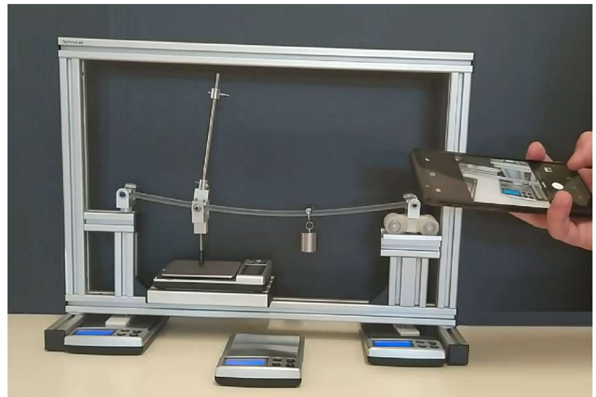

Figure 1b: Experiment F8 - Shear and Bending Moment in a simply supported beam

Video/photographic capture of these two experiments being performed by a model student was organised ahead of Semester 2. The "footage" was edited in such a way as to provide all the key step by step details and identification of the key results, both as viewed in the video, and in still photographs, to lend authenticity to the presentation of the results.

Students had an opportunity to provide some "targeted" feedback of their experience with the video presentations and the conduct of the experiments themselves via a short questionnaire noted on the structured report sheets for each that they were required to submit as personal reports forming part of their assessment for the subject.

The short block of feedback questions and the mean response scores to these in the reports for the two experiments T3 and F8 are reproduced below in Tables 1 and 2 respectively.

Table 1: Mean Scores for T3 7-bar Warren Truss - Laboratory Session Feedback

In this practical, rank the parts (on a scale of **1 - lowest to 5-highest**) you gained most from:	
1. Matching theoretical calculations to actual measured values.	3.2
2. Learning about measurements using photogrammetry.	3.3
3. Visualising what a pin-jointed truss actually looks like and seeing how it works.	3.6
4. Overall, has this laboratory session helped you understand more about trusses?	3.7
5. Other feedback: ______________________________	

Table 2: Mean Scores for F8 *Shear Force & Bending Moment in a Simply-supported Beam* - Laboratory Session Feedback

In this practical, rank the parts (on a scale of **1 - lowest to 5-highest**) you gained most from:	
1. Matching theoretical calculations to actual measured values.	3.7
2. Visualising what a simply supported beam actually looks like and seeing how it works.	3.6
3. Was this laboratory session worth doing (compared to working through more examples)	4.5

The high percentage response levels of 64% and 65% of this class of 287 students, respectively, for the rated questions in these two online Lab session questionnaires was attributed to the fact that these formed part of a Report for each submitted for assessment purposes. However, a much smaller percentage of students in the class actually provided "Other feedback".

The scoring for both online lab sessions in the short questionnaires largely suggested that inclusion of these sessions was indeed helpful to the students' learning (ie on top of the lecture treatment and the online worked examples).

For Experiment F8, a question was specifically focused on the value of delivering the Lab Session online. 90% of the students that responded, preferred experiencing this online session over the option of otherwise going through more worked examples on the topic.

Specific Student Comments – Experiment T3 (7-bar Warren Truss)

The few student comments (less than 10% of the class) for Experiment T3 are reproduced below:

1. *this lab was pretty interesting just took ages to complete, helped me understand how to do the calculations a lot more which was awesome*
2. *the lab really useful but I wish to do it in the campus for more understanding*
3. *This lab has shown me the areas I need to improve on and has demonstrated my understanding in particular of analysis of trusses using joint and section method is insufficient.*
4. *Good practice for method of joints and section*
5. *In this class, I have a great understanding of the calculation of the carriage structure, and I also learned to use photography to measure data.*
6. *I feel as though personally I struggled a lot with this lab, my understanding on what was required and how to proceed was highly hindered with how it was delivered due to not being in person*
7. *I learnt how to effectively use the summation of internal forces in two systems.*
8. *Hard during COVID-19 but still understood the exercise.*
9. *However, it would have been more beneficial to actually be there to interact with the experiment, obviously this wasn't possible.*

The majority of students appreciated the learning experience offered them and some went so far as to suggest the online presentation was next best to having the opportunity of performing the experiment for themselves. The perceived value to them of a "hands-on" experiment performance, was mentioned in several of the written responses.

Specific Student Comments – Experiment F8

Very few students (only two) provided comments on Experiment F8, as, although there were "lines" drawn for such in the Questionnaire block for these, a specific heading "Other Feedback" in front of these lines was inadvertently missed when compiling the Report Sheets for this experiment. The two specific comments are reproduced below:

1. This Lab would have been cool to do in person.
2. Honestly I found this prac very confusing however I understand it was originally meant to be taught in person not online.

With only two written comments for the online form of presentation for Experiment F8, perhaps at best a case can be made that the students concerned, believe that there would be value in performing this experiment for themselves, hands-on, rather than working off its video presentation.

ENG10003 Subject Learning Assessment Survey Semester 2, 2020

At the conclusion of Semester 2, students were invited to complete the Student Learning Assessment Survey (SLAS) for all subjects studied in that semester, that included those enrolled in subject ENG10003 Mechanics of Structures. The 2020 Semester 2 version of the SLAS's was modified to include an extra statement specifically requesting their rated opinion of the effectiveness of the online delivery of ENG10003, on top of their rated opinions against the six "standard" statements of satisfaction of subject delivery.

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The rating value results for the subject ENG10003 compared to whole-of-university and that of the Faculty of Science, Engineering and Technology, FSET, are presented in Table 3.

Table 3: Mean SLAS Scores for ENG10003 – Standard six and additional for “online” learning

Rate your level of agreement with the following statements about this unit...	Mean /10	Mean /10	Mean /10
	Subject	University	Faculty
“Standard” six statements of satisfaction of subject delivery	7.70	7.82	7.70
I found online learning an effective way to study this unit.	6.80	6.96	6.84

The rating values for subject ENG10003 were consistent across all six standard statements of student satisfaction and with the results for FSET and for the University as a whole, viz in the high 70’s when expressed as a percentage.

The additional request for a SLAS rating, that for the level of satisfaction with the online delivery of the subject, was a clear 9% below the mean rating level for the standard six statements of satisfaction, and this too was in keeping with scoring levels for the faculty and for the University as a whole.

Response to requests for suggestions to improve delivery of ENG10003

There was also provision on the SLAS forms for students to provide their feedback on two requests, one being*: In my opinion, aspects of this unit that could be improved are…*

Some 83 responses were offered by way of opinion (29% of the class) on this request. Most dealt with relatively minor individual issues, especially related to lack of one-to-one communication/assistance and on their relative perception of the delivery of topics in the subject as presented by the three separate lecturers involved with it in Semester 2, 2020. Several dealt with the perceived inequity in fees paid relative to service received which would be more of a “gripe” on the overall course than specific to subject ENG10003.

A “guarded” selection of some of these is listed below.

1. This unit is important for all engineering student so it is better to study this unit on campus but the fact is corona virus is the barrier.
2. the labs as having more and an ability to test more structures and the way in which they work i feel could be very beneficial
3. The labs were somewhat frustrating, having to use photos to measure values. Obviously it's difficult at the moment to have an alternative to this, but maybe providing the values might help students feel more confident in their answers.
4. Better communication of assessment and lab tasks especially information on what needs to be done in assessment area.

As is usual when requesting feedback, there’s some differences of opinion that can easily be seen in this list.

Item 2 in the comments list, in particular, supports informal comments made by students during the live subject presentation sessions that it would be useful to have more, but shorter, targeted videos of hands-on experiments in the subject delivery.

Responses to student opinion of best aspects of ENG10003 (Semester 2 2020)

The other request for feedback from students on the ENG10003 SLAS forms was*: In my opinion, the best aspects of this unit are…*

Only 12% of the class, provided their opinion on this request. Most were quite succinct and there was a clear favourite aspect - the “Truss Build” exercise – which involved individual student construction and load testing of a pin-jointed truss subject to well-defined constraints on geometry, materials used and application of the loading to “failure/collapse”.

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Again, a “guarded” (some comments included names of lecturers/tutors) selection of these opinions from the SLAS for this subject are listed below.

1. very clear lectures that are really good length - weekly assignments and tests work well with the provided tutorials - building a bridge is really fun
2. I felt I learned most from tutorials in this unit as it gave me the chance to do probs using the methods attained in lectures, providing the opportunity to actually apply the theory to better consolidate how to do certain types of problems. I also found the labs quite useful, however admittedly felt they were hindered by our inability to attend and perform the experiments ourselves. Despite this I felt taking real measurements of a given experiment aided in understanding how the equations in theory translate to real world applications.
3. The videos for the assignments and tests are very clear and helpful to understand
4. Truss lab was really good. Lectures are well prepared and easy to understand

In summary, students appreciated the hands-on opportunities of the Truss Build exercise, the videos (labs) and the assignments (includes the video-labs), and opportunities interacting in detail with tutors and lecturers, albeit online.

It was deemed likely that the inclusion of shorter videos of experiments (than for the assessed T3 and F8 assessable lab. sessions) in the online delivery of ENG10003 for Semester 1 2021, had the potential to improve on the student online delivery experience.

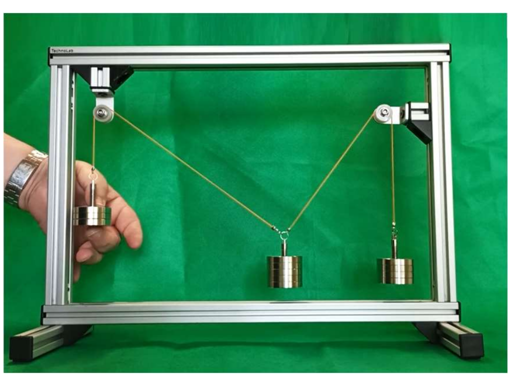
Short videos that provide experiment-based evidence of key Engineering concepts or corroborate the results of worked examples of application of theory dealt with in the subject, were made available to ENG10003 from www.Mechanics-Lab.com for trialling purposes.

Feedback from Questionnaires & Student Learning Assessment Survey in Semester 1 2021

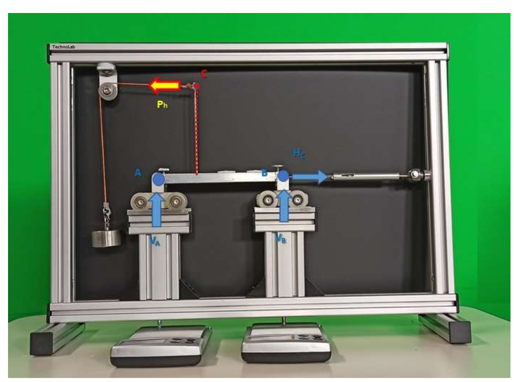
A selection of four of these experiment-based video lessons, on top of Experiments T3 and F8 (the two Lab. Class experiments adopted for assessment), was included in the online delivery of ENG10003 in Semester 1, 2021, averaging one topic per fortnight of delivery.

Still-photo extracts from these four experiment-based lessons, defining the topic for the additional material treated in this way, are depicted in Figures 2(a) to 2(d). The time spent in the online delivery of these segments varied from 5 minutes for the segment 2(a) and 15 minutes for the segment 2(d), so formed a small, but significant component of the delivery.

The SLAS statements on which scoring was being requested was modified by SUT from the “standard” six in Semester 1, 2021 to only five similar statements. The extra statement on the effectiveness of online mode of delivery for learning was “dropped”. Other differences noted for the 2021 Semester 1 ENG10003 class included a much smaller student cohort of only 80 students (of which only 25 responded to the SLAS) and 2 weeks of COVID lockdown “relief”.



2(a) 2D equilibrium of 3 Forces at a point



2(b) 2D equilibrium of a rigid bar

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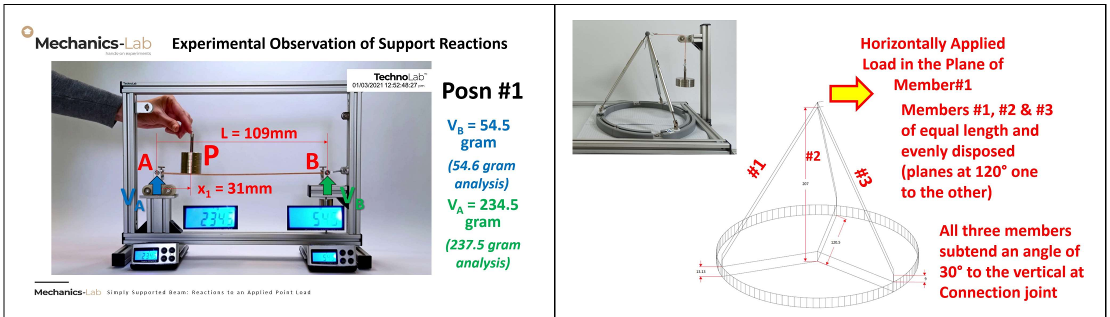

2(c) Reactions of a simply supported beam | **2 (d) Forces in a tripod under horizontal load**

Figure 2: The four additional experiment-based verification video segments adopted within the online delivery of ENG10003 in Semester 1 2021

The result for the mean of scores for all five statements for subject ENG10003 in Semester 1 2021 is compared against that for the University as a whole and for the faculty FSET, in Table 4 below. The result for the subject is now higher than for both FSET and SUT as-a-whole, whereas in Semester 2 2020, (see Table 3) the score for a comparable set of statements, was on par with that for FSET and lower than for SUT as-a-whole.

This suggests that an "improvement" has been achieved with the changes made in the subject delivery for Semester 1 2021 compared to Semester 2, 2020.

Table 4: Mean SLAS Scores for ENG10003 – Semester 1, 2021

Rate your level of agreement with the following statements about this unit...	Mean /10	Mean /10	Mean /10
	Subject	University	Faculty
Revised five statements of satisfaction of subject delivery	7.92	7.48	7.76

Response to requests for suggestions to improve delivery of ENG10003

A small number of students provided their feedback on the request*: In my opinion, aspects of this unit that could be improved are…* A selection these is listed here.

1. Adjust lab session so that off-shore students can participate as much as they can.
2. More in person classes if allowed by uni
3. Provide examples of previous final projects
4. Providing more support to students who need help
5. Would have been better to have more face to face learning, but that was not aloud
6. Unit is handled very well, with almost all resources easily found through recordings or lecture slides, nothing to improve in my mind.

Most of these suggestions related to assessment improvements. A couple (responses 2 and 5) appreciated the short stint of relaxed COVID restrictions when a near 50% capacity of Prac Classes/Tutorials rooms was permitted for classes to enable an on-campus experience.

It was during this short stint before the next lockdown that hands-on performance of Experiment T3, that of the 7-bar Warren Truss, was made possible in the ENG10003 Prac-Class room. Students in ENG10003 performed Experiment T3 individually (instead of in pairs), on each of the 12 replicates of the test rig of this experiment in this room, whilst respecting the 1.5m distancing rule. (The normal capacity of this room is 24 students).

Responses to student opinion of best aspects of ENG10003 (Semester 1 2021)

Only 12 responses from the cohort of 80 students were received on their opinion of *the best aspects of this unit are…* A selection of half of these is listed here, again "as received".

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1. Going through the Mastering Engineering assignment during tutorials was helpful, rather than on our own
2. Having the Lab to be able to build on everything we had previously learnt
3. In person labs.
4. Interesting and well structured content. Lab activities were useful - along with the on-campus demonstrations. The final project was very insightful in the sense that we had to build a model bridge from scratch, and apply analysis techniques learnt from all the modules learnt thought the semester.
5. The lab sessions, with the use of the interactive beams and truss' are a great.
6. The practical aspects in the unit, from building a bridge to seeing how trusses and beams work has been really helpful. The practical aspects in this unit have made it really enjoyable and feel like its own experience compared to other units. the teaching staff have all been really nice, supportive, helpful and approachable throughout the unit.

The hands-on aspects of the subject (bridge building and experiments) figured largely here.

A separate quiz was run in ENG10003 to obtain further clarity on student appreciation of their limited hands-on experiences and the online experiment-based support material inclusions.

The four TechnoLab™ experiment test rigs that were used to provide experiment-based evidence of basic principles and/or experimentally derived solutions to worked problem exercises and included in the online delivery of ENG10003 in Semester 1 2021, (as depicted in Figure 2) were made available to students of the subject at two Open Sessions by the suppliers of this test equipment. The timing of these was out-of-class-session and out-of-lockdown but still respecting COVID distancing restrictions.

The quiz contained four separate components with sub-questions and was made available to all students enrolled in ENG10003 for response. Again, a small portion of the students in the cohort (approx. 20%) provided feedback to the quiz. Details are presented in Table 5 below.

Table 5: Feedback from ENG10003 Semester 1 2021 quiz on experiment-based material

(a) Bridge-Building Project	**Excellent - good**	**Fair - poor**
Helpfulness of bridge project in understanding how a real-life bridge performs	95	5
Relevance of bridge project to theory learnt in Modules 1 - 5	90	10
Helpfulness of bridge project in understanding theory learnt in Modules 1 - 5	90	10
(b) Mechanics-Lab Clips in Online Delivery	**Excellent - good**	**Fair - poor**
Relevance of video clips of experiments presented in lectures to theory (for example: truss game, centre of gravity, force equilibrium)	86	14
Helpfulness of video clips of experiments presented in live lectures to supplement lecture materials	90	10
Relevance to theory of Week 10 online lab on bending moment and shear force diagrams	62	38
Helpfulness of Week 10 lab in understanding how beams behave under bending	71	29
(c) Hands-on TechnoLab™ Warren Truss Experiment	**Excellent - good**	**Fair - poor**
Relevance to theory of Week 7 Truss lab experiment performed individually on campus	84	16
Helpfulness of Week 7 lab experiment performed individually in understanding how a truss behaves when loaded	78	22
(d) Hands-on TechnoLab™ Experiments – "open" session	**Excellent - good**	**Fair - poor**
Helpfulness of performing hands-on experiments compared with performing more worked examples of applying the theory	84	16

It is clear, that students in ENG10003, recognised the learning value from their hands-on performed exercises on physical systems i.e. Bridge-Building project, Experiment test rigs on

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Warren 7-bar truss (assessable exercise) and those used to produce the experiment-based support material for on-line presentation.

It is also clear that the students valued the experiment-based support material segments presented to them on-line.

Concluding Remarks

This paper presented and discussed student feedback prior to and after implementing changes in response to this timely feedback by Swinburne University of Technology in subject ENG10003 Mechanics of Structures. Feedback in consecutive semesters of subject delivery, was obtained under significant COVID restrictions and even lockdown.

Students reported highly valuing the inclusion of experiment-based support material segments presented to them online as a change made in approx. every second online delivery session in Semester 1 2021. Action to implement these changes was instigated from student comments made in the SLAS for ENG10003 by the class in Semester 2 of 2020.

The bridge-building project (in 2020-2021) and test rigs for Experiment T3: Warren 7-bar Truss, together with the physical model kits used to produce the experiment-based support material for on-line presentation, when made available to perform experiments on-campus “hands-on” in Semester#1 2021, (albeit under restricted distancing requirements), were noted as being highly appreciated by students in the relevant ENG10003 classes.

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Know your stuff, show enthusiasm, keep it on message: Factors influencing video engagement in two mechanical engineering courses

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ABSTRACT

CONTEXT

Video usage in higher education has increased markedly over many years, but ongoing disruptions caused by the COVID-19 pandemic have accelerated this trend. Consequently, a growing number of educators are grappling with how to best approach video production. Although a range of factors such as video quality, video length, and the presenters' style are known to influence student engagement with videos, more research is needed to understand the extent to which these factors impact, particularly in higher education. This can support educators producing video content that prioritises those aspects which are most critical.

PURPOSE

This research seeks to understand what factors are most influential on students' decisions to engage versus disengage with video resources in the higher education context. This aims to develop a series of recommendations for educators to focus on when producing videos for inclusion in higher engineering education courses.

APPROACH

This research considers two mechanical engineering courses taught at different Australian universities. These courses used videos as the primary delivery mode during Semester 2 (July to November) of 2020. Approximately half of each course explicitly applied production recommendations of a highly influential study. Students were surveyed at the end of the semester about their engagement preferences.

OUTCOMES

The quality of the presenter's explanations and their enthusiasm in delivery were the most important factors influencing engagement, while seeing the presenter was least important. Video length and quality were more likely to cause disengagement when poor, than drive engagement when done well.

CONCLUSIONS

Characteristics of the presenter's delivery (that is the quality of their explanations and their enthusiasm) are more influential in producing engaging video content than technological choices relating to the video capture and length. Therefore, educators should seek to prioritise the quality of their explanations and their stage presence, before working to improve the video/audio capture quality and reducing video durations. Including the face of the instructor in educational videos has little impact on students' usage decisions.

KEYWORDS

Educational videos, student engagement, video production

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Introduction

Video usage in higher education has increased markedly over many years (Fyfield et al., 2019), but ongoing disruptions caused by the COVID-19 pandemic have further accelerated the trend. Consequently, a growing number of educators are grappling with how to best approach video production within their contexts. Although a range of factors such as video quality, video length, and the presentation style are known to influence student engagement with videos (Dart, Cunningham-Nelson, et al., 2020; Guo et al., 2014; Kay, 2014), more research is needed to understand the extent to which these factors impact, particularly in higher education. This can support educators to prioritise those aspects which are most critical when producing video content.

The increase in videos in educational contexts been motivated by improved accessibility of authoring tools, and research demonstrating the benefits of videos for learning (Berger & Wilson, 2016). Videos have subsequently been incorporated in a wide range of ways to engage students, with video styles varying according to learning objectives (Winslett, 2014). Overwhelmingly, research has shown that students value learning with videos because of increased accessibility of the resources, enhanced flexibility that enables tailoring to students' individual needs and preferences, and better learning outcomes (Dart, Cunningham-Nelson, et al., 2020; Dart, Pickering, et al., 2020).

A body of research has examined what factors influence video engagement and the quality of learning undertaken. For example, Di Paolo et al. (2017) emphasises the importance of the instructor's social presence within videos given the lack of real-time, face-to-face interactions in asynchronously delivered online courses. This presence can be achieved through visual representations of the instructor on screen, their use of language, and non-verbal cues such as body language. Kay (2014) highlight the criticality of instructional explanations in supporting students to understand and apply concepts using videos. They note that the use of examples is particularly effective in maths-based subject areas as it supports simplification of abstract concepts. Mayer (2021) developed a series of principles for designing effective educational multimedia content. This advises educators to avoid extraneous material while signalling key material, locate printed text near relevant graphics, and present words as narration rather than printed text.

One of the most influential studies on educational video production was performed by Guo et al. (2014). This study empirically analysed user interaction logs from videos used in four massive open online courses (MOOCs). Based on this analysis, seven key recommendations were made (Guo et al., 2014, p. 2):

1. Invest heavily in pre-production lesson planning to segment videos into chunks shorter than 6 minutes.
2. Invest in post-production editing to display the instructor's head at opportune times in the video.
3. Try filming in an informal setting; it might not be necessary to invest in big-budget studio productions.
4. Introduce motion and continuous visual flow into tutorials, along with extemporaneous speaking.
5. If instructors insist on recording classroom lectures, they should still plan with the MOOC format in mind.
6. Coach instructors to bring out their enthusiasm and reassure that they do not need to purposely slow down.
7. For lectures, focus more on the first-watch experience; for tutorials, add support for rewatching and skimming.

The present study investigates how strongly selected attributes of educational videos contribute to students' decisions to engage and disengage with videos. This is explored in the context of two mechanical engineering courses, which each adopted the above recommendations of Guo et al. (2014) to varying degrees throughout the courses.

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Method

Context

This study considers two mechanical engineering courses taught during Semester 2 (July to November) of 2020. The courses were:

- "Modelling and Control" at the University of Newcastle, which was compulsory for students in mechanical, mechatronics, electrical, aerospace, and medical engineering programs during their second or third year of study. The course enrols about 250 students per semester.
- "Dynamics" at the Queensland University of Technology, a second-year course taken by students in the mechanical engineering stream that also enrols about 250 students per semester.

Both courses were team-taught, and utilised pre-recorded lecture videos for the first time in 2020. In Modelling and Control, the course content had long been delivered through two consecutive streams – the former focused on mathematical modelling of physical systems and the latter focused on design of controllers for these systems. While both streams utilised pre-recorded lecture videos, they approached the production of these videos differently, owing largely to different teaching styles of the two lecturers. The modelling stream – as much as possible given time constraints – explicitly applied each of the recommendations made in Guo et al. (2014). The control stream applied only some of these recommendations. Similarly in Dynamics, the first half of the course that focused on particle dynamics primarily used classroom lecture recordings with minor editing from the previous year. The second half of the course's lectures that focused on rigid body dynamics were pre-recorded by applying many of the recommendations made in Guo et al. (2014). A direct comparison of adoption is given in Table 1, and indicative screenshots of videos from each stream (with the faces of presenters blurred for anonymity) are shown in Figure 1. It is worth noting that the lecture videos are described as either concept introduction (CI) videos where a new theory or idea is discussed, or worked example (WE) videos where a problem is worked through step-by-step (Dart, 2020).

Data Collection

Given each course had experienced a range of production styles, students in these courses were considered well-positioned to comment on their preferences. An anonymous online survey was circulated at the end of the semester. This asked students about their engagement with the videos throughout the semester, including frequency and methods of interaction, perceptions of learning, and preferences. This paper focusses on two high-level questions from the survey, which probe student perceptions around video attributes that incentivise and disincentivise engagement. The attributes of interest were:

- Audio Capture Quality
- Video Capture Quality
- Seeing the Presenter
- Enthusiastic Delivery from the Presenter
- High Quality of Explanation
- Short Video Duration

Students were asked to score each of these attributes on a 5-point Likert scale (where 1 represented low impact and 5 represented high impact) according to:

1. How strongly they contributed to their decision to *engage* with a video.
2. How strongly they contributed to their decision to *disengage* with a video.

Survey response data is summarised in Table 2. Overall, 109 responses to the survey were received, representing a response rate of 21.7%.

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Table 1: Characteristics of lecture videos by course component

Recommendation from Guo et al. (2014)	Modelling & Control		Dynamics	
	Modelling	Control	Particle	Rigid Body
1: Create short videos	Average length (mins): CI 3.8, WE 14.0	Average length (mins): CI 14.7, WE 11.1	Average length (mins): CI 80.2, WE 25.4	Average length (mins): CI 18.8, WE 23.2
2: Display instructor's head	Face present in all videos	Face present in all videos	Face present in all videos	Face present in CI videos only
3: Create for personal feel	Videos filmed with presenter 'full screen' and graphics added in post.	Screen recording of PowerPoint slides.	Classroom recordings of lecturer presenting slides and writing under document camera.	Screen recording of PowerPoint slides for CI videos and OneNote for WE videos.
4: Motion and continuous visual flow	WE screen-recorded iPad writing	WE screen-recorded iPad writing	WE solved on paper under document camera	WE screen-recorded Microsoft surface writing
5: Create with online format in mind	Videos newly created exclusively for online format	Videos newly created exclusively for online format	Minor editing of previous classroom recordings	Videos newly created exclusively for online format
6: Speak fast and with high enthusiasm	Average 203 words per minute	Average 119 words per minute	Average 122 words per minute	Average 169 words per minute
7: Design lectures for first watch experience, tutorials for re-watch	Popups used to highlight important information. Longer WE timestamped.	Boxes used in PowerPoint slides to highlight important information.	Boxes used in PowerPoint slides to highlight important information.	Highlighting of final answers for WE videos.

Table 2: Survey response summary

Attribute	Modelling & Control	Dynamics	Overall
Responses	81	28	109
Population	250	252	502
Response Rate	32.4%	11.1%	21.7%

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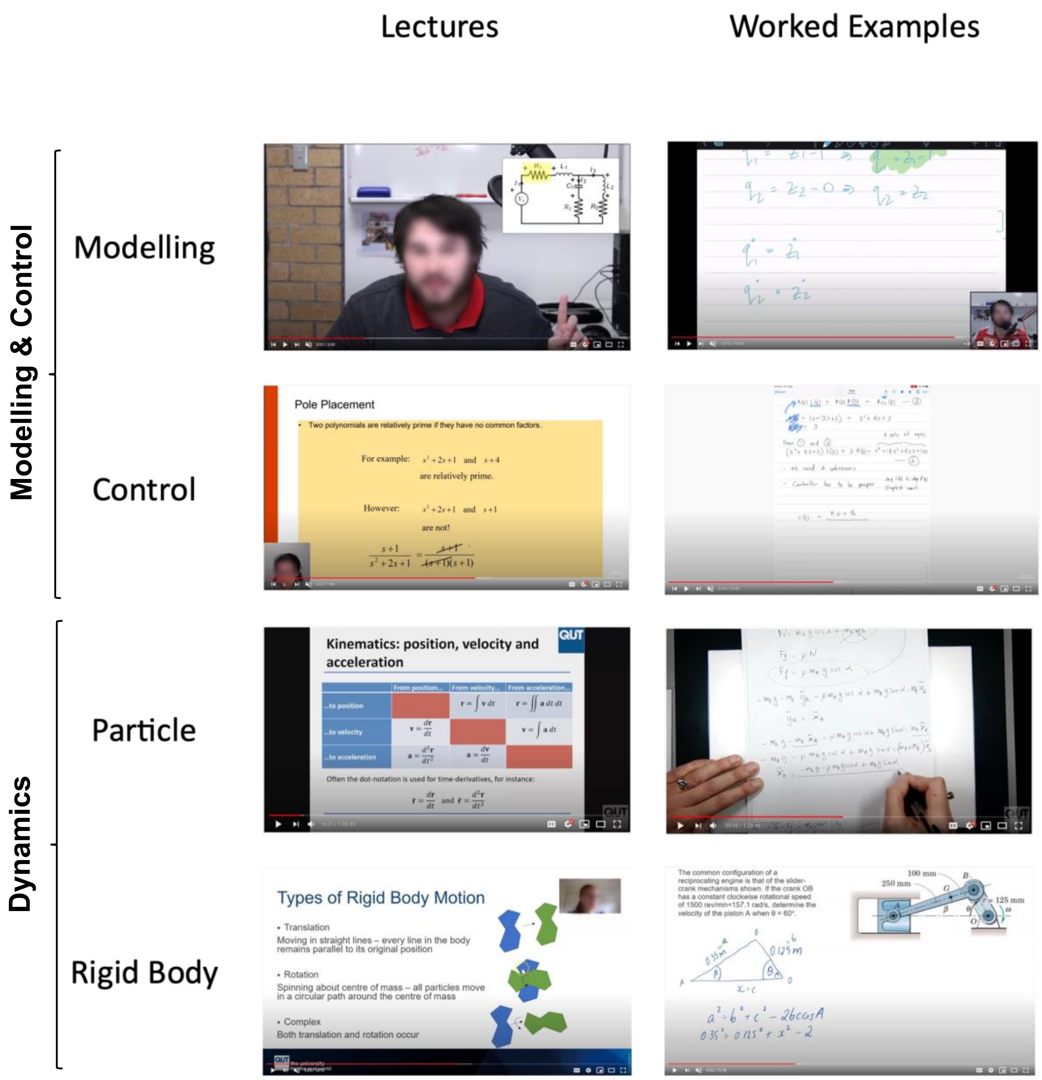

Figure 1: Indicative screenshots of videos from each course component

Results

The distribution of responses for the survey questions are shown in Figure 2 and Figure 3. The mean Likert score for each attribute is further summarised in Table 3. This shows that the contribution of the attributes to engagement and disengagement follow a similar pattern.

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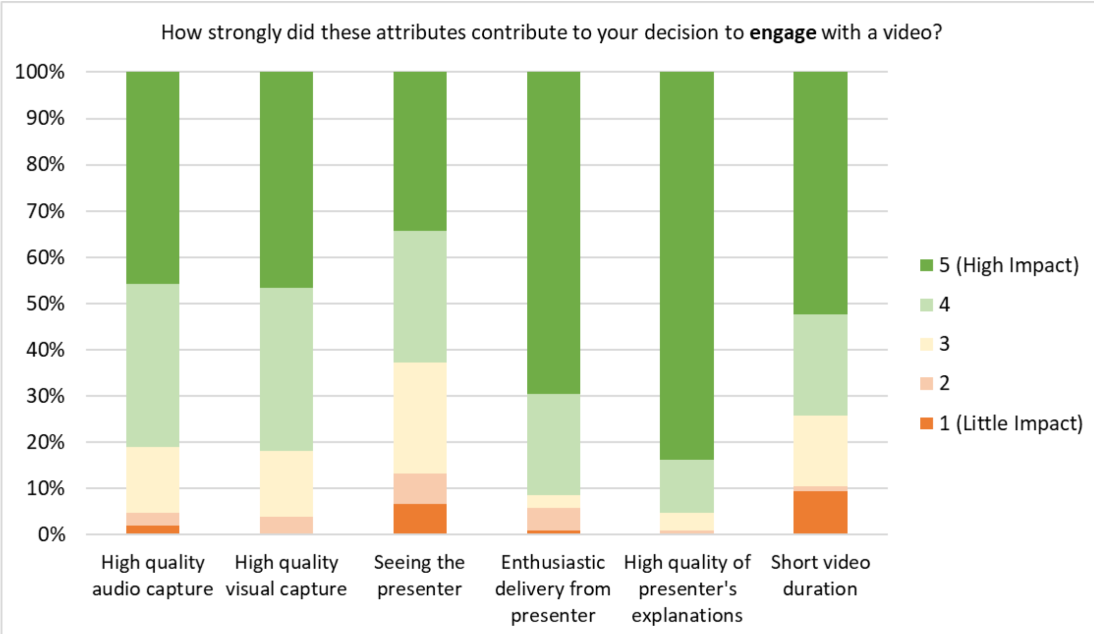

Figure 2: Likert scale responses to how strongly video attributes contributed students' decisions to engage with a video [N=109]

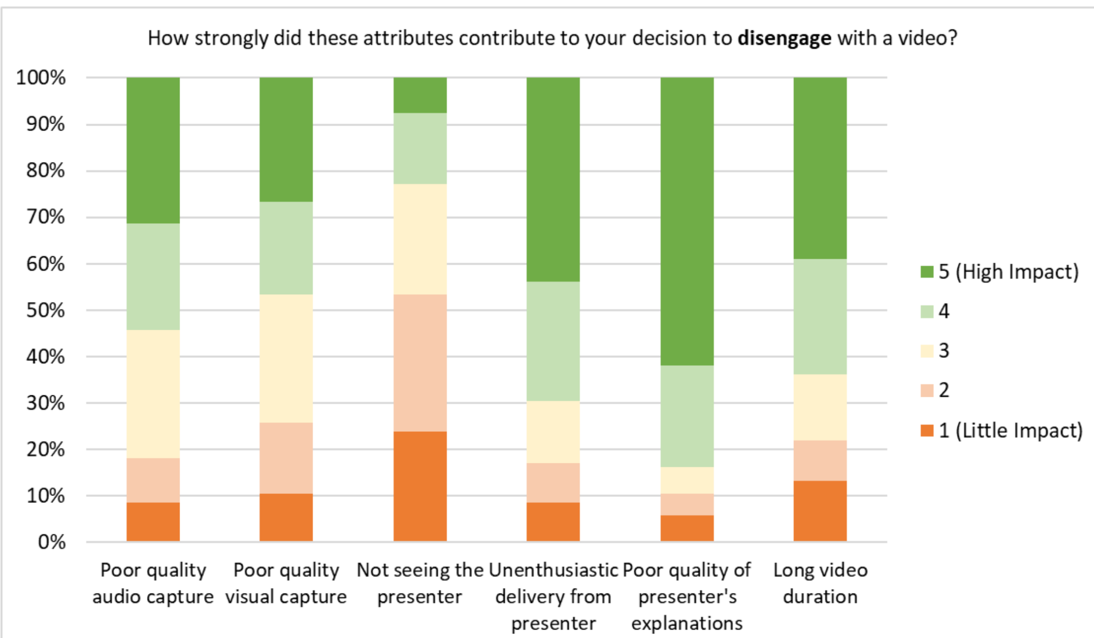

Figure 3: Likert scale responses to how strongly video attributes contributed students' decisions to disengage with a video [N=109]

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Table 3: Attributes ranked from highest to lowest impact based on mean Likert score

Rank (Highest to Lowest)	Contribution to Engagement		Contribution to Disengagement	
	Attribute	Mean Likert Score	Attribute	Mean Likert Score
1	High quality presenter explanations	4.78	Poor quality presenter explanations	4.30
2	Enthusiastic delivery	4.54	Unenthusiastic delivery	3.88
3	High quality visual capture	4.25	Long video length	3.68
4	High quality audio capture	4.20	Poor quality audio capture	3.59
5	Short video length	4.07	Poor quality visual capture	3.37
6	Seeing the presenter	3.77	Not seeing the presenter	2.53

Discussion

Interpretation of Results

Table 3 shows that the quality of explanation and enthusiasm of delivery were the most important factors in influencing students' decisions to use the videos. This was true in both directions – students indicated that high quality explanation and high enthusiasm were important factors in driving engagement, and where these characteristics were lacking, it drove disengagement. This finding is consistent with previous work by Dart, Cunningham-Nelson, et al. (2020) who found that narration that delivered explanations for understanding was a fundamental contributor to students' perceptions of the usefulness of educational video resources. Kay (2014) note that the narration is particularly important for worked example videos where a problem is worked through step-by-step to a final answer. They note that the explanatory component should seek to explicitly break down the problem "into meaningful cognitive steps, explaining the reasoning for each step…using visual supports" (Kay, 2014, p. 23). Delivering this in an enthusiastic manner clearly contributes further to the effectiveness of this approach.

Audio and video capture quality varied in importance – these were more likely to drive engagement when done well than to cause disengagement when done poorly. This implies making an effort toward enhancing these aspects of video production can help improve engagement, but that it is a case of diminishing returns. This result is consistent with Shoufan (2019) who analysed the likability of educational videos on YouTube. Their study found "a video is disliked due to bad quality 3.5 times more frequently than a video that is liked due to good quality" (Shoufan, 2019, p. 452).

Interestingly, the length of a video also varied in its importance depending on whether engagement or disengagement was probed. Having a short video was ranked fifth out of the six attributes explored in terms of its contribution to engagement. In contrast, having a long video was ranked third out of the six attributes for its contribution to disengagement (Table 3). Like the audio and video quality, this suggests that reducing the length of videos can lead to greater engagement, but this has diminishing returns.

Finally, seeing or not seeing the instructor was perceived to have the least impact on both video engagement and disengagement. This implies that the second recommendation of Guo et al. (2014) to display the instructor's head at opportune times through editing in the video is not particularly important in determining the desire to use a video.

Recommendations

Overall, the results indicate that the most important factors influencing educational video engagement relate to the instructor's teaching quality rather than the production choices made within videos (such as visual/audio capture quality and editing). This is encouraging as it implies engagement can be improved irrespective of resources, budget, and video production skill limitations. Given the more 'mechanical' aspects of video production are less influential over engagement decisions, it is worth considering the extent to which these are worth focussing on.

For the modelling stream of Modelling and Control, which attempted to adopt all recommendations from Guo et al. (2014), it was found that video production was extremely time-intensive. This was despite the course already having reasonably well-developed content which tended to have natural places where this could be segmented in shorter chunks. In this case it was estimated that a single five-minute video would take approximately two hours to plan, film, and edit. In contrast, the particle component of Dynamics took a more efficient approach to production, which relied on a simpler style requiring less planning and editing. Here videos were typically filmed in one take with no post-production editing applied, and those demonstrating worked examples did not include the instructor's face. In this situation it was estimated that videos took about three times their length to pre-work, record, and then upload for students.

While employing a more polished production style contributes to engagement (as evidenced by students' ratings in this study), it appears that the extent to which the production recommendations of Guo et al. (2014) are followed could be relaxed without a substantial loss. This is particularly the case for the video length attribute, where Guo et al. (2014) recommended videos should be less than six minutes. Our results suggest that long videos drive disengagement, but that working to create extremely short videos (which is very time-consuming due to the amount of planning, filming, and editing required) does not have a large pay-off. This is consistent with Dart (2020) who found that the average view duration for similar videos held a reasonably linear relationship with video duration. This contradicted the relationship shown in Guo et al. (2014) which showed a significant drop in viewing time for videos longer than six minutes (which was how their video duration recommendation was derived). Thus, we recommend instructors should seek to minimise video durations by keeping on message and concise, but to not work excessively to trim time through over-planning and editing. Additionally, we recommend against post-production editing where this is needed to include the instructor's face.

Limitations

This study considers only student responses to 12 Likert scale survey questions. Some ambiguity exists in these questions, such as what constitutes a 'short' or 'long' video. The sample size and demographic are also limited - only a 21.7% response rate across a single iteration of two engineering courses, during the COVID pandemic. Future work will centre on validating these findings across a larger and more diverse sample, as well as triangulating the results using thematic analysis of free-text comments and correlation with quantitative usage analytics.

Conclusion

This study has investigated what factors are most influential on students' decisions to engage versus disengage with video resources in the higher education context. This found that

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characteristics of the presenter's delivery (that is the quality of their explanations and the enthusiasm in their delivery) are more influential in producing engaging video content than technological choices relating to the video capture and length. Therefore, educators should seek to prioritise the quality of their explanations and their stage presence, before working to improve the video/audio capture quality and reducing video durations. Including the face of the instructor in educational videos has little impact on students' usage decisions.

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Community in classrooms: Practical strategies to foster engineering students' sense of belonging

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ABSTRACT

CONTEXT

"Loneliness, defined as a subjective experience of social isolation, has been identified as the next public health epidemic of the 21st century" (Lim, 2018). When combined with the recent impact of COVID-19 on engineering education, advancing our understanding of belonging and community forms a critical and timely challenge. Mounting evidence points to student belonging as a foundation of engaged learning, persistence to graduation and student wellbeing. However, understanding *how* to foster a sense of belonging to a community remains elusive as there is an absence of scholarly literature pointing to the practical activities and approaches that can be applied to develop inclusion and a sense of close connection between students and their learning communities.

PURPOSE

The purpose of our work is to explore the aforementioned gap in the literature, and to establish a foundation for practical methods to foster students' sense of belonging to learning communities within undergraduate engineering classrooms. Our scope includes pre-COVID and during-COVID timelines, and thus includes face-to-face, blended and fully online learning environments.

APPROACH

As part of a case study research design, informal pedagogical interventions were designed and delivered within face-to-face, blended and online tutorial and lecture settings, aimed at building relationships and fostering students' sense of *membership, partnership* and *ownership.* The cohorts included undergraduate engineering mathematics courses with ~500 local and international students. Our mixed method approach captured quantitative and qualitative data relating to students' experiences of interventions and their sense of belonging to the learning community.

OUTCOMES

Our results indicate that there are practical activities and approaches that teachers can incorporate to give students a sense of feeling included or believing they are closely connected to a learning community in face-to-face, blended and completely online environments. Successful strategies involved flexibility, friendliness, interactivity, encouragement, and support.

SUMMARY

Our work supports the position that students' sense of belonging can be enhanced in the classroom through teacher-led pedagogy. Furthermore, instilling in teaching staff an awareness of the importance of cultivating community and enacting pedagogical warmth is also impactful and can lay the necessary foundation for more specific interventions.

KEYWORDS

Community in the classroom, belonging, practical strategies, COVID-19.

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Introduction

The recent impact of COVID-19 on engineering education has highlighted the importance of learning communities and belonging in universities. The challenge of belonging in education has captivated researchers for decades, and there is mounting evidence that points to student belonging as a foundation of engaged learning, persistence to graduation and student wellbeing (Allen et al, 2018).

In particular, a growing body of literature points to the impact of teacher behaviour on students' sense of belonging and sense of community in the classroom (Allen et al, 2018). For example, Astin (1993, p.223) draws on studies that show increased frequency of student-faculty interaction is related to students' satisfaction with college, and that interaction between students and faculty has a stronger relationship to student satisfaction than any other variable. Furthermore, Endo and Harpel (1982) concluded that informal interactions between faculty and students have a stronger impact on more student outcomes than do formal interaction. In addition, Felten (2019) takes the position that:

> *"if students perceive academic staff to be approachable, helpful, and encouraging, they are likely to be open to interactions with staff and to thrive at university; if students perceive staff to be remote, discouraging, or biased, they are likely to avoid interactions and to disengage from their studies".*

However, the recent and rapidly evolving context of COVID-19 is yet to be fully understood with regards to community and belonging. In particular, understanding practical examples of *how* teachers can foster a sense of belonging to a community remains elusive. There is an absence of scholarly literature pointing to specific strategies, case studies and approaches that can be applied to develop inclusion and a sense of close connection between students and their learning communities.

Herein, we aim to explore the aforementioned gaps with the purpose of establishing a foundation for practical methods to foster students' sense of belonging to learning communities within undergraduate engineering classrooms. Our scope includes pre-COVID and during-COVID timelines, and thus includes face-to-face, blended and fully online learning environments.

As part of a case study research design and action research, informal pedagogical interventions were designed and delivered within tutorial and lecture settings, aimed at building relationships and fostering students' sense of *membership, partnership* and *ownership* motivated by the work of Schreiner (2010).

We evaluated the impact of our interventions via the assessment of student perceptions involved by employing surveys, leading to a qualitative and quantitative analysis. Our interpretation indicates that there are practical activities and approaches that teachers can incorporate to give students a sense of feeling included or believing they are closely connected to a learning community in face-to-face, blended and completely online environments. Successful strategies involved embedding flexibility, friendliness, interactivity, encouragement, and support.

Research Design

The Intervention in More Detail

Tinto (1997, p.599) describes the classroom as "the crossroads where the social and the academic meet", making it the ideal site in which to build learning communities. In the context of this paper, we include face-to-face, blended and online environments as classrooms.

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The case in our case study falls within the domain of a large, first-year class in mathematics termed MATH1131 at University of NSW. MATH1131 is a large, compulsory first-year course for all engineering undergraduates at UNSW. Its syllabus for our intervention included an introduction to vectors, complex numbers and matrices, see Tisdell (2021) for more context of this course.

Our intervention involved two, ten-week terms: firstly, during Term 3, 2019 in blended mode; and secondly, during Term 3, 2020 in fully online mode. In each of these terms the timetable of classes involved: 5 hours of lectures per fortnight, and 2 hours of tutorials per week.

The population size over the two terms was approximately 500 students. Our case study MATH1131 ran in Term 3 during each year which is traditionally a popular time of international student intake at UNSW, and so most of the students in our study were international (and male).

Our teacher-led strategies throughout the intervention periods may be summarized by the teacher

- Being friendly and welcoming
- Offering students choice and flexibility
- Fostering interactivity between students and teacher
- Displaying encouragement and support.

Let us unpack these behaviours briefly.

During our intervention, the teacher promoted a position of “relentless welcoming” (Felton, 2019). For example, at the beginning and end of each class, whether it was face-to-face or online, students were warmly greeted or thanked in a polite and friendly way to communicate that their presence was gladly acknowledged and received. This was done collectively (“Hello everyone and welcome back to MATH1131”), but also at the individual level when each student entered “the room”. The use of individual student names (“*Welcome, Lingtong!*”) was particularly easy for the teacher in the fully online live-streamed classes due to the names of all participants appearing on the computer screen. These actions align with the belief that teachers displaying friendly and welcoming behaviour has the potential to ensure everyone in the community feels welcome and a part of the group, fostering relationships that have the potential to thrive (Felton, 2019). An inclusive learning environment, one that creates a sense of belonging and connectedness, helps students to feel cared about and supported (Allen et al, 2018).

Throughout each term, the teacher offered flexibility and choice to the students. An example of this involved decisions regarding revision for medium stakes assessments. Students could choose when and how much class time was devoted to revision (e.g., A revision lecture to be held one week or one day before the mid-term? For a full lecture or just 30 minutes?). Another example involved tutorials, where the teacher was completely open to each student choosing to work on specific ideas that interested them during each class, such as the students: undertaking an online weekly quiz, exploring the practice questions from the textbook, or something else related to MATH1131. These actions acknowledged the position that teachers providing students with real choices in the classroom can boost engagement, motivation and sense of ownership, enabling them to capitalize on their strengths, and enable them to meet their individual learning needs (Parker et al, 2017; Wolpert-Gawron, 2018).

The teacher consistently created opportunities for interactivity with the students. For instance, the teacher regularly arrived at each class approximately 20 minutes before its timetabled start and stayed another 20 minutes after its timetabled conclusion. These actions opened a window for regular “*how are you*?” dialogue and presented opportunities to get to know students on non-academic levels. In addition, during tutorials at the start of each term, students were encouraged to introduce themselves and share some personal stories with the class. This was reciprocated by the teacher, and academically balanced by the

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teacher asking questions and probing students' understanding during classes, enabling students to reflect and develop their ideas (DfEE, 1998, p. 8). These actions recognize that teacher interaction plays the most important form of interaction within classrooms (Johnson, 1981) and has the potential to influence belonging and community within this social network of relationships.

Finally, the teacher engaged in an encouraging and supportive practice. This was embodied, for example, by listening, noticing, boosting morale, praising effort and input, and celebrating. Some key catchphrases employed by the teacher included "I'm glad you asked that question" and "you *can* do it!". These actions align with the position of Evans (2005) that the more students are encouraged, the more belonging they experience, and that encouragement is an enabler of embedding "social interest" and "psychological hardiness" in individuals (Griffith & Powers, 1984).

Methodology

Our methodology for this work draws on elements of case study research, action research and impact evaluation which are appropriately aligned with our study in the following ways.

Case study methodology is a well-known research genre in the social sciences (Day Ashley, 2017, p.114) and involves "an empirical investigation of a particular contemporary phenomenon within its real-life context using multiple sources of evidence" (Robson, 2001). A recognized advantage of case study research design in its ability "to enable the research to intensively investigate the case in depth, to probe, drill down and get at its complexity" (Day Ashley, p.114). Case study research is well-matched with our setting due to our intervention taking place in MATH1131 over two terms, which form the cases under investigation.

Action research has a long history in educational research and is becoming increasingly popular in other fields (Munn-Giddings, 2017, p.71). Action research is based within practice and not separated from it, that is, the researchers are part of their research context. One of the acknowledged advantages of this way of working is that being an insider "brings both a unique and rich knowledge base to their research" (Munn-Giddings, 2017, p.72). Action research aligns with our study due to one of the researchers also being the lecturer and tutor for the courses under consideration.

Our approach to interpret the experiences of students within our intervention draws on the concept of impact evaluation, which is a long-standing and popular way of working in the social sciences. Higgins (2017, p.145) describes impact evaluation as an assessment on the effects of initiatives or other intentional change that may include the perceptions of those involved. One of the strengths of impact evaluation is in its ability to guide scholarly-based policy and decision-making in education (Gertler, 2016).

Instruments and Data

To help us interpret the experiences of students, we employed surveys as our central instrument. Survey research forms a suitable tool for this due to its ability to gather information about population groups to "learn about their characteristics, opinions, attitudes, or previous experiences" Wang (2009, p.128) and thus is well aligned with the intentions of our research. Morerover, Murphy, Hill and Dean (2013, p.1) capture the essence of survey research: "Conducting survey research is at its core, a social interaction between a researcher and a (potential) respondent – a conversation with a purpose". Survey methods have enjoyed increased popularity in recent decades to form an important, accepted, cost-effective and time-efficient way of enabling research within the social sciences (Berends, 2006).

In Table 1 we summarize our evaluation overview, including the two sets of survey statements that we employed, the timing of the surveys and their focus.

Table 1: Evaluation Overview

Approach	Timing	Years	Evaluation Focus
Bespoke Survey	Both post intervention and at end of term.	Both run in 2019 and 2020	Interpreting the impact on students' attitudes regarding their experiences under the intervention
Institutional Course Survey			

The statements in our surveys are captured in Table 2. Their form and intent can be aligned with the four dimensions on belonging and community identified and discussed in the previous subsection.

Table 2: Statements in Surveys (Bespoke *A-K*, Institutional *L*)

Item	Statement
A	The teacher makes me feel like I am a member of this course.
B	The teacher encourages me to devote time and effort during this course.
C	The teacher sharing personal experiences and stories has helped to build a relationship between teacher and students.
D	The teacher is friendly.
E	The teacher is helpful and supportive.
F	Students are given opportunities to share their thoughts and opinions during class.
G	The teacher provides opportunities for students to make some choices about learning activities.
H	The teacher makes me feel like I have input into the learning group.
I	I feel like I am part of a learning community in MATH1131.
J	I feel a sense of learning partnership with my MATH1131 class.
K	I feel a sense of learning partnership with the teacher.
L	I felt part of a learning community.

In each survey, students were asked to respond to the each of the statements in Table 2. For our bespoke survey, students could respond at a high level for Items ***A-K*** by selecting either: Disagree (D); Mildly Disagree (MD); Neither Agree nor Disagree (N); Mildly Agree (MA); or Agree (A). For the institutional course survey, students could respond to Item ***L*** by selecting either: Strongly Disagree (SD); Disagree (D); Mildly Disagree (MD); Mildly Agree (MA); Agree (A); or Strongly Agree (SA). We note that there are two sets of scales here, however, according to Allen and Seaman (2007) "there's really no wrong way to build a Likert scale" and that augmenting these two sets of data for each term gives us the potential to triangulate. Participants were not forced to make a choice regarding any of these statements. If they did not wish to answer then they could simply leave it blank.

Each statement was followed by a free text box where students could elaborate more on their thoughts regarding their experiences and attitudes towards the statement. Once again, if students did not wish to provide additional comments they could leave this part blank.

In Tables 3 and 4 we have reported the spread of data captured from our bespoke and institutional course surveys over 2019 and 2020. Note that due to an oversight Item ***K*** was accidently omitted from the 2020 survey.

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Table 3: Bespoke Survey Data 2019, 2020 (Terms 3)

	Term 3, 2019						Term 3, 2020					
Item	D	MD	N	MA	A	n	D	MD	N	MA	A	n
A	2	2	10	42	62	118	0	0	4	21	57	82
B	2	4	12	46	54	118	0	0	5	32	45	82
C	3	4	24	35	52	118	0	0	7	30	45	82
D	3	0	2	20	93	118	0	0	0	16	66	82
E	2	1	5	32	78	118	0	1	2	17	62	82
F	2	1	15	40	60	118	0	0	5	21	56	82
G	2	5	11	47	53	118	0	1	6	28	47	82
H	2	7	16	44	49	118	0	0	7	27	48	82
I	3	5	13	30	67	118	1	0	4	27	50	82
J	4	6	18	34	51	113	1	1	7	31	42	82
K	0	6	15	34	59	114	Not asked					

We can see in Table 3 that there was a total number of respondents of ~200 to the bespoke surveys, and in Table 4 that there was a total of 240 respondents to the institutional course survey.

Table 4: Institutional Course Survey Data 2019, 2020 (Terms 3)

	2019							2020						
Item	SD	D	MD	MA	A	SA	n	SD	D	MD	MA	A	SA	n
L	3	0	5	15	78	73	174	0	0	1	8	21	36	66

Analysis and Discussion

To analyze the data from the previous section we employ quantitative and qualitative approaches below.

We established a 5-point Likert scale for our bespoke surveys (D = 1, MD = 2, N = 3, MA = 4, A =5) and a 6-point Likert scale for the institutional course survey (SD = 1, D = 2, MD = 3, MA = 4, A = 5, SA = 6). Table 5 contains the mean score, confidence interval (CI) and standard deviation (SD) for each of the sets of responses which have been rounded to two decimal places. In addition, we provide some high-level data via the Overall Agree %, which is defined as those percentage of responses of: Mildly Agree; Agree; or Strongly Agree. Finally, we have included the effect size (Cohen, 1988), where we compare the standardized mean difference between 2019 and 2020 data. Although there is no “control group” at play here, we thought it would be interesting to compare to see if there was some improvement in the 2020 intervention above the 2019 intervention.

We can see from Table 5 that all mean scores were between 4 and 5, or between 5 and 6. In 2019 most scores remained in these ranges when applying the lower end of the confidence interval. In 2020 all scores remained in the above ranges when applying the lower end of the confidence interval. This suggests that overall, we may interpret the students as agreeing or mildly agreeing with the statements in Table 2 regarding their experiences of our intervention.

Table 5: Analysis of Bespoke Survey Data 2019, 2020 (Terms 3)

	2019		2020		
Item	Mean, CI* (SD**)	% Overall Agree***	Mean, CI (SD)	% Overall Agree	Effect size
A	4.36 ± 0.15 (0.84)	88	4.65 ± 0.12 (0.57)	95	0.40
B	4.24 ± 0.16 (0.89)	85	4.49 ±0.13 (0.61)	94	0.33
C	4.09 ± 0.18 (1.00)	74	4.46 ± 0.14 (0.65)	91	0.44
D	4.69 ± 0.13 (0.75)	96	4.80 ± 0.09 (0.40)	100	0.18
E	4.55 ± 0.14 (0.77)	93	4.71 ± 0.12 (0.58)	96	0.23
F	4.31 ± 0.15 (0.85)	85	4.62 ± 0.13 (0.60)	94	0.42
G	4.22 ± 0.16 (0.91)	85	4.48 ± 0.15 (0.69)	91	0.32
H	4.11 ± 0.17 (0.97)	79	4.5 ± 0.14 (0.65)	91	0.47
I	4.30 ± 0.18 (0.99)	82	4.52 ± 0.15 (0.71)	94	0.26
J	4.08 ± 0.20 (1.07)	75	4.37 ± 0.17 (0.79)	89	0.30
K	4.29 ± 0.16 (0.89)	82	Not Asked		
L	5.21 ± 0.14 (0.93)	95	5.39 ± 0.18 (0.76)	98	0.22

*Confidence interval at 95%, **SD is the standard deviation

***Overall Agreement is defined as those responses of: Mildly Agree; Agree; or Strongly Agree.

We also note that items ***D*** (friendliness), ***E*** (helpful and supportive) and ***A*** (membership) were the three highest scoring items across both years, suggesting that the teacher's behaviour had more of an effect here than in other areas, such as items ***J*** (peer to peer partnership) and ***C*** (sharing stories), which where the two lowest scoring items across both years. This suggests student felt more strongly about the first set of items than the second set.

In addition, we observe that the effect size ranges from 0.2 – 0.47 across all of the items except one (***D***) which was very high already in 2019. This suggests small to medium improvements between the 2019 intervention and the 2020 intervention. One way of explaining this is due to maturation – the teacher was probably more adept at the intervention the second time around, even though this was within a completely online environment.

Over 600 free text comments were collected as part of our bespoke surveys. The data was analysed via NVIVO to produce a frequency of terms. We established word stems, so "help" and "helping" would be coded together. The rankings are presented in Table 6.

Table 6: Ranking of Coded Themes from Bespoke Survey Data 2019, 2020 (Terms 3)

Theme	**2019 Rank**	**2020 Rank**
Question, questions	1	1
ask, asked, asking, asks	2	11

helpful, helping, helps, help	3	N/A
encourage, encouraged, encouragement, encouraging	4	5
answer, answered, answering, answers	5	4
friendly, friend	6	7
share, shared, sharing, shares	7	6
time, times	8	N/A
understand, understanding, understandable	9	N/A
approachable	10	9
interact, interactive, interactions, interaction	11	10
discuss, discussion, discussed	12	8
engaging, engaging, engages	13	12
learn, learning, learns	14	13
motivated, motivation, motivates, motivating	15	14
student, students	N/A	2
chat, the chat, in the chat	N/A	3

If we consider Table 6 then we notice that the identified themes relate to the concepts of community and belonging discussed earlier in this paper. For example, the responses of "question", "asking", "interact" and "discussion" can be linked with the concept of fostering interactivity. In addition, "Helpful", "encouraging" and "understanding" can be aligned with the dimension of support and encouragement. Overall, Table 6 can be interpreted as the students providing consistent feedback across both years acknowledging the impact of our intervention on their sense of community and belonging.

Conclusion

By designing and applying basic teacher-led interventions such as friendliness, choice, interactivity and encouragement, we gained valuable insights into *how* teachers can apply practical strategies to create conditions and opportunities that foster students' sense of belonging to community. These small, practical strategies were grounded in established theories of belonging and community, and were consistently and positively received by students. Our rerunning of the intervention resulted in a small to medium improvement. More work needs to be done, including further explorations of what kinds of practical community-building strategies work best, and for whom?

We encourage teaching staff to build on this work, and cultivate community and enact pedagogical warmth in their own way that is meaningful and impactful within their own classroom environments.

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Rapid Learning Cycles for project-based learning

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ABSTRACT

CONTEXT

The Massey University Bachelor of Engineering (Honours) programme is based on a series of Project-based learning (PBL) courses. It is observed historically that students have difficulty initiating project work, planning projects and deciding what decisions and information should be their focus. "Rapid Learning Cycles", developed by K. Radeka, combines New Product Development models "Lean Product Development" and "Agile Scrum" into a framework that uses regular cycles for project execution. The process identifies Key Decisions to be made in a project and determines the Knowledge Gaps to be closed within cycles. This allows team members to make these high impact/ high unknown decisions with a better understanding of the alternatives, maximising the value of the time spent learning. The approach has the potential to be used where student projects are short (one or two semesters), allowing students to make better-rationalized decisions and complete projects with a disciplined framework.

PURPOSE OR GOAL

It is hypothesised that the Rapid Learning Cycles (RLC) framework, or an adaption of it, is a suitable learning framework for Project-based learning courses, where project teams have to complete a project in a reasonably short time frame, resulting in improved learning outcomes, and project quality and delivery. In particular, those projects within a Product Development context may benefit, improving the relevance of students' skills to industry.

APPROACH OR METHODOLOGY/METHODS

Final year engineering students majoring in Engineering and Innovation Management (EIM) complete a double semester Industry-based Capstone project in small teams. An EIM team at one Massey University campus was introduced to RLC informally and encouraged to use the approach to manage their project. Other EIM teams at a second Massey University campus were not introduced to RLC and used other product development processes to manage their projects. A post-project survey was used to review the project management methods considering such aspects as ease of project planning, ease of decision making, project delivery, knowledge management, ease of project start-up, and attainment of learning outcomes. This was to understand the factors that the students found difficult in managing and completing projects.

ACTUAL OR ANTICIPATED OUTCOMES

As expected, the students using the RLC framework, being self-taught in it, adapted the RLC framework to their circumstances and also reduced their use of the framework as the project reached a conclusion at the end of Semester 2 when other course work made maintaining a regular cycle of learning difficult. The project was completed successfully. The results from all students of the elements of project management indicated that different methods were used with success.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The adoption of the Rapid Learning Cycles framework produced a project that was planned well, had a high degree of completion, had few issues getting started, and use of the framework decreased as the project neared completion. With a low survey participation rate there was no evidence of RLC being better than other methods used of managing projects but flexible methods seemed to help students in managing their projects. The use of RLC and other flexible methods of project management will be considered further for PBL based courses

KEYWORDS

Project-based learning, Rapid learning cycles, project management

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Introduction

The Massey University Bachelor of Engineering (Honours) programme is based on a series of Project-based learning (PBL) courses that form 25% of the programme in each year, and is termed the 'project spine'. It is observed historically that students have difficulty initiating project work, planning projects and deciding what decisions and information should be their focus. In 2012 Massey University offered a redesigned Bachelor of Engineering (Hons.) [BE (Hons.)] degree, using a curriculum based on the CDIO standards (www.cdio.org). The redesigned degree was aligned to meet the revised accreditation criteria of Engineering New Zealand (ENZ). ENZ had identified the graduate attributes required from engineering education to increase the relevance of graduates' skills to what employers required (Engineering New Zealand, 2010), aiming to reduce the gaps between graduate attributes and professional competencies of the International Engineering Alliance (IEA, 2013) and the then current ENZ accreditation criteria and graduate profile (Goodyer & Anderson, 2011).

The redesigned programme was to address not only the need for graduates who are "rounded" with stronger "soft" or professional skills around teamwork, ethical considerations, sustainability, management and leadership, life-long learning and have a greater practical appreciation of the theoretical knowledge that they were being taught but also meet the graduate attributes of the Washington Accord WA6 – WA12 (IEA, 2013) that are part of the graduate profile. PBL is believed to develop these skills more than a traditional learning approach (Mills & Treagust, 2003), (Hadim & Esche, 2002)) and by having PBL in each year of an engineering programme it follows the fourth principle towards guiding the transformation of Engineering Education for the greater engagement of students (Beanland et al., 2013).

The Washington Accord Graduate Attribute Profile for 'Project Management and Finance' states (IEA, 2013):

> *WA11: Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work as a member and leader in a team, to manage projects and in multi-disciplinary environments*

Project Management activities (Planning, Costing, Ethics, Team Development, Project Monitoring, etc. and combinations of these) were seen as the most important activities in Engineering Management by more than 50% of responses in a survey of the Engineering Profession in New Zealand (Pons, 2016). In the redesigned BE (Hons) degree at Massey University project management and teamwork are introduced in Year 1 of the degree with teams of students, guided by academic staff acting as supervisors, planning a project and carrying out its implementation during the semester or double semester of the project.

At Massey University the courses are mapped to the graduate attributes using a 3-level system. The level of competency expected increases each year. For WA11, for example, in Year 2 for the students are expected to have obtained at the end of the course a programme-defined Level 1-2 where the basics of project management are reinforced and consideration of basic financial principles, particularly related to return on investment from a new product (the context of the project), are an important aspect of the project.

In Year 4 (the final year) Capstone Project there is an expectation that at the end of the course students will have obtained Level 2-3 where students are expected to take full responsibility for the definition and completion of this project – they are required to apply all aspects of engineering management and economic decision-making which have been introduced in other courses and projects throughout the degree. Students work in a team environment, being expected to take individual responsibility for specific tasks (taking leadership in specific areas) and to contribute to overall team management and successful project completion. Level 3 is expected to meet the indicated levels of attainment defined by

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ENZ in “Requirements for Accreditation of Engineering Education Programmes” for a student meeting the graduate attribute requirements (Engineering New Zealand, 2020).

It has been observed that students have difficulty in planning and monitoring team projects, particularly double-semester projects, as the team may not realise that they have fallen behind (Konings & Legg, 2020). To some degree this is avoided through regular meetings with supervisory staff but where increasing autonomy is expected, there is less contact with staff, and the workloads of other courses are high, especially in the final year, it is easy for student teams to end up significantly behind planned objectives (Konings & Legg, 2020). Lawanto, Cromwell, and Febrian (2016) presented the components of project management used by students for self-regulation of the Capstone projects broken down into team management, time management and resources management. They found that students adopted a teamwork strategy from a task interpretation standpoint and ‘such strategic actions and monitoring of personal, team and project status were employed to a lesser degree’ (Lawanto et al., 2016). Students tended to be focussed individually on completing assignments, skill development and defining their role, rather than on the team capability and utilisation. A significant concern from the study was the lack of, and infrequent efforts to define, update and adhere to a project schedule with a conclusion that project teams could be more successful if time and scheduling management was adhered to (Lawanto et al., 2016) and this would be necessary to meet the expectations of WA11 (IEA, 2013).

There is a wide body of knowledge on project management, in particular the Project Management Institute’s (PMI) ‘Body of Knowledge (PMBOK)’® (Project Management Institute, 2017) that describes the activities a project manager would consider. However, the context and scope of the engineering student projects, the limited time frames for student projects where the project is competing for the attention of the student against the demands of other courses, the difficulties the students face in completing projects, the strategic approach students take of focussing on their individual tasks, and the level of understanding required by students to complete the project suggests a need for a project management framework that will develop the understanding and learning of the student.

There are many processes to manage product development projects such as Stage-Gate®, Integrated Product Development (often taught as concurrent engineering), Lean Product Development, Waterfall, Agile (using Scrum) as discussed in the Product Development and Management Association (PDMA) Body of Knowledge (Anderson & Adkins, 2017). However, recent developments have focussed on hybrid processes with a focus on short iterative cycles within the phases or stages of a project such as Agile-Stage-Gate® (Cooper & Sommer, 2016). Since one of the critical success factors for product development is the work done at the front end of the project (Cooper, 2019) these hybrid processes help promote front end work where there is the least known about a project and reduce the uncertainty for those doing the project. A lesser known hybrid product development process has been titled Rapid Learning Cycles by its creator Katherine Radeka (Radeka, 2015). which combined short learning cycles from Lean Product Development (Ward, 2002) with Agile Software development methods.

Rapid Learning Cycles (RLC) combined these processes into a framework that uses regular learning cycles for project execution. At the beginning of the project the process identifies Key Decisions to be made and the Knowledge Gaps to be closed to be able to make those Key Decisions. The key elements in order of overarching hierarchy are the Core Hypotheses (the reason for doing the project or why the company believes in the product), Key Decisions (decisions that are high impact, unknown and must be made in order to complete the product or process but cannot be made with confidence yet), Knowledge Gaps (things the team needs to learn in order to make the key decision the knowledge is related to) and Activities (what will be done to close a knowledge gap or other processes in the product development process) (Radeka, 2015). These definitions fit well with the Activities, Information, Decisions (AID) model that has been used in Capstone Projects previously, where students define the decisions to be made in the project as the first step. The ‘kick-off event’ is used by the team

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led by a facilitator to determine the key decisions and the knowledge gaps and then plan these in a regular cadence of learning cycles and decision points as shown in Figure 1.

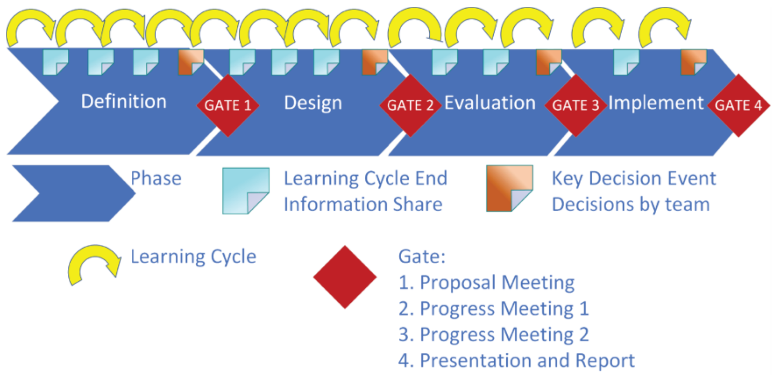

Figure 1 RLC interpreted for the BE (Hons) Capstone Project, based on Radeka (2015)

The knowledge gained is documented in a short A3 template (a single page) to be shared at the end of the learning cycle event (Information Share in Figure 1) to allow knowledge to be shared and easily found. Each key decision event is also documented with the decision(s) made on a short A3 template. The cadence of the learning cycle is set, dependent on the project, to 2 -4 weeks normally and the event for key decisions at every third or fourth learning cycle. Each event requires resetting and planning the next cycle. The use of documentation is seen as an important part of student capstone projects (Keogh & Venables, 2009) and this process promotes short and concise documentation that should reduce the workload on students when communicating project information and decisions.

In exposing the knowledge the team needs to make a decision, it encourages the team to use more time to build knowledge and make these decisions as late as possible. With the emphasis on learning and decreasing unknowns within a project this approach has the potential to be used where student projects are short (one or two semesters), allowing students to make better-rationalized decisions and complete projects with a disciplined framework as well as promoting the self-regulated behaviours that are desired in projects, particularly capstone projects as described by Lawanto et al. (2016).

Methodology

Final year engineering students majoring in Engineering and Innovation Management (EIM) complete a double semester Industry-based Capstone project in small teams. An EIM team at one Massey University campus was introduced to RLC informally and encouraged to use the approach to manage their project at the start of the academic year. Other EIM teams (three in total) at a second Massey University campus were not introduced to RLC and used other product development processes to manage their projects. There were a total of 15 students in the four projects and no project was the same as the other. Each project had elements that required technical knowledge that was not part of the taught content of the programme. The student teams had weekly supervisory meetings with an academic staff member although there was some flexibility in this, and the student team managed their communication and contact with the project's industry sponsor as negotiated with the sponsor. An abridged version of the learning outcomes for the Capstone project are.

1. Manage a complex engineering design/development project in a "near to commercial context"
2. Complete a detailed design solution based on a complex engineering problem related to the specific major being studied, where the final solution requires full evaluation.

3. Work effectively as both team leader and team member to successfully complete a complex, multidisciplinary project.
4. Exercise professional judgment, self-monitoring, peer assessment and adherence to ethical principles and professional codes of practice.
5. Identify key stakeholders and effectively communicate key information that is appropriate to specific stakeholder requirements and expectations.
6. Evaluate the feasibility of a project from a commercial perspective.

The Capstone project has six assessments for group and individual assessment including a project proposal meeting to define the project, progress meetings, presentations, and a final report as well as self-assessment and evaluation of the team performance.

A full human ethics application was completed and approved (SOB 17/30). After final report submission (the last assessment) a post-project survey was sent to students using the course's Stream site with instructions to return to an independent administrator. The students had two weeks to return the survey though this was extended due to the low response rate. The administrator entered responses to the survey in a spreadsheet to anonymise the data collected. The data was available to researchers after the release of final grades. The purpose stated to the students was that the survey would 'allow a qualitative and quantitative determination of what areas the teams find successful or challenging in a Capstone project-based course before considering what improvements could be introduced to make project execution easier'.The survey used to review the project management methods considered these sections (number of questions): Getting started on the Capstone project (5), Capstone Project Planning (11), New Product Development Process (7), Knowledge gathering, storage and reuse (7), Ease of decision making (8), and Attainment of learning outcomes (6). There were 45 questions in total, with a mixture of open-ended and Likert-scale questions. The survey was sent to 15 students but only 4 responses were received, which meant that quantitative analysis was not tested for significance.

A statistical analysis of Likert scale questions was conducted. The responses were scored 1-5 (1 being strongly disagree or poor, 5 being strongly agree or excellent) for each question and averaged.) Open-ended questions were reviewed to provide qualitative analysis of the data to establish themes in the answers given by the students (identified as A, B, C, D).

Results and Discussion

The first five questions were aimed at understanding whether students had difficulty getting started on the project and what the key challenges were. The responses to the ease of getting started ranged from easy (A and D) to difficult (B). Although three of the four students said that understanding and engaging in the project took 1-3 weeks, Student B said it took 4-5 months. However, in identifying the key challenges faced in starting the project the responses were similar around understanding expectations from the client and the academic staff, and identifying the scope of the project, which are the normal activities identified as critical to success in a project at the front end (Cooper, 2019). The students were asked if any particular NP process was adopted to overcome the challenges in starting the project. Only one student (A) answered that:

> *Rapid Learning Cycles was adopted identifying key knowledge gaps, and distributing activities for filling these gaps amongst the team members. Each team member focussed on a key knowledge area from which they would then become the "expert" in the team on that particular area.*

However, other NP Processes included "double-diamond" and "relatively fluid (like Agile)" both of which are similar in their use of iterative cycles and focus on learning. Double-diamond refers to the process which was the UK Design Council's interpretation of Design Thinking (Design Council, 2007). All responses indicated adoption of an NP Process.

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The next eleven questions were focussed on Capstone Project Planning – a summary of the responses is shown in Figure 2 where the response to the question "We created a project plan at the beginning of the project" was strongly agree from three students and Student B, the one that indicated 4-5 months to understand the project, put 'neutral." Students mostly maintained a plan that they were mostly all responsible for and reduced the scope during the project to maintain delivery of the project at the end of the course. Interestingly all students planned task delivery on regular cycles, although regular cycles was not defined in the question. One student (A) commented that there was constant recognition that "the plan was 'just a plan' and was likely to change as the project progressed".

When asked about NP Process (seven questions) the responses were mixed in their agreement to them – there was agreement that all adopted an NP Process, though the use was not necessarily maintained throughout the project. Students C and D, who identified the Agile and Double-Diamond processes for getting started, used these throughout. However, Student A, who identified RLC to get started identified Stage-Gate® as the NP Process used – this suggests that RLC was used as a tool or method in their overall management of the project. The majority agreed that they adapted the NP process used for their project.

With respect to knowledge management the seven questions were aimed at teasing out an important aspect of RLC use. However, all students agreed that there was a process to gather knowledge, there was access to knowledge, it could be easily retrieved and reused. Students used Google Drive and communicated updates to information stored although Student A using RLC communicated detail on the structure used. This student did not communicate that initially knowledge was stored as one page A3 briefs as shown by Radeka (2015) but this documentation decreased as the project progressed.

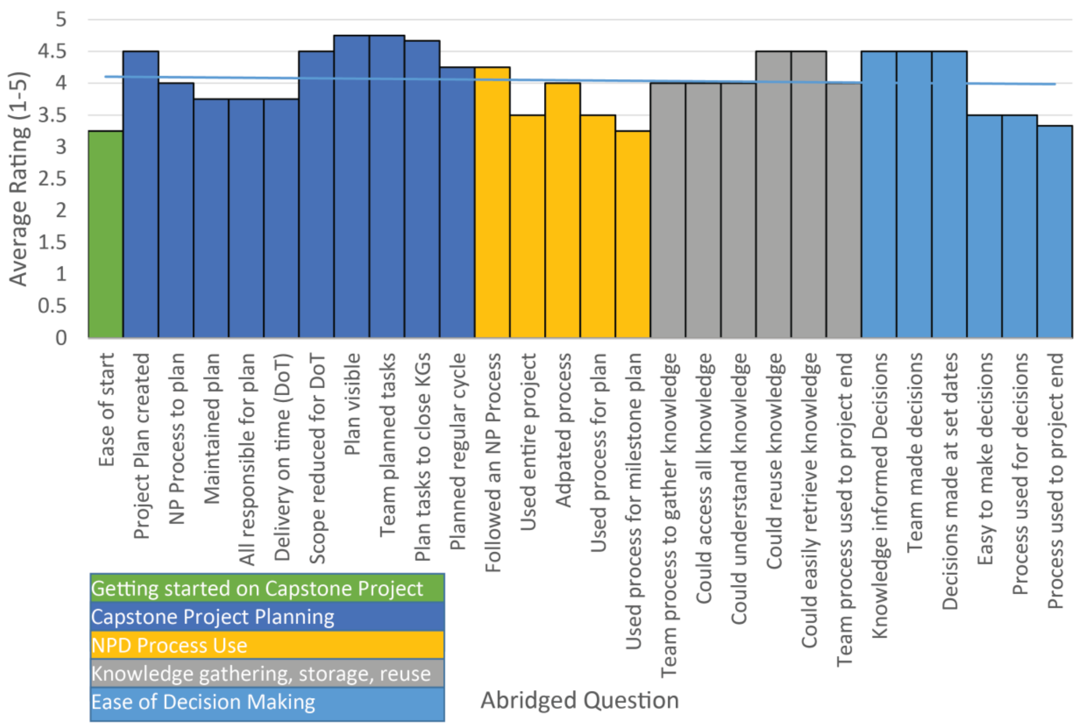

Figure 2 Student Responses (Averaged) to Survey Questions (N=4)

The last section of questions (8) was around the ease of decision making, another key aspect of RLC. Students agreed that the knowledge found informed their decisions and was made by the team at set dates. Students A and C, who identified as using RLC/Stage-Gate® or Agile, agreed that it was easy to make decisions and only the former agreed that there was a process used to make decisions and it was used throughout the process. Yet all identified they used some form of Decision Matrix with weighted criteria but not necessarily for all decisions. The students also commented that discussion of the decisions as a team was important as sometimes decisions were made without closing off the relevant knowledge gap.

In reviewing the responses, it became clear that the original purpose of the study being to identify if RLC was a more suitable method for the student management of their Capstone projects was not evident. It was evident that the students had success in managing their projects and that they used processes largely throughout the project. This was evident in how the students rated themselves when assessing their achievement of learning outcomes for the course. The responses are shown in Figure 3.

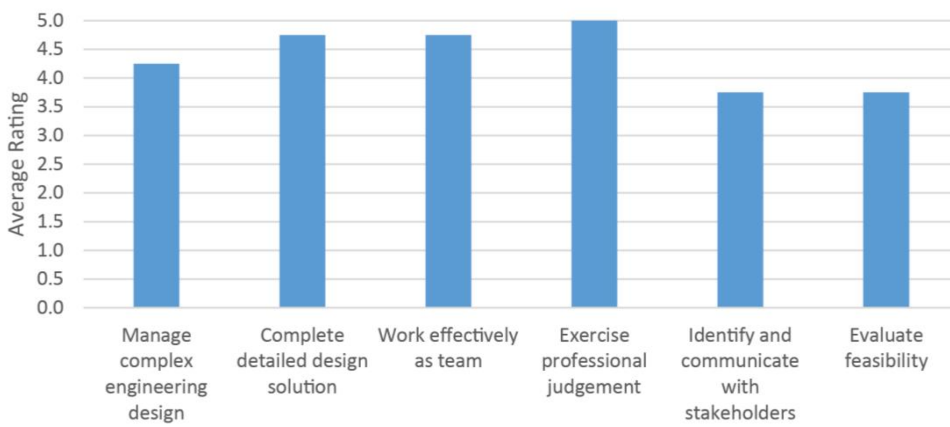

Figure 3 Student self-assessment of learning outcome achievement (N=4)

Manage a complex engineering design, working effectively as a team and exercising professional judgment encompass project management activities and students were largely in agreement that they had achieved these outcomes. This is similar to the results seen from an evaluation of the redesigned engineering degree where graduates of the redesigned programme rated themselves higher in the attributes of Societal considerations, Ethics, Teamwork, Communication and Management than graduates of the replaced programme (Tunnicliffe & Brown, 2017). However, the student comments clearly identified that there were issues in communicating with the company or other major stakeholders sponsoring the project and also having the knowledge to complete an effective evaluation of commercial feasibility of the project.

Massey University's project spine's PBL courses use regular supervisory meetings of staff with student project teams, and also include progress (sometimes termed gate) meetings with the team within the assessment schedule for the course. For example, one of the learning outcomes of the second year PBL course Product Development is 'Recognise the inputs and processes required for project management and apply the key elements through a product development process' and this is assessed through a component 'project planning and management' as part of the project proposal, progress meeting 1 and progress meeting 2 assessments. The average mark at progress meeting 2 for this component of the assessment ranges from 71 to 81% (mean 75.6%, median 75%) for 2015-2021 with no pattern that shows improvement or otherwise. The criterion for >75% is given as 'Clear evidence of use of a plan and that the plan is a living document. The planning for the report includes key sections of the report to complete and a plan for their review within the team'. In Year 2 there is still significant guidance for the students in managing and directing their projects, which is recognised as necessary when students are unfamiliar with project management (Verderber & Serey, 1996). At Year 4 in the Capstone Project with an expectation that students are autonomous in their planning and management of projects the

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learning outcome is ‘Manage a complex engineering design/development project in a "near to commercial context"; requiring problem definition, scoping of system and sub-systems, planning to complete required deliverables and outcomes, sound decision-making based on well researched knowledge and definitive action’ and there are project proposal, progress meeting 1 and progress meeting 2 assessments where a component assessed is the Project Planning and Management. The marks for this component ranges from 70-80% with no pattern to show improvement or otherwise.

Although these results indicate students are performing above average at both Year 2 and 4 (and this is similar to the conclusions of Konings and Legg (2020) for a Year 3 project) the students often modify the scope of the project to meet the constrained time of the semester or double semester project as well providing only very high level detail Gantt charts and sometimes a Kanban system of task management. The responses by the students confirm that students are modifying the project scope but were able to mainly maintain processes throughout the project. Students often express concern over getting started in projects, lack of time, the workload, and the uncertainty of what needs to be done. Students are introduced to the Engineering Method and Project Management in Year 1, and the Product Development Processes and the Work Breakdown Structure in Year 2, which could be seen as giving them necessary tools to plan and manage projects and the lack of these concerns being evident in the responses to this study of Capstone Projects suggests a developing confidence in project execution.

Overall, in this study students used both a team management and time management approach, as defined by Lawanto et al. (2016), but did not use a resource management approach. This might be due to the resources being largely out of their control. The concerns expressed over lack of, and infrequent efforts to define, update and adhere to a project schedule were not evident in this study perhaps because of the small sample size and students whose major is focussed around product development and engineering management. Yet, when these students started their final year they had had only a small exposure to courses specific to their major. In the time since this study was conducted there has been a noticeable uptake in the programme of students using electronic tools for task and time management, largely Kanban systems (To do, Doing, Done) that fit within the Agile and Lean NPD processes. All of these processes can be viewed as tools that fit within an overarching Stage-Gate® process (Furr & Dyer, 2014), a process which is used throughout the ‘project spine’. In teaching project management there is an unanswered question as to whether staff have the experience and knowledge of project management tools to guide students though it is seen as moderately to highly important (Brown & Tunnicliffe, 2017).

Conclusions

The adoption of the Rapid Learning Cycles framework produced a project that was planned well, had a high degree of completion, had few issues getting started, and use of the framework decreased as the project neared completion. A similar conclusion can be reached with the use of the other processes adopted by students in different teams. With a low survey participation rate there was no evidence of RLC being better than other methods of managing projects. This might be because the other processes adopted (Agile, Double Diamond) are also processes that use regular iterative cycles emphasising flexibility, knowledge and learning and these all fit within a Stage-Gate® approach that is taught in the programme as an overarching management process. All methods allowed students to achieve the learning outcomes as self-assessed, which is supported by the grades the students achieved. The few responses received from students indicate that flexible methods of management help students with project delivery. The motivation is to help students earlier in the programme with project management and these methods will be considered further for PBL based courses including further study on project management in the Capstone project.

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Work ready engineering graduates through WIL processes

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ABSTRACT

CONTEXT

Work Integrated Learning (WIL) requires an engagement approach that incorporates workplace partners, universities and students. Effective collaboration between students, universities and workplaces provides an enhanced engagement experience and enables students' to graduate with work-ready skills. CQU's Bachelor of Engineering (Honours) and Diploma of Professional Practice (Co-op) students participate in two 6-month WIL placements over the course of their university studies. As part of practice assessment, industry partners provide an evaluation of our students' performance against the Engineers Australia (EA) Stage 1 Competency Standard for Professional Engineers.

PURPOSE OR GOAL

A WIL student engagement framework was developed and adopted. This paper investigates the effectiveness of the WIL program to make CQU graduates work ready as compared to the Quality Indicators for Learning & Teaching (QILT)national survey data.

APPROACH OR METHODOLOGY/METHODS

A CQU formatted template of student capability against the Engineers Australia (EA) Stage 1 Competency Standard for Professional Engineers is sent to the employers to assess our graduates. These data sets indicate that the level our graduating students work abilities are at the national average or higher on a 5 Likert scale where 3.0/5.0 is the average level. On the other hand, the work readiness capabilities of current CQU engineering students and new graduates are then compared against the QILT national survey data to identify the graduates' standings on various descriptors such as overall student reaction, their skill development, rated teaching practices positively, interaction with staff and students, facilities and resources, positive support services, skill developments, starting salary etc.

ACTUAL OR ANTICIPATED OUTCOMES

The student assessment data from 2012-2019 indicated that the EA competency standard trend for CQU students was consistently above the average (3.0/5.0 on the Likert scale) of a graduate engineer. The QILT data suggest that, in some of the descriptors, the performance of CQU students and new graduates is comparable to that of the national standard.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The CQU WIL program students are consistently evaluated as work-ready, as they are rated above the average performance expected for a graduate engineer. They perform better than the average in some areas. Overall, CQU engineering graduates are work-ready compared to the national standard managed by the QILT. In order to further assess the impact of WIL-based programs on graduate outcomes, we suggest that more specific post-graduate surveys could further establish a causal link between WIL education, employer assessments, and graduate outcomes.

KEYWORDS

Work Integrated Learning; work readiness; industry engagement; collaboration, national standing.

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Introduction

The previous studies on WIL focussed on many factors of WIL engagement with workplace employers, universities and students. These factors include challenges and barriers of WIL processes, benefits and engagement styles of WIL to produce engineering work ready graduates. A thorough literature search is carried out to illustrate all these aspects.

The challenges and barriers faced during the WIL processes are evident. Some studies articulated an examination of employers' understanding of WIL, reasons for participation in the WIL placements (Ferns, Russell & Kay, 2016: Jackson et al., 2017). Jackson et al. (2017) indicated that the relationship between university and industries was in the form of 'placement to engineering workplaces' and 'non-placement to engineering workplaces'. Engineering students achieved a real-world work experience in the placement to engineering workplaces option. The development of work-related skills was achieved through engineering workplaces-based projects and simulations. Ferns, Russell and Kay (2016) pointed out that WIL employed real-world learning options into the curriculum and assisted engineering graduates to face the challenges of real-world problems. Ferns et al. (2016) also presented some challenges and barriers that the employers were facing including support for mentoring students, insufficient resources, cost, and the complexity of collaboration with universities. Walker and Rossi (2021) articulated that students experienced coping issues, self-belief doubts, and mental stress. It was not known which personal qualities the student should bring to their WIL journey to succeed during WIL placements and future employments. Student stress problems are significant in some WIL placements (Warren-James et al., 2021). The above literature suggested a few more challenges in WIL processes including an effective engagement on WIL, barriers of hosting students in workplaces, embedding real-world learning into the curriculum, evaluating WIL assessment, identifying suitable projects and tasks to assign to the students, sourcing of quality students, and maintaining quality of student performance.

There are some significant benefits of WIL placements to prepare work ready engineering graduates. Kaider (2017) suggested that WIL was an important engagement approach in increasing students' employability. He urged that the integration of theory and engineering practices of workplaces was key to the development of graduate employability. Blicblau et al. (2016), on the other hand, illustrated in their study that relevant work-experience improved the academic grades for engineering students. In some instances, a few engineering students were offered further full-time employment at the same place at the conclusion of their work placements. The studies of Male (2010), Male et al. (2011) and Jackson (2014) supported this point. Jackson et al. (2017) argued that WIL placements were the main vehicle to increase students' employability. Trevelyan (2019) also commented that curriculum reforms focussing on workplace skills and graduate attributes had not been attributed to significant employment opportunities. A structured work experience model, on the other hand, could improve the student employability (Edwards et al., 2015).

A broader benefit among universities, students and workplace employers through WIL is also evident. Ferns (2016) mentioned that the workplaces partners were interested in contributing to authentic learning through engineering workplace-focused resources. Agwa-Ejon and Pradhan (2017) and Glavas and Schuster (2020) explained that WIL enabled engagement of university academics and engineering workplace engineers for their mutual benefit. The authors articulated the potential of students' employability and impact of WIL on workplace organisations. They also reported that there was a lack of collaboration in terms of university assistance and lecturers' visits during the WIL period in selected industries. Therefore, a non-placement type WIL can be effective in many applications (Reedy et al., 2020).

The workplace dynamics are very important in WIL workplaces. Fleming and Pretti (2019) and Lu et al. (2018) carried out research to find whether a WIL student in the workplace community changed the workplace dynamics. They urged pre-placement preparation of

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students regarding workplace relationships and scenarios. It was also necessary to support for student wellbeing during their WIL experience.

The above literature pointed out that a structured WIL program could be an effective learning method in developing work-ready engineering graduates. The main focus on the WIL processes is on activities such as assessments, pre-placement preparation, employer engagement and barriers to effective outcomes. It is also necessary to focus on student work readiness for employment by ranking or benchmarking against employers' evaluations of student capability to judge employability through mapping against the Engineers Australia Stage 1 Competency Standard. There is limited study reported in this direction. Therefore, comparison of CQU engineering graduates data with the national survey on engineering graduate employability (QILT, 2020) data helps in this direction.

Methodology

At the 2019 Australasian Engineering Education Conference, a framework on the WIL process was presented (Mandal & Edwards, 2019). It focused on four stages: Stage 1: Relationship Formation, Stage 2: Recruitment and Selection, Stage 3: Industry Placement and Stage 4: Capability Assessment. As part of Stage 4 of this process, data was collected on student work readiness capability via assessments conducted by employers of students' performance compared to the Engineers Australia Stage 1 Competency Standard. Graduate Outcome Survey (GOS) indicators were obtained from QILT (2020 which provides data from graduates of Australian higher education institutions approximately four to six months after finishing their studies. The GOS measures short-term employment outcomes including skills utilisation, further study activities, and graduate satisfaction.

In order to provide the basis for evaluation of a structured WIL program on student work readiness, the WIL employer work readiness assessments were compiled, along with student satisfaction surveys of the relevant WIL unit. GOS indicators for the Co-operative Education Program (CEP) students were then filtered and presented in tabular format, along with the national averages for all engineering students. The following steps represent the steps undertaken to collect and manage the student data set (Figure 1) for trend analysis through the MS Excel graph and tabular forms. These stages are further discussed in detail below.

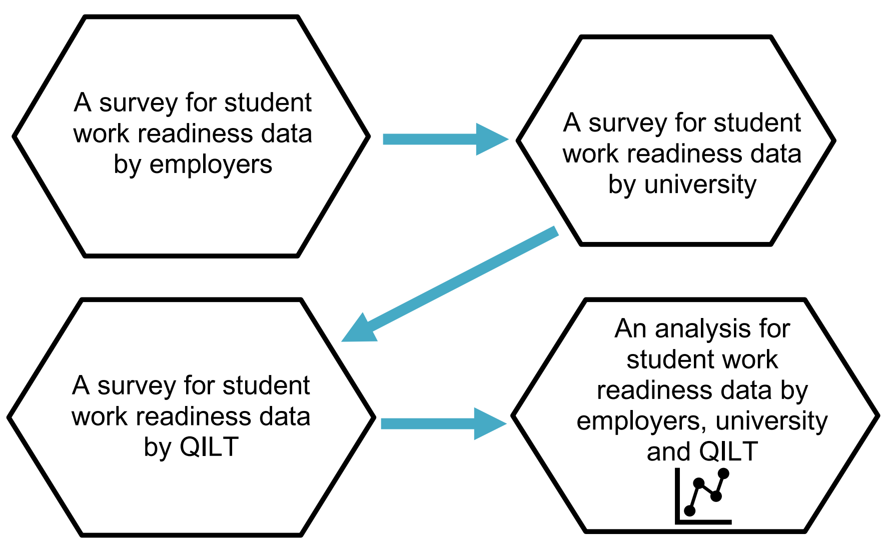

Figure 1: The proposed steps for collecting and managing student data set

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Stage 1: a survey of the student work readiness is carried out by participating WIL employers on standard forms prepared by the university mapped to the Engineers Australia Stage 1 Competency Standard, via a WIL unit called Industry Practice 2. Employer assessments are undertaken independently by the student's direct supervisor.

Stage 2: A student survey through the Industry Practice 2 unit is offered to students by the university Moodle system on various descriptors to judge their satisfaction in the placement unit. This is a standard practice applied to all units across the university's offered units, and completed by students toward completion of the relevant term.

Stage 3: The results of the national graduate outcome survey (GOS) of engineering graduate data carried out by QILT (2020) are compared with that for the recent CQU engineering graduates. As indicated above, this data includes graduate employment outcomes and graduate assessment of course satisfaction.

Stage 4: An Excel spreadsheet is used to compile all data results and present the analysis via figures and tabular forms.

Results and Discussions

As stated in the methodology section, the student evaluation survey data on work readiness rated by the employers were recorded and processed by the MS Excel. The data showed a comparison of student work performance as a newly graduated engineer against the Competency Standard categories of knowledge base, engineering ability and professional attributes using a 5-point Likert scale. To evaluate work placement value to employers, we analysed the past seven years of employer evaluation assessments. These assessments were undertaken by organisations within Construction, Electricity, Gas and Water Supply, Manufacturing, Mining, Local Government, Professional, Scientific and Technical Services. The data for CQU students shown in Figure 2 are classified using the three EA Stage 1 Competency Standard categories. As indicated, each competency is rated at a level well above the average graduate rating of 3.0 out of 5.0. We note that the professional attributes competency is consistently rated higher than engineering knowledge and ability. Further analysis of the data indicates some supervisors do not rate students in every element of competency, as the position scope has not afforded students the opportunity to exercise all competencies. Recent data indicates this situation applies to competencies PE 2.4 Proficiency in engineering design, and PE 3.3 Capacity for creativity and innovation (Engineers Australian, 2019). Finally, in response to the re-employment question, employers answered in the affirmative for 100% of evaluations.

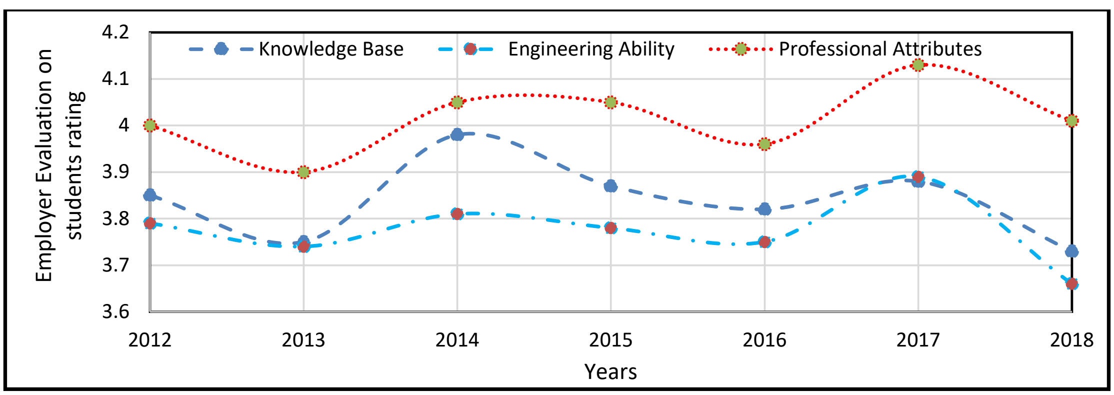

Figure 2: Employer evaluation on CQU student rating against EA Stage 1 Competency Standard: Knowledge Base, Engineering Ability and Professional Attributes.

In addition to employer ratings of CQU engineering graduates, the CQU engineering graduates themselves are providing their reactions and evaluations of the WIL learning and teaching (L&T) processes and practices in relation to their development as engineering work ready

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graduates through anonymous responses to a CQU survey tool. They allocate ratings on a 5-likert scale with 5 indicating strongly agree, 4 agree, 3 neutral, 2 disagree and 1 strongly disagree. CQU sets a student satisfaction level of 4 on this scale as a corporate target. Examining the student data in the WIL unit of Engineering Practice 2 (Figure 3), the student overall unit satisfaction average (far left of figure) is currently over the corporate target in the recent years. For the other descriptors, the WIL unit has also been performing well in recent years.

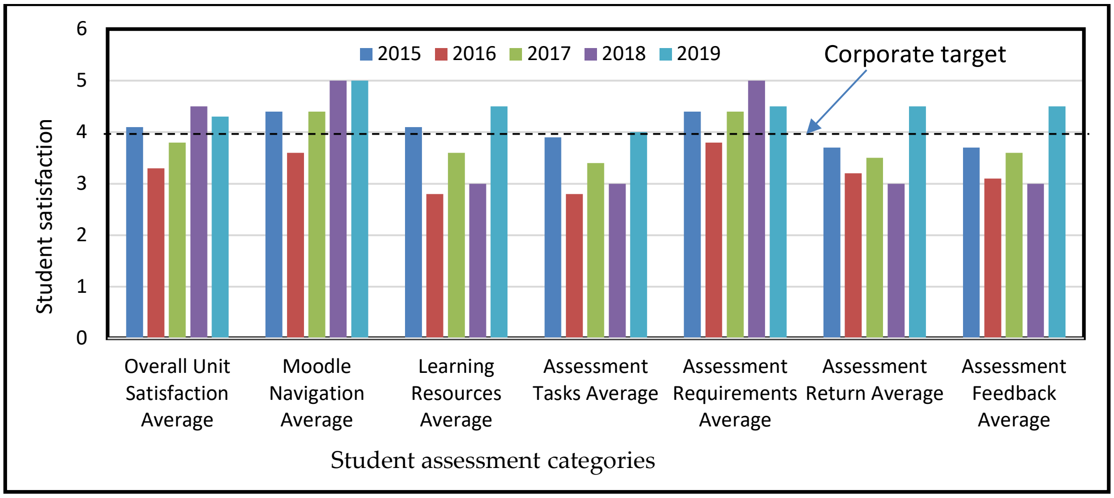

Figure 3: CQU student satisfaction data of engineering practice unit 2 on various descriptors.

The impact of the influential WIL processes on L&T student engagement practices and learning is also supported by the QILT (2020) national higher education survey data (funded by the Australian Government Department of Education, Skills and Employment) relating to CQU undergraduate engineering on current student experience, recent graduate satisfaction and recent graduate employment and salary. These data put into context how CQU's L&T practices employing WIL are linked to the engineering student experience at CQU (Figure 4). It shows that, in all areas of student skills development, teaching practices, engagement with students and resources and facilities, the CQU undergraduate engineering students are rating those positively at well over national averages. In relation to recent CQU engineering graduates, 85.8% of them were satisfied with how their skills improved compared to the national average (NA) of 83.3% (Figure 5), and 89.1% of them found full-time employment just after their compared to the NA of 82.4% with a median graduate salary of $70,400 (NA of $65,000) (Table 1).

Further, adding the employers' perceptions on graduate ability indicates the benefits of student WIL engagement. The 2019 employer satisfaction survey by QILT confirmed that supervisors rated Australian graduates highly; their overall satisfaction was 84%. The ‘overall satisfaction’ means that the proportion of those employers are likely or very likely to consider hiring another graduate from the same institution and course if a position is created. This satisfaction is based on five graduate attributes: foundation skills (general literacy, numeracy, communication, investigation and the ability to integrate knowledge), adaptive skills (the ability to apply and adapt skills and knowledge and work independently), collaborative skills (interpersonal and teamwork), technical skills (application of technical and professional knowledge and Australian Standards) and employability (ability to perform and innovate in the workplace). In engineering, the employers’ overall satisfaction on Australian graduate capability is 89.9% (QILT, 2020), slightly higher than the general national average data for all professions. These national engineering results can be linked to the CQU engineering data relating to the WIL processes stated before and CQU results are competitive and 100% of employers involved with WIL respond positively to the re-employment of the CQU graduates.

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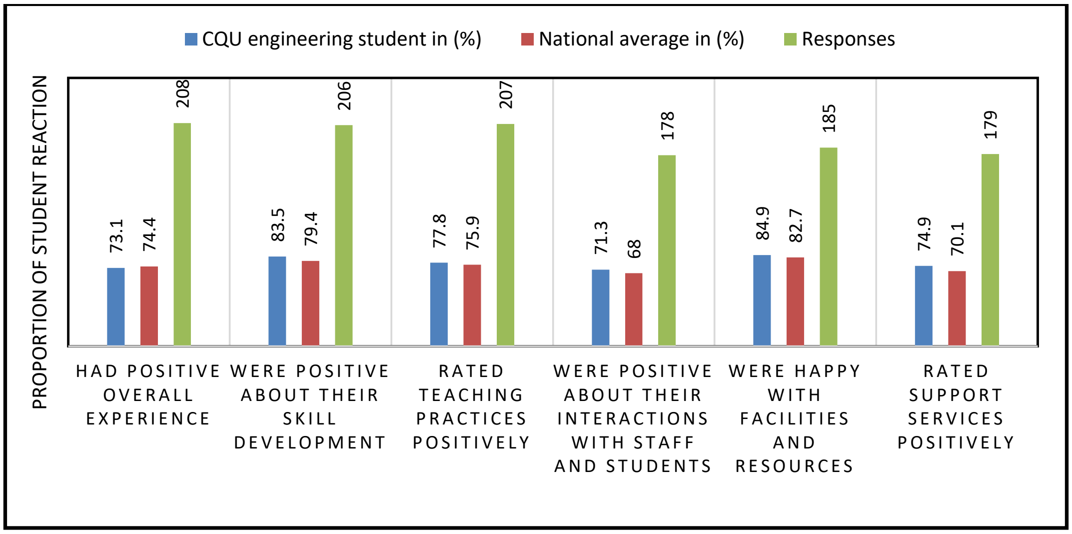

Figure 4: Current CQU engineering student experience survey (2017 - 2018) by QILT (2020).

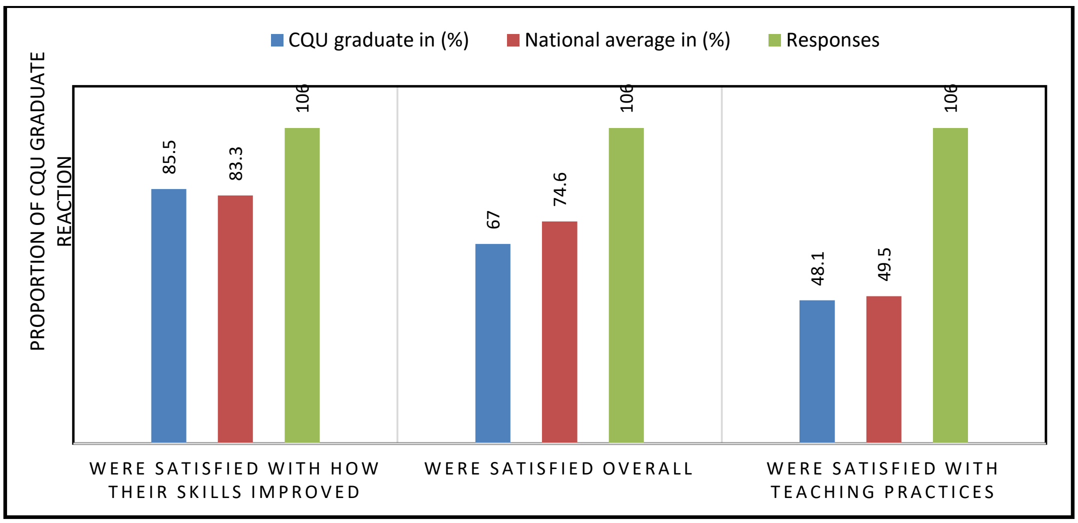

Figure 5: Recent CQU engineering graduate satisfaction survey (2018 – 2019) by QILT (2020).

Table 1: Recent graduate employment and salary survey 2017 – 2019 by QILT (2020)

Graduate outcomes	Proportion of CQU students	National average	CQU Responses	Confidence interval
Found full time employment	89.10%	82.40%	165	85.2% - 91.7%
Found employment	91.60%	87.70%	167	88.1% - 93.8%
Continuing to study full-time	3.20%	14.00%	157	1.9% - 6.0%
Median salary	$70,400	$65,000	105	$65,400 - $75,400

Whilst the analysis suggests potential benefits of WIL engagement, some limitations in the analysis are evident. Firstly, the employer work readiness surveys are carried out on a subset of the students included in the QILT survey data. The influence of WIL practices is difficult to correlate to the graduate survey data, as QILT data does not distinguish students by course, and hence is reflective of both non-WIL and WIL-based education programs. Secondly, the unit survey data focusses on one unit of the program, whereas the QILT survey is a broader program-wide survey tool and is similarly influenced by the inclusion of non-WIL graduate data.

Conclusions

As an assessment of work placement value to employers, we analysed the past seven years of employer work placement evaluations, whereby engineering workplace supervisors rate students against the Engineers Australia Stage 1 Competency Standard along with the self-evaluations by current CQU students and recent graduates of their learning through the QILT survey. Based on the data available, the following conclusions can be made:

- CQU engineering students are consistently rated above the average performance expected for a graduate engineer by their engineering workplace employers.
- They perform better than the average in all areas, however the highest rated competency is Professional and Personal Attributes.
- CQU engineering graduates are work-ready compared to the national standard, however more specific post-graduate surveys could further establish a causal link between WIL education, employer assessments, and graduate outcomes.

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What Do Students Say About Complexity?

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ABSTRACT

CONTEXT

Practicing engineers solve problems in complex environments that are dynamic, nonlinear and where cause and effect may only be clear in retrospect. They use engineering science, creativity, critical curiosity and engineering judgement to understand the context, define problems, manage trade-offs and develop solutions for competing and evolving needs. When faced with complex tasks, students often experience difficulty and resist these assessment tasks. Perhaps because working with complexity pushes them outside their comfort zone, requiring a different approach to evaluate their knowledge and skills. Students' feelings of competence are challenged and their motivation is affected. Few activities in engineering education authentically assess students' development of managing complexity. Students need opportunities to engage with and manage complexity, measure their progress and develop feelings of competence in dealing with complexity.

PURPOSE OR GOAL

This research is one phase of a study investigating students' experiences of working with complexity. The full study aims to increase understanding of students' experiences dealing with complexity and inform activity design and assessments for authentic engineering practice problems intended to develop their skills. To structure a future phenomenographic interview protocol and determine a representative sample, students' perceptions of complexity need to be better understood. In this phase, we aim to identify students' capacity to distinguish between complicated and complex problems with the goal of pinpointing their understanding of elements that make a problem and/or task complicated or complex.

APPROACH OR METHODOLOGY/METHODS

This research used a survey with a range of demographic, select response and open-ended questions to elicit students' experiences of working with complexity. The researchers used the language of learning in complexity and complexity frameworks to analyse the responses for themes and features that convey students' perceptions of complexity.

ACTUAL OR ANTICIPATED OUTCOMES

This research revealed varying but generally low levels of students' ability to recognise complexity and the approaches needed to solve complex problems. The results highlight the need to present engineering students with activities that give them the opportunity to engage with complexity, and which explicitly conveying that the skills and approaches needed for addressing problems and assessing solutions that are complex, will usually differ to those most frequently used in their engineering science subjects.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The research points to an opportunity for educators to use the complexity inherent in group work to introduce students to complexity frameworks. It can give students a language and context to understand different environments and foster development of their capacity to manage and solve complex problems.

KEYWORDS

Complexity, professional skills, group work

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Introduction

Practicing engineers solve problems in complex environments that are dynamic and nonlinear and where cause and effect may only be clear in retrospect. They use engineering science, creativity, critical curiosity and engineering judgement to understand the context, define problems, manage trade-offs and develop solutions for competing and evolving needs.

Graduate engineers leave university with specialised technical knowledge forming part of their identity. However, the ability to solve the complex problems that face practicing engineers requires experiences and knowledge unlike those typically acquired in university engineering science subjects. Engineers learn to operate in complex contexts over time through exposure to complexity and by working with others who model approaches needed to solve complex problems.

Few engineering education activities authentically assess students' progress towards effectively dealing with complexity within broader applications of engineering knowledge. The capacity for working with complexity develops through practice and reflection, including recognition of when problems require familiar thinking or need entirely new thinking. We argue that, in terms of developing professional skills at university, 21st century students will be well served by directly engaging with complex problems during their studies, so that they develop capabilities for solving such problems at an earlier stage. Students need opportunities to engage with and manage complexity, measure their progress, and develop feelings of competence in dealing with complexity.

At University of Technology Sydney (UTS) and The University of Sydney students complete a series of project-based subjects intended to develop professional practice skills. Our experience in designing and teaching these subjects has been that, when faced with tasks we consider to be complex, students often resist. It is becoming evident that such resistance links to the fact that working with complexity needs a different approach to evaluating knowledge and skills (Brookfield, 2017). Students' feelings of competence are challenged by such a change, and their motivation is affected (Willey & Machet, 2018, 2019).

This paper investigates the extent to which students can describe complex problem-solving contexts (as opposed to more familiar complicated contexts) and whether they can identify strategies most suitable for solving complex problems.

Complexity Framework

The Cynefin Domains of Knowledge frame knowledge in a way that uncovers relationships among apparently irreconcilable clashes and gaps. It emerged from research aiming to 'understand how informal networks and supporting technologies allow greater connectivity and more rapid association of unexpected ideas and capabilities than formal systems' (Snowden & Curry, 2007). This gradually morphed into a framework challenging 'the universality of three basic assumptions [about] order, of rational choice, and of intent' (Kurtz & Snowden, 2003) underlying the belief systems of many orthodox approaches to education.

The Cynefin framework differentiates among five decision making contexts: Clear, Complicated, Complex, Chaotic, and Confusion. Each context, has characteristics that affect how decisions are made. Of particular interest to us are the 'Complicated' and 'Complex' Domains. 'Complicated' problems have right answers needing work to be identified, and all unknowns can be resolved with expertise. Conversely, in the 'Complex' domain there is no known 'right' answer, and cause and effect may only be ascertained in retrospect and there will continue to be remaining 'unknowns' (Kurtz & Snowden, 2003).

Engineering science can be technically challenging, and students gradually acquire knowledge to help them solve problems that are impossible to resolve until they have that knowledge (or know where to find it). Such problems meet the criteria for Cynefin's

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‘Complicated’ domain, and students resolve these problems by making sense of the problem, analysing what needs to be done and responding appropriately to reach a resolution (Kurtz and Snowden, 2003). Problems existing in the ‘Complex’ domain require that students probe widely and deeply to find the real nature of the trouble and only then can they make sense of the context and devise appropriate responses. In this domain, the nature of the context ensures that it is not possible to determine, in advance of enacting it, whether a solution will be successful or not. Transitioning to this mode of identifying problems and assessing solutions, challenges students’ sense of their own competency, leading to resistance.

Willey and Machet (2018) describe using the Cynefin framework to develop a complexity framework for engineering students. They applied the Cynefin framework to characterise working in complexity as involving: no single correct solution; no clear cause-and-effect relationship to be determined in advance; no possibility of resolving all uncertainties in the system, and no single person already ‘knows the answer’ to the problem.

The complexity framework for engineering students differentiates between ‘learning absolutes’ and ‘learning with complexity’ emphasising that in familiar contexts students are operating in ‘known’ situations with few uncertainties all of which they can expect to eventually be resolved. In the complex domain, even after a learning activity, there will always be some degree of uncertainty which is acceptable and expected. The framework is illustrated in Figure 1 where the difference between domains is shown before an activity or assessment (a) and after the activity (b) along with the processes used to manage the uncertainty in the problem context (Willey & Machet, 2018). The left hand side of the figure represents learning in complexity and the right, learning with absolutes. After the learning activity it is clear that in a complex context there is residual uncertainty, whereas the absolute domain results in all uncertainties and unknown components being resolved as “known”.

In professional practice subjects at The University of Sydney and UTS, tutor training includes an explanation of the framework and students are exposed to this to help them understand the context of their learning. Students learn a language with which to discuss and understand their learning experiences and explore any discomfort and loss of feelings of competence with the aim of moving to a mindset of *I can succeed in doing this* reducing their resistance to such contexts (Willey & Machet, 2018, 2019). Despite this, we find some students, and tutors, do not make use of the language or framework and are still resistant to working in a problem space where there is residual uncertainty and no single correct answer.

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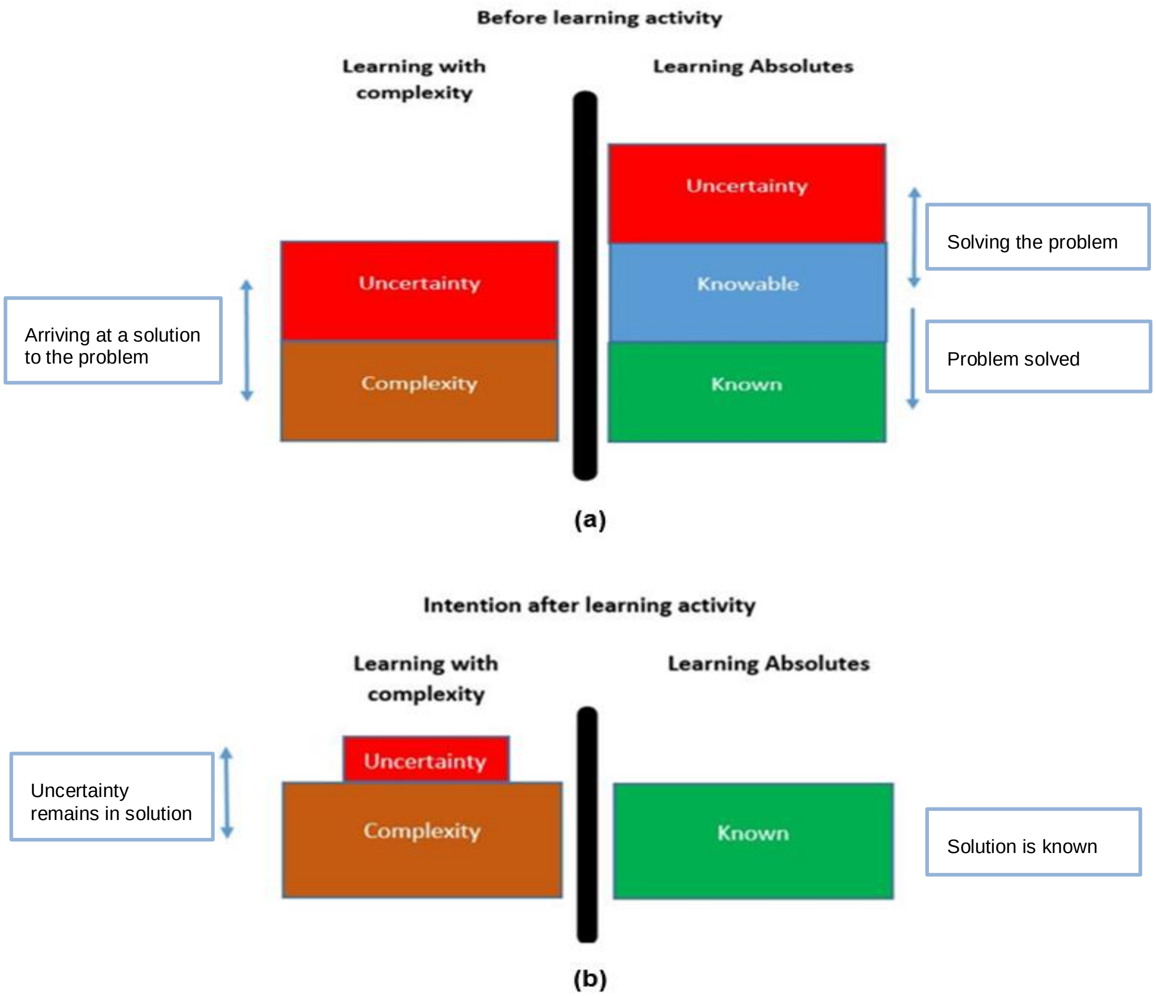

Figure 1: Complexity Framework: Representing learning with complexity vs absolutes (adapted from Willey & Machet, 2018)

Teaching Complexity

For educators, understanding the difference between Complicated and Complex, and being able to articulate this and manage learning in each context, brings a need to develop new skills and competencies. These include the ability to design, manage, assess and provide feedback on less familiar complex learning activities. It is clear that integrating complex learning and assessment activities into familiar applications of engineering science programs inevitably brings a degree of uncertainty for all.

Design problems are often seen as a good choice for providing a context for students learning how to manage and deal with complexity. Cennamo et al (2011) describes the studio learning environment as having an expectation that students will learn to experiment, iteratively generate and refine solutions, communicate effectively and collaborate with others. While instructors use prompts, reminders, modelling and coaching to help students grapple with complex problems. Jonassen and Hung (2008) conclude that 'the extremely high level of ill-structuredness [of design problems] may present challenges or even negative effects on students' learning' as they involve multiple possible solution paths. Jonassen and Hung (2008) emphasise the need to solve design problems in professional practices, indicating

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that engineering education should also prepare students to solve complex, ill structured problems which they will have to grapple with in their professional practice.

It is worth noting that the teaching of complexity is, in itself, a complex task rather than a complicated one. For example, the individual stages of skill development of each student, their previous experiences and the educators own pedagogical content knowledge all play a part in creating a context where there is unresolvable uncertainty, and the outcome cannot be determined in advance. Together with the combination of large class sizes, the lack of suitable teaching spaces, instructors without required skills and with a preference for avoiding student resistance, these factors contribute to the avoidance of designing tasks that could contribute to assessing complexity in engineering studies.

This research aims to further inform good practice teaching approaches to developing complexity skills, through building on the use and application of the Willey and Machet application of the Cynefin complexity framework. It reports on a preliminary study into whether students can identify complex contexts within which they will need to apply decision making and problem-solving techniques suited to the Complex rather than the more comfortable Complicated domain.

Methodology

This research used a survey containing demographic, select response and open-ended questions to elicit responses to working with complexity. The survey was validated using a pilot group of five students. The group were asked to complete the survey while participating in a one-on-one dialogue with the researcher to understand how they were interpreting the questions and to identify ambiguities.

The final survey was sent to undergraduate engineering and IT students at UTS. Some students had previously been exposed to the complexity framework and had therefore been provided with access to a language for describing learning in complex contexts.

Students were asked to identify a complex problem they had had to solve at university, indicate why they believed it was complex and then describe their strategies for solving the problem and dealing with uncertainty in the problem. The initial prompt was a statement mentioning uncertainty and the ‘practice’ of engineering but not explaining what was meant by complexity:

> *In practice, engineers and IT professionals have to use their judgement to manage uncertainty to solve complex problems.*

Not providing a definition of a complex problem was intentional. We are seeking to understand how students perceive this concept currently and, in part, to identify whether those exposed to the complexity framework and its language are more able to identify the kind of contexts most likely to generate a complex problem.

A ‘group and rank’ question allowed students to rate a series of problem-solving strategies using categories from ‘most important’ for solving complex problems, through ‘helpful’, to ‘not useful’ or ‘should not be used’. An open-ended question invited students to justify their reasons for identifying the most important strategies. The chosen strategies were derived from literature on dimensions that factor into learning how to learn, the effect of prior experiences and natural attributes (e.g. curiosity and creativity), and the language of learning in complexity (Crick et al, 2013).

Only those responses from students who answered all questions were included in the analysis. These were analysed to find themes and patterns emerging from the open-ended questions. Of particular interest was discovering whether the data would indicate whether students a) identified complex (rather than complicated) problems, b) could identify suitable strategies to solve complex problems, and c) used appropriate language for discussing complex problems and the strategies to solve them.

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Determining whether a student identified a ‘real’ complex problem was based on their own description of the problem, their justification for its complexity and steps taken to resolve the problem. We looked for key terms including *uncertainty, lack of information, unpredictable outcomes, conflicting demands* or *no single optimal outcome* and any references to the literature on complexity, or the use of the complexity framework language

In analysing rank order responses for usefulness of strategies in solving complex problems, we looked for patterns indicating an understanding - or not - of complexity. To find indications of an appreciation of complexity we looked at whether students categorised the following two approaches as being of ‘little’ or ‘no’ help to resolving complex problems:

- *“Checking your decisions along the way with someone who knows the solution”* implies there is a knowable solution in advance and therefore the problem is not complex
- *“Resolving all the uncertainties before trying to solve the problem”* suggesting that this is possible which indicates it is not a complex problem context

We analysed the data to determine whether the ability to identify problems in the complex domain improved over time spent at university.

Results and Discussion

The results of the survey include 27 full responses from students in their second to fourth year of study. No students managed to identify a complex problem while also avoiding identifying as useful the types of strategies that are unsuitable for solving complex problems.

We anticipated (based on the literature and our own teaching experiences) that students would confound ‘complex’ and ‘complicated’ and our assumption was supported by the data (Willey and Machet, 2018, 2019). Twelve students clearly associated complexity with ‘encountering a difficulty’ leading them to incorrectly identify complicated (or in some cases simple) activities as complex. As an example, a student identified the following problem and associated justification:

> *XXXX was probably one of the most complex projects I had so far. It had involved programming a robot, in C, to map its way through a maze and identify and collect goals in order.*
>
> [It was complex because] *there was very little information online on how to do it and working with arrays was difficult*

The problem may have presented challenges to the student, but it is not complex. How to produce a programmed robot is well known and the difficulties identified were about gaining the right skills and knowledge. There are no ‘residual unknowns’ in the process. The strategies students chose to solve such incorrectly classified problems were in line with solving complicated problems and include such approaches as trial and error, persistence, asking for help to arrive at a known solution (sensing, analysing and responding).

If students cannot differentiate complex problems from complicated ones, they are highly likely to employ unsuitable approaches for solving problems in the Complex domain. They may have unrealistic expectations of having no uncertainty in a solution to a complex problem. Assumptions about problems as always being amenable to known solutions limit their knowledge. Students given a truly complex problem may assume that not knowing a solution indicates a lack of personal knowledge, skill, available information or resources and be unaware that there is no optimal solution. In this case, the problem would be one needing thinking and learning strategies that are also unfamiliar to the student. Until they recognise the need to explore the problem context to understand which approaches may be suitable, students may continue frustratingly applying known solutions - in vain.

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The colloquial use of ‘complex’ as an incorrect synonym for ‘complicated’ is likely to contribute to this observation of confounding the contexts. However, most respondents (n=23) had been introduced to the simplified complexity framework for engineering students and all respondents had done a subject requiring them to solve a complex problem. That so few students could identify a complex context for problem solving indicates that the exposure to the framework and its language had been insufficient. Students’ failure to make the connection between the complex context in their subjects and “a complex problem they had solved” suggests ongoing misunderstanding of complex environments and/or misunderstanding of the assessment context for these subjects. A single encounter seems insufficient, emphasising that the concepts need to be embedded throughout an undergraduate degree. In support of this, there was no obvious pattern to the understanding of complexity between senior students (3rd and 4th year) and those in earlier years of study.

Three students identified a complex learning activity and gave a suitable justification for its complexity, describing approaches to problem solving consistent with operating in this domain. However, each one chose strategies indicating their belief in a ‘correct’ answer. To illustrate, one fourth-year student identified the problem of having to ‘identify the complex system of schooling and … to find the holes and fix it’ as complex, and also explained that ‘being okay with sitting in uncertainty’ was important for solving problems in complex environments. This same student, however, put both ‘checking your decisions along the way with someone who knows the solution’ and ‘resolving all the uncertainties before trying to solve the problem’ as helpful to solving complex problems. This suggests that the student believes there will be a single correct solution and that all uncertainties can be resolved.

A large number of students (n=11) identified group work as a context in which they had solved a complex problem. As examples, student identified a complex problems as:

- *Group members not showing up or attending group meeting late.*
- *In a group project, half of the group agreed with one idea whereas the other half agreed with another. Neither side of the group was ready to reconsider the idea for the assignment.*

The students identifying group work as a complex problem, did not support this with reasoning that would show they understand complexity. These students did not identify the uncertain nature of outcomes, uncertain cause and effect relationship or lack of a known solution in describing why the situation was complex, rather that they saw it as challenging. For example, one student identified the following complex problem:

> *I had to deal with a subject that was group-based where the members of my team were not on the same page*.

However, they reasoned that it was complex because:

> *As the members of my group did not attend tutorials, I had to complete the work for them by myself. I was unable to get their opinion and therefore had to go with the idea that I had come up with …*

Again, problem solving strategies selected were better suited to complicated environments. It is worth noting that even without a language to explain the complexity inherent in group work or strategies to deal with it, these students have made the link between professionals dealing with uncertainty (as framed in the question) and their own group work.

Reflecting on this we have concluded that group work can contribute to complexity in problem solving situating decision making in the Complex domain. Study teams, where members have their own motivations and approaches, are in different disciplines with differing study schedules, have a variety of anticipated work outcomes, all create uncertainty and an absence of predictable outcomes – all features characterising the Complex domain. As well, the cause and effect of group successes and failures can only be known - if at all - in retrospect.

This awareness gap indicates an opportunity emerging from this research. Group work is a professional practice skill we look to develop in our subjects and often assessments requiring students to work in the complex domain are group work-based projects by design. How to manage group work in terms of equity of contributions, sharing ideas and credit and aligning motivations is always a concern. The complexities of group work are a familiar experience for students, and we believe they will readily understand the relevance and value of developing strategies to solve group work problems. By introducing the concepts of decision making in complexity in the context of managing the uncertainty in group work, may provide the opportunity to improve students' skills and feelings of competence in dealing with complexity.

Referring to the research reporting on the development of the complexity framework for engineering students, the identified aims of the framework are (amongst others) to:

- "Provide a vocabulary to understand, reflect on and discuss learning when managing complexity in order to improve students' feelings of competence and their capacity to evaluate their competence. …
- Enable instructors to build a case for, and students to value, learning to manage complexity and view it as a legitimate and important part of professional practice". (Willey and Machet, 2018)

We propose that complexity frameworks can be introduced to students within a discussion of group work to achieve these aims. Most students have experience working with others, making group work a familiar context for managing complexity. This means that not everything will be new, allowing students to reflect on previous contexts to construct new learning. This may be most useful where groups are required to solve a problem in the Complex domain.

Group work is more than students working in a group to create something that individuals could not create alone. It is a context, and an opportunity to leverage learning by including strategies, methods, techniques, and through reflection on managing complexity. We can take advantage of existing group work to help students identify and appreciate how managing problems in complexity helps them. Introducing the complexity framework and its language along with suitable reflection and self and peer review will allow students to evaluate their learning, identifying what worked and what didn't. This enables the skill of managing complexity to be developed and transposed to other contexts.

Using group work explicitly as a vehicle to introduce students to complexity and develop their skills to manage and work with complexity allows this learning to be integrated with any group work learning not simply design based projects. This will also give instructors a context and relevant experience to pass on to students helping them to scaffold, provide feedback, insights and challenge and prompt students to promote learning.

Well scaffolded learning designs that include examples of how students can use strategies to manage complexity in group work are an anticipated outcome of future research. With some guidance such designs can be transposed to different contexts, such that group work can become a vital way of introducing students to both the *need* to develop and the *process* of developing skills for managing complexity, particularly in first-year subjects.

Recommendations / Conclusions

This study indicates that students' lack both the ability to identify problems in the complex domain, and suitable strategies to address them. Academics have a responsibility to address such gaps. As Ramsden (2003) noted, assessment drives learning. Engineering programs that expand their repertoire to include experiences relevant to learning how to address complexity through use of appropriate learning and assessment activities will enable students to accept the importance of engaging with and managing complexity.

A key step in developing students' capacities to work with complexity involves ensuring they understand the difference between complex and complicated problems and contexts. Next is

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devising tasks of appropriate quality and difficulty for engaging students with complexity in their engineering studies. Third is helping individuals and groups build personal capabilities to identify contexts clearly enough to ensure they choose and implement appropriate actions.

This requires action by both students and educators. Students must recognise that not all problems have known solutions. Educators must help students understand the difference in problem solving contexts - making the contexts of tasks and problems assigned for learning and assessment explicit. Both must accept that some problems have solutions grounded in known facts and data, while for others, everything known is insufficient for resolving the problem due to the non-repeating complex context. This work identifies group work as a powerful potential context for introducing and integrating the learning of these concepts throughout a degree program.

Our research has provisionally identified how to expand the value of group-based learning activities. These provide opportunities to introduce the task of managing and dealing with complexity. Group work is a familiar context, making it a good starting point. Within this context and with suitable scaffolding and opportunities, students can evaluate their own learning and continue developing these skills throughout their study program.

The findings from this study will guide further investigation of students' understanding of complexity. Future work will investigate whether students' seeming inability to identify complex contexts and suitable strategies for solving problems within them is an issue of insufficient language, not yet having the knowledge to distinguish complex and complicated contexts, lack of experience engaging in authentic complex problems or lies elsewhere.

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The Development of Personal Growth, Self-Awareness & Graduate Attributes in Engineering & Design Factory Students – Part 1

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CONTEXT

Engineering, like many workforces, is adapting to the technological advances the world is experiencing which is creating new engineering roles as well as requiring more links between roles. This, therefore, is putting pressure on undergraduate students to enter a workforce that is constantly evolving and to quickly feel comfortable to contribute meaningfully. Currently, engineering education tends to focus heavily on technical teaching and practical experiments with little emphasis on work-ready skills. The use of student-centered teaching & learning pedagogies is essential engineering disciplines though are still assessed heavily on outcomes rather than process; with repetition of a skill seen as growth. This paper is an investigation into how a Level 7 engineering project and Design Factory Module can develop and enhance student's growth which in turn, can create students who can assimilate faster into the workforce.

PURPOSE

The purpose of this study is to understand the engineering educational approach to prepare students for industry and to record the progression of student's personal growth, self-awareness, and graduate attributes, which are measured against our observations.

APPROACH OR METHODOLOGY/METHODS

The Engineering project and Design Factory courses have industry connections and are believed to create the most change in personal growth of students. This study involves ongoing collection of student data from semi-structured interviews at the beginning, middle and end of year. The interviews collect data about the learners' profile, learners' progress, and employability skills self-assessment to analyse their competency throughout the course. As well as this, part of the Design Factory course assessment includes a personal development plan which measures the soft skill development of the students during their study.

ACTUAL OUTCOMES

Early indications show students want involvement in industry projects, participate in hands on exercises and practical learnings to gain work-ready skills. Students tend to rate themselves highly on their employability skills, until placed in a situation that is new to them. As more data is received (over a long term study) this study will help identify graduate attribute areas which require development and aid in identifying activities that work the best for student growth.

CONCLUSIONS

Reid and Ferguson state, "To develop and enhance student's growth, it is necessary to praise a student's professional learning – not just a student's intelligence". This study is a first step to building on this statement, by creating an understanding of engineering students needs in relation to future engineering employability.

KEYWORDS

Work-ready skills, Engineering Education, Student Centered Learning

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Introduction

In the last few decades, there has been an increase in attention to the current educational framework of delivering engineering & design courses, which is academically demanding. The structure of engineering and design qualifications focuses strongly on technical (theoretical & practical) teaching and less on the guidance and support of students' personal growth. In terms of engineering assessment, an undergraduate student performance is assessed by standard approaches, for example assignments, tests and exams. However, minimal input of time and resources are invested towards non-academic exercises, which develop students' personal growth, self-awareness, and graduate attributes, which are broader and more encompassing than "employability," helping to develop academic and career competencies (Hill et al., 2016). In tertiary education, students' personal growth, self-awareness, and graduate attributes should be considered as an integral part in the study plan for engineering and design courses, as it can significantly impact the chances of attaining successes in students' future careers (Auðunsson et al., n.d.).

The structure of engineering and design courses are traditionally content-centered, and over the last decade there has been an increase in student centered learning that consists of interactive activities and blended learning pedagogies. To complement student centeredness, it is also essential for students to be engaged in varied forms of learning that strengthen their personal development (Belahmer, 2015, p. 194-198). Personal growth in the engineering context means to develop attributes such as, flexibility, self-confidence, a sense of responsibility, or enhancing engineering identity. It is extremely advantageous for learners to be involved in activities/exercises to develop their personal strengths, values, and skills. The importance of graduate attributes is increasing rapidly in international bodies such as higher education universities & institutes, the industrial platform, governing agencies, and accrediting sectors. Research has suggested that graduates' success rates in their jobs depends majorly on graduate attributes than on narrowed discipline specific academic content. It would be beneficial to have course's structured with assessment criteria focusing on students' awareness on graduate attributes and embedded in the learning activities for their development (Treleaven & Voola, 2008, p. 160-173).

In order to create graduates with skills ready for industry, higher education institutions are adapting 21st century teaching approaches, most commonly using activities related to Project-based Learning (PBL) and Work-Integrated Learning. These two learning pedagogies are useful approaches as they achieve the desired content knowledge while creating opportunities for personal development such as self-confidence, self-esteem, being self-aware and developing work ready skills.

Development of Personal Growth, Self-Awareness & Graduate Attributes

The planning of academic curriculums of any undergraduate programme is centered upon graduate attributes/work-ready competencies. These graduate attributes demanded by industry in students can be categorised in two distinct groups: technical & generic. The generic attributes include soft skills, which graduate students must attain irrespective of the area of study. Many educational platforms, such as polytechnics & universities have redefined graduate attributes that can assist in learners' personal development, flexibility, and sense of responsibility towards multi-disciplinary projects (Moalosi et al., 2012). Personal growth is vital in the academic world, as it is a process of establishing awareness and identity of yourself, that allows a student to build on self-esteem, confidence, motivation, and professional skills. Personal growth in learners incorporates cognitive components such as, awareness to change, believing that change is possible, and delivering positive behavioural components by taking the initiative to accept challenges (Patanapu et al., 2018).

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Self-awareness is another component that plays a crucial role in learners. As a student, it is important to be aware of their own strengths and weaknesses, acknowledging the shortcomings in the field of study and employment will help them to learn, embrace and succeed. As educators, this can take form in many ways such as setting self-awareness goals and objectives, which gives students' motivation to succeed and create belief in themselves (Positive Action, 2020).

Development of Employability Skills and Engineering Curriculum

Mills & Treagust, (2003), suggested that the review of accreditation criteria from many educational bodies around industry requirements from engineering raised issues such as:

- Engineering curricula is only focusing on theoretical concepts around science and technical courses without providing sufficient integration that can relate to industrial practice.
- Minimal design experiences are delivered to learners throughout their programme
- Graduates are lacking in teamwork, communication and interpersonal skills when entering the workforce
- Most of the existing teaching and learning strategies are traditionally driven in engineering and programs need to become more student-centred (Mills & Treagust, 2003)

The use of pedagogical approaches such as Project-based Learning and Work integrated learning address some of these issues. The use of these pedagogies enables active cooperation and interaction that create opportunities for learners to gain technical and personal skills. Uses of PBL & WIL creates a student-centered learning environment in the classroom, as it allows students to acquire knowledge by working and solving an authentic industry problem. The problem is created so that students discover what they need to learn, to address that problem and resolve the problem. Specifically, these pedagogies are an effective teaching tool, that motivates student and clearly demonstrate the development of teamwork and communication skills in learners (Ríosa et al., 2010, p. 1368-1378).

Reflective Practice (Learner Profile & Employability Skills-Self Assessment)

This research paper centres around engineering students and their understanding of the skills they need when they go into industry. It involves finding out from students their awareness of graduate attributes embedded in their degree, what they believe is important and how they rank themselves on what industry believe are important. It also asks students the teaching and learning methods that they believe work for them in learning engineering content and developing industry skills. To achieve this understanding two tools have been developed, a learner profile questionnaire and an employability skills self-assessment survey. It involves ongoing collection of student data from semi-structured interviews at beginning, middle and end of year, (Engineering Project students only – 4 interviews) (Design Factory and Engineering Project Students – 5 interviews). The interviews collect data about the learners' profile, learners' progress, and employability skills self-assessment to analyse their competency throughout the course. The learner profile assists in gaining the information around who the learner is, their background, culture, and awareness around graduate attributes.

The employability skills self-assessment survey is based on attributes identified by the ministry of education (New Zealand Ministry of Education, 2019) and students reflect and rank themselves on their ability with the skills (twice in the year).

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Methodology

With a growing emphasis in higher education institutions in enabling personal growth and learners' employment, educators have spent extensive time and effort to create collaborative projects and learning activities with the objective to allow learners to gain personal skills and graduate attributes in their final year of engineering & design qualifications (Rowe & Zegwaard, 2017, p. 87-99). This research project is continuing this theme, with the first step to understand the current approaches that prepare students for industry and to record current perciefved student employability skill progression. To do this we are gathering data from students who are studying within two courses; Engineering Project, a level 7 course which is made up of students across three vocational engineering disciplines, Civil, Electrical & Mechanical. We have also included students from the Design Factory course, which has students from the same engineering disciplines but also includes students from Information Technology, Media Arts, Business, etc. All the students participated in the research are pursuing level 7 qualifications in Engineering.

The sequence of collecting data was conducted from semi-structured Interviews that incorporated the following tools: Learner profile questionnaire & Employability skills self-assessment survey.

- Recorded interviews of engineering students BEFORE they start Design Factory and Engineering Project modules.
- Recorded interviews of engineering students during their course once in each semester.
- Recorded interviews of engineering students at completion of the two courses (Due to this research being focussed on personal development we are not considering interviewing employers at this stage).
- The employability survey is completed twice by the student. Once within the semester and once at the end of the course

The data collection varies slightly if a student is completing both Design Factory and the Engineering Project course at the same time compared to if they are doing the courses in different semesters. The first stage of data collection was to implement the learner profile questionnaire during the first week of semester 1. The following is a sample of questions that were created to gather information around students' background and career aspirations:

- How would you describe yourself, in terms of culture and hobbies?
- What do you know about graduate attributes?
- What do you think are the work ready skills a graduate engineer needs?
- What do you think will help you the most in achieving these goals & barriers?
- Tell us a story about teaching and learning activities that you have experienced in the past that have helped your learning the most (and the opposite)

The second stage of data collection was to implement the employability skills self-assessment survey in the mid-semester for the students. The employability attributes targeted for the survey were: Communication Skills, Teamwork, Self- management, Resilience and Engineering Knowledge. The students were asked to choose the most suitable option (Needs work, Can do, Can do well, and Very good at this) and be reflective by providing real life examples, where they have demonstrated the specific graduate attribute.

Design Factory & Engineering programmes offer a range of learning experiences for students seeking to prepare for the future workplace – such as:

- Industry Breakfast: two networking sessions at breakfast, which students organise and run where they project information and ask for feedback from industry

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- Lunchtime Learnings: 30 Minutes of Lunchtime Learning with Industry partners around innovations and real-world problems
- Design Factory Gala: A final presentation of the 15-week project in the form of a “sell” of the solution presented to 60 – 100 stakeholders (industry, educators, colleagues.
- Site Visits/Field Trips: Industry tours to give real-world exposure to students
- Guest Lecturers: Inviting professionals/employers from industry to share current engineering practices & industry demands for students
- Student & Industry Projects – Embedding connections via industry projects for students

All the external engagement of students involve stakeholders, industry partners, community partners, government, and employers, whose input into curriculum is vital to ensure it remains relevant to the needs of employment markets.

Quantitative data is analysed through visual graphs and analysing for patterns.

Qualitative data is analysed using thematic analysis (Braun & Clarke, 2006, p. 77-101). Data is shared amongst the researchers in a visual way with important key points shown. Each student may have 20-30 individual data points. This data is then clustered according to similarities in words or intent (coding). Each cluster is then turned into an insight. An insight is a summarised statement of many data points, written from the students’ point of view while also including an action. Insights are then merged further to create themes. Themes are reviewed against each other, the data and the original research question to ensure there is a compelling story.

Limitations

As this is the start of a longitudinal study there is only a small amount of student data (9 students) though this student data does represent 66% of all level 7 engineering students. This data set will grow per semester as the study progresses.

At the time of writing, this final stage has not been completed yet and will not be completed until final questionnaires and surveys have been carried out, which are currently in progress.

Lockdowns due to the pandemic have meant that some opportunities to develop their personal growth did not eventuate (i.e. networking events).

Lockdowns have Influenced students’ wellbeing which may have an indirect effect on some of the responses in the second half of the year.

Results & Discussion

Themes from the Learner Profile Questionnaire:

The learner profile questionnaire from students were analysed, and data points were clustered into themes. The most important themes related to this study are explained below.

The first theme revolves around students and their connections with industry. Students value industry connections as they believe it will help them to attain employment once graduated. Engineering students also have a fear that they won’t be useful on the job, so it is important to them that they have confidence in what they are learning and are exposed to many different engineering situations.

Summarised insights relating to this theme are as follows:

- Students want to connect with industry during their engineering programme – as they believe this will lead to career opportunities.

- Students want to be confident in their technical ability, so they are useful for their employer as soon as they start work.

- Students believe developing high quality professional engineering conversational skills will aid to gaining employment.

- Students want connections with industry so they can see engineering process and application in the real-world context

The second theme relates to the approaches used to prepare students for industry. Students recognise and value a range of assessment approaches and recognise employability skills are embedded in these approaches. This theme was based on the following insights:

- Students value a variety of assessment types such as formative & summative integrated in their classroom learnings and believe it helps to develop them as a professional.

- Students value a variety of real-life examples, guest lecturers and site visits to familiarise with industry practice and grasp the teaching content easily.

- Students have identified that the Design Factory module is a great teaching & learning resource to develop graduate attributes, industry connections, and professional skills due to its real-life project.

- Students identified project related exercises helps in better learning and development of graduate attributes as professionals.

- Students found that time management has been the strongest barrier for them to succeed in their studies because of competing pressures such as work and young family

A final theme would be the students' belief that technology will continue to advance, and they will need to continually be learning to stay current. Being a lifelong learner was important to them.

- Students believe that engineers of the future will need well developed soft skills to be adaptable and practical as technology will always advance.

As an aside, there are a few themes that don't relate to this particular study that we found interesting. We would like to acknowledge the following one in particular:

- Students found learning situations challenging when they lost trust in the system to provide a quality education and had to take it on themselves, such as; when the tutor did not know topic well enough, or the technology wasn't capable, or the tutor wasn't adaptable.

The reason we would like to acknowledge this is that if students lose trust, then they focus only on grades and not on continual development that is required for effective integration into industry. As mentioned, at the time of writing, these are initial themes and insights. The researchers will retheme and refine as more data is collected whilst also including the quantitative data from the employability surveys.

Employability Surveys

Quantitative data from the employability survey was collected from the students. The students were required to rate themselves on the following graduate attributes: Communication, Teamwork, Self-Management, Resilience and Engineering Knowledge. The following show an excerpt of data that related to the themes generated from the learner profile questionnaire.

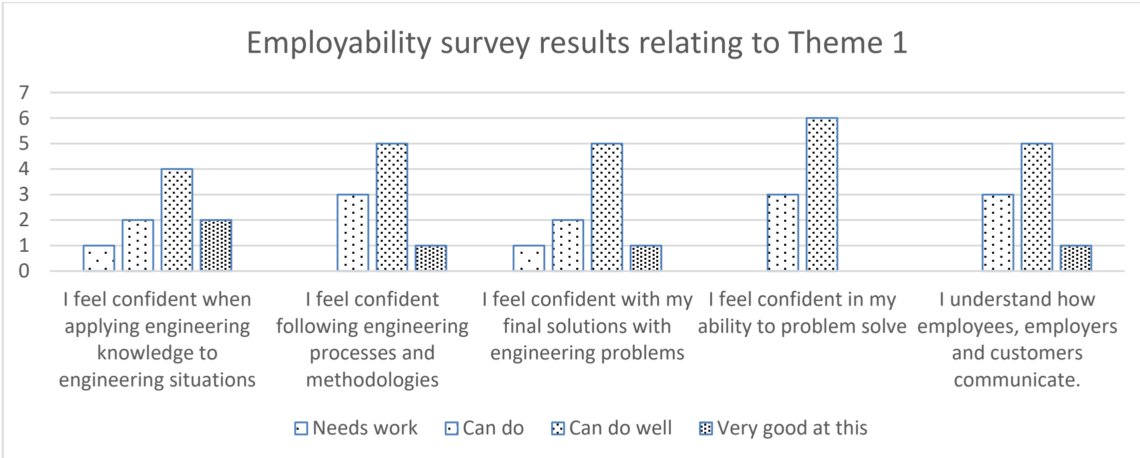

Figure 1: Demonstration of the results for theme 1 – students and their connections with industry

The survey results from figure 1 show that students have a varying confidence in applying engineering knowledge to engineering situations and feeling confident in their abilities with engineering processes and methodologies. These questions all had more students ticking the "needs work" or "can do" boxes than other questions. Students believed they had a good awareness of how communication within an organisation works, though there are still a few at the "can do" as opposed to "can do well". These results compare well with theme 1 in the earlier section, which was summarised as students not being confident of their skills once in the workforce and wanted opportunities to connect with industry to build their industrial knowledge.

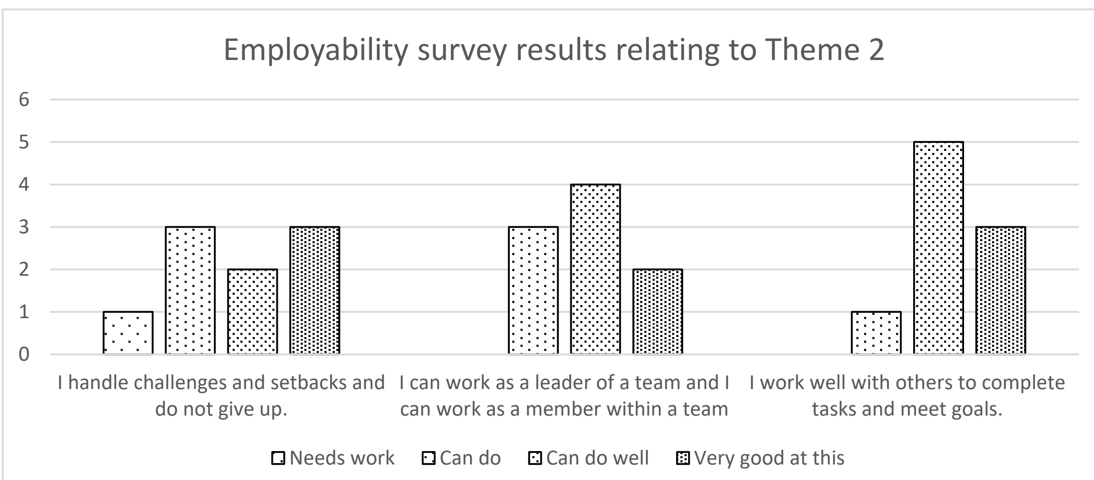

Figure 2: Demonstration of the results for theme 2 – approaches and recognising employability skills

Students in general believed they had very highly developed employability skills. Students ticked "can do well" or "very good at this" for many questions. We will be interested in the analysis of the second round of surveys to see if students become more aware of the real-world context of employability skills. The results in figure 2 show that students have a varied ability to be resilient. This shows us that it is important for students to apply engineering knowledge within their educational settings without fear of feedback. The second set of results in figure 2, show that students have a varied ability to switch roles from leader to team member in a group but they thought that they were effective at working within a team.

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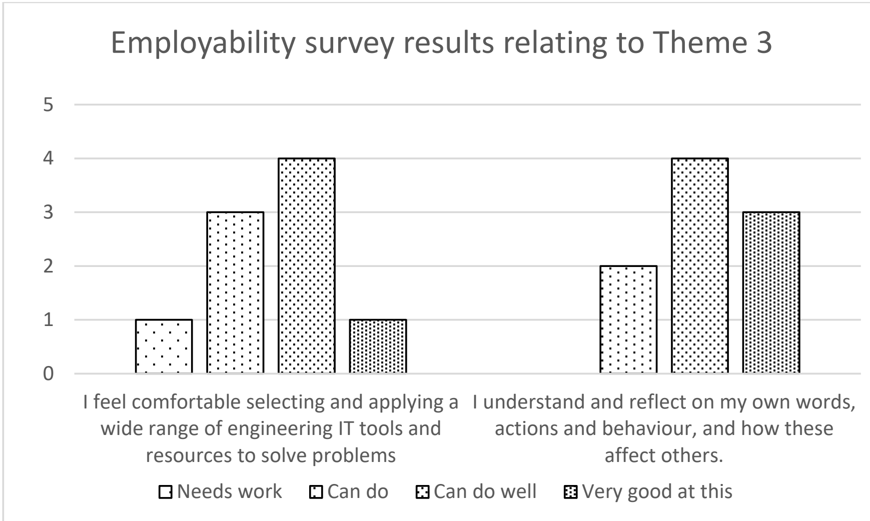

Figure 3: Demonstration of the results for theme 3 – technology and lifelong learning

In the earlier section it was stated that students know that technology will advance throughout their careers, and they therefore recognise the need for lifelong learning. Figure 3 shows that not all students surveyed felt confident in the use of technology though and some thought they can just do it. Pleasingly, reflection does seem to rate high as an engineering skill which is a key aspect of lifelong learning.

Conclusion

Overall, the authors of this research have collected valuable feedback from the first half of the year, which has indicated the students urge and aspirations towards industrial connections for professional development.

From the first round of feedback the following themes have been identified:

- Students want connections with industry and engineering application while studying so they feel confident when they go into workplaces.
- Students value a range of educational approaches that link clearly with employability skills
- Students want to attain lifelong learning skills to help keep up with technological advancements

The researchers note that students still believe they need more interaction, to develop confidence, this will become clearer as sample size grows.

This is the first step of a longitudinal study, and we expect insights, themes and survey data to become more refined over time.

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How and when do Engineers in the mining industry in Australia learn about Safety Culture and start to associate it with their Engineering Identity?

Andie Gell, Sally Male, Melissa Marinelli and Ghulam Mubashar Hassan

ABSTRACT

CONTEXT

After several high-profile accidents in the late 20th century, there was an increased effort to focus on safety within Engineering. This is now known as Safety Culture, and it has become a priority for many Australian mining companies. Most previous literature about safety culture is mainly focused on a company perspective instead of an individual one. Additionally, there is little research on an individual's development of safety culture. This study is building on the Engineering Research project "Investigating Safety Culture and Engineering Professional Identity in the Oil and Gas Industry" by Payne (2020) which started to investigate these issues.

PURPOSE OR GOAL

The study focuses on engineering within the Western Australian mining industry. The rate of deaths in the Western Australian mining industry has fallen since 2000, however, the incident rate has stayed consistent which highlights the need for continued focus on safety (Department of Mines Industry Regulation and Safety, 2020).

APPROACH

The qualitative research was conducted through semi-structured interviews of purposefully selected participants. The sample consisted of three main categories to create a matched sample, this was done to view a progression of understanding.

1. Current University students with no vacation experience.
2. Current University students with vacation experience in the mining industry.
3. Engineers working in the mining industry.

After transcribing, the data was inductively coded to identify recurring themes using the software Nvivo (Maguire & Delahunt, 2017). Thematic analysis followed the framework by Braun and Clarke (2006), which consists of data familiarisation, generating codes, searching for themes and review. An initial interview of the researcher was also conducted to acknowledge any biases that may be present before starting.

ACTUAL OR ANTICIPATED OUTCOMES

There were significant findings that were new, it was found that Engineers learn about safety culture through multiple avenues including University, Training courses, previous course-related part-time work or through the company culture. However, a transformative experience was required for a richer understanding of safety culture and for students to start to associate it with their engineering identity

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This study focuses on where students are learning about safety culture and associating it with their engineering identity. This research can be used to identify gaps in engineering education.

KEYWORDS

Safety, Engineering, Education.

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Research Problem

"Safety Culture" is the result of high-profile accidents in the late 20th century, it is still a recent concept, which raises the question if it is being effectively taught in engineering education. To investigate this, a qualitative research approach was undertaken to determine when students, graduates and engineers learnt about safety culture and associate it with their professional engineering identity.

Literature

This study is building on the Engineering Research project "Investigating of Safety Culture and Engineering Professional Identity in the Oil and Gas Industry" by Payne (2020). It focused on defining safety culture, exploring how it is a part of engineering identity and how it is developed. Payne (2020) found that safety culture was a part of engineering identity in the oil and gas industry and was dependent on an individual's experience, with site experience and mentoring having an impact. Payne recommended research into how safety culture is developed and incorporated in engineering curricula, which this paper focuses on.

Safety Culture

Safety culture can be defined in layman terms as, "the way an organisation behaves with respect to safety when no one is watching" (McKinnon, 2013, p. 1). Reason (2000) argues that safety culture is becoming increasingly important in the workplace as we have reached a plateau of safety technology, as most incidents are now attributed to human error. However, safety culture is not a miracle, it is easy to have inflated expectations of what safety culture can achieve.

Safety Culture Development in a Company and Individuals

Hudson (2001) says that safety culture in companies correlates to increased trust, accountability, and communication.

Novak, Farr-Wharton, Brunetto, Shacklock, and Brown (2017) surveyed 284 Australian engineers and found that high employee individual commitment to safety was correlated to a high level of safety outcomes in a corporation. Stemn, Bofinger, Cliff, and Hassall (2019), found higher individual levels of personal elements such as care, respect, accountability, and coaching correlated with higher safety culture at a person's workplace. However, there are limited studies that focus entirely on an individual's perspective on safety culture.

Engineering Identity

Engineering identity "comprises the attributes, beliefs, and values one uses to define oneself in the profession of engineering" (Morelock, 2017, p. 1). Atman et al. (2010) noted most previous studies about engineering identity have been focused on evaluating engineering identity in an academic sense such as competence and technical skills. The studies do not cover professional soft skills such as a student's association with safety culture.

Safety Culture in the Western Australian Mining Industry.

In industries with risky conditions, such as mining, there is a focus on safety concerns (Bisbey et al., 2021). The safety behaviours survey from 2001, surveyed 14% of the WA mining industry employee found 44% of employees took shortcuts to meet production pressures (MOSHAB, 2002). This showed a culture that was in earlier stages of company safety culture development (Hudson, 2001). Figure 1 displays the count of mining fatalities in WA from 1980 to present, there has been a decrease since the early 2000s. This coincides with the first resources about safety culture on the WA Department of Mines website are from 2005 (Department of Mines, 2005). Thus, we can presume safety culture was starting to form in the WA mining industry in the early 2000s. The incident rate has stayed consistent at 2500 a year since 2010, demonstrating the need for continued focus on safety within the industry.

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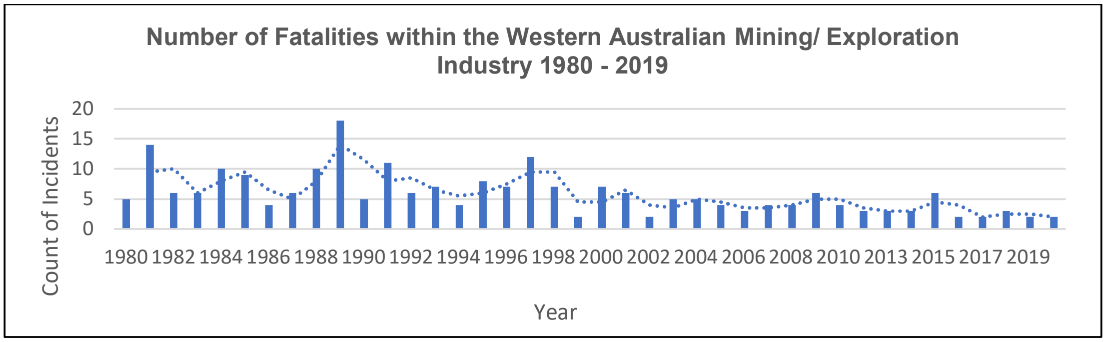

Figure 1. Number of Fatalities within the Western Australian Mining/ Exploration Industry 1980 – 2019 (Department of Mines Industry Regulation and Safety, 2020)

Safety culture in the Australian Engineering Curriculum and Teaching

Safety is covered in the Stage 1 competencies by Engineers Australia. As discussed by Male, Bush, and Chapman (2011), There is an increasing difference between what is taught at Australian Universities and what is required in the workplace.

Hamel (2018) says that safety is commonly taught using methods such as online quizzes and tests which are easy to mark and have paper documentation for legal requirements but do not effectively teach safety. Case studies if chosen and presented with intention can be powerful enough to impact one's own Engineering identity (Loui, 2005). Pitt (2012) found personal experience is essential when teaching safety, these can act as transformational experiences for students.

Research Question

There is a gap in the literature on individual association with safety culture and engineering identity. Mining is a high-risk industry, and many of the large mining companies in Australia list safety as a main priority. It is beneficial for mining companies to be hiring employees that already have a high safety commitment. One of the purposes of tertiary engineering education is to effectively prepare students for jobs in the industry, and thus safety and safety culture should be covered in the education of students. The study addresses the research question: "How and when do Engineers in the mining industry in Australia learn about Safety Culture and start to associate it with their Engineering Identity?

Theoretical Framework

Theoretical Frameworks have been used to guide the understanding and findings of this project. Social Identity Theory is a "person's knowledge that he or she belongs to a social category or group" (Hogg & Abrams, 1988). Loui (2005) studied found that students developed their engineering Identity by mirroring the engineers that they interacted with over their career. Constructivism is the idea that students gather ideas and then they construct the ideas in their own way (Zulkarnaen, 2019). Students build on their previous knowledge with new knowledge. As students have different vacation experiences this means they all have different "building blocks" of knowledge about safety culture.

Method

A qualitative research method has been chosen for this exploratory study as it suits topics that have minimal previous research (DiCicco-Bloom & Crabtree, 2006). Researcher bias was minimised through bracketing interviews where a preliminary interview of the researcher was conducted to acknowledge any assumptions, beliefs, biases, ideas, or perceptions that the researcher may have before starting the research process (Creswell & Miller, 2000).

The human research ethics approval was approved as an amendment for the "Virtual Work Integrated Learning Modules for Engineering". The interview questions were based upon the

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questions by Payne (2020) and the framework by Kallio, Pietilä, Johnson, and Kangasniemi (2016) about developing semi-structured qualitative interviews. The interviews were semi-structured interviews conducted via Zoom or in-person for 0.5 to 1 hour. Participants were invited to complete a voluntary preliminary demographic survey before their interview. After the conclusion of the interviews, the recordings were transcribed, the data was then inductively coded to identify recurring themes using NVivo (Maguire & Delahunt, 2017). The thematic analysis followed the framework by Braun & Clarke (2006) which consists of data familiarisation, generating codes, searching for themes and review.

Data Collection

The participants were purposefully selected and invited to participate. For this project, a sample size of 6 interviews was conducted, as this captured recurring themes and "saturation" of opinions while also considering the limited timeframe to complete the project (Malterud, Siersma, & Guassora, 2016). The sample consisted of three main categories to create a matched sample and to view a progression of understanding.

1. Current University students with no vacation experience.
2. Current University students with vacation experience in the mining industry.
3. Engineers working in the mining industry.

Age, Demographic, Years of Experience, Industry

Participants were selected with purpose, to maximise the depth of data (DiCicco-Bloom & Crabtree, 2006). A mix of genders, ages, specialisations, and experiences was selected to capture multiple viewpoints. Mechanical and Electrical Engineering was chosen due to the prevalence of these disciplines in the mining industry. The concept of safety culture has only been very prevalent in the industry since the early 2000s. Engineers that finished their studies earlier than this would have learnt about safety culture while in the industry, thus were not selected. Safety culture is prevalent in other high-risk industries such as medicine, aviation or chemical processing, so participants with experience in these industries were not considered (Wiegmann, Zhang, von Thaden, Sharma, & Gibbons, 2004).

Before beginning the interview participants completed a demographics questionnaire and consent form. All participants studied or are currently studying at The University of Western Australia (UWA). The following abbreviations are used to discuss a participant's role and level of experience, for example, Participant A is a Graduate Mechanical Engineer (MG).

M – Mechanical Engineer
E – Electrical Engineer

G – Graduate/Working Engineer
V – Student with Vacation Experience
S – Student with no Vacation Experience

How and when do Engineers in the mining industry in Australia learn about Safety Culture

From my analysis, participants have learnt about safety Culture through the following methods.

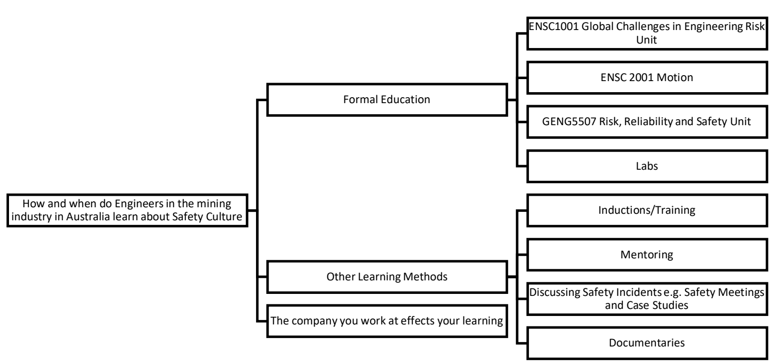

Figure 2 - How have participants learnt about safety culture?

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Initial Understanding

First, participants were asked to define safety and safety culture to see if they understood the concepts before beginning the interview. There were various levels of understanding of safety, participants with work experience had a richer understanding of safety which was more in line with the formal definition. Participant A (MG) showed a deep understanding by defining safety in terms of emotional safety by mentioning mental health. Both students without any work experience, C (MS) and F (ES) believed safety was limited to the business and engineering work they performed and did not consider any human or people aspects of safety. Participant C (MS) did not mention keeping oneself safe or others safe and instead mentioned only keeping the business safe. Participant B (MV) & D (ES) both worked at Company A, a large mining company, and recited the company response of "going home at the end of the day in the same condition you went to work in.

Within the mechanical engineering matched sample there is evidence of growth for the definition of safety culture. Participant A (MG) had a comprehensive definition, Participant B (MV) was unsure of their answer, hesitating and saying "maybe" and Participant C (MS) was not able to put into words what they believed safety culture was. With more experience came a richer understanding of safety culture.

Formal Education

All participants besides Participant D (EG), who graduated in 2004, stated that they had learnt about the concept of Safety Culture while studying at university. The main areas that students learnt about safety culture at UWA were in the GENG5507 Risk, Reliability, ENSC1001 Global Challenges in Engineering and ENSC 2001 Motion. Participant E (EV) said that university was their "first exposure" to safety and that university "definitely like awoke me to the definition". Participant C (MS) said, "I think the foundations [of safety] was set at University."

However, learning about safety and safety culture at university seemed to only provide a surface level introduction to the concept. Participant C (MS) said learning about safety at university "was more of a formality" and that it felt "disconnected". They said, "If you're just outside of the realms, if you're wearing shorts and not long pants you can still get in". Participant B (MV) said they feel "protected" in the labs "not on the same scale, and the risks aren't as high as they are out on-site". While Participant F (ES) made the point that "a PowerPoint is different from an actual disaster".

Students are being introduced to the ideas of safety and safety culture while at university, however, they described this as feeling "disconnected", "formality", "wishy-washy", "not the same scale" & "fictionalised". This shows that although students learn about it at university, they do not associate it with their engineering identity at this time.

Inductions/ Training

Training by companies is a way to promote the safety culture they would like perpetuated within their company. Participant A (MG) mentioned that the induction and training modules that Company A provided had a positive impact on their safety culture. These introductions and training courses allow students to build on previous knowledge they learnt at university. Participant B (MV) said that on-the-job training such as "Take Fives" taught them about safety as "you really sit there, and you think about everything that could go wrong".

Mentoring

Dehing, Jochems, and Baartman (2013) mention that mentoring can develop professional identity, this is evident in the data. Participants D (EG), E (EV) and A (MG) all mentioned mentoring. Participant A (MG) said as a graduate "Your first learning experience will always be from your leader, if your leader focuses on safety more, the more you pick up from it".

Discussing Safety Incidents

Jamieson and Shaw (2019) discuss how safety moments can be used to effectively develop safety culture. A company can create a place where the values they would like are emphasised. This can be done by structured and assessable parts of the job such as a Safety Meeting or Job Hazard Analysis. Participant A learnt about safety culture through daily safety meeting, these provided continuous learning and the ability to bounce off other people's experiences.

> *"An opportunity where you can identify risks on previous days and discuss that with your team and identify how we can mitigate them or make sure those risks are eliminated or making sure that they don't happen again."*

Participant B (MV) mentioned the importance of safety meetings for communication and gaining knowledge about safety and safety culture.

> *"Being involved in all the safety meetings ... You realise you don't have all the answers and you do need to rely on other people to manage the risks around you and to keep everyone safe."*

Participant C (MS) said that "Hearing about the bad stuff that happens in our case study. The big explosions and people dying sort of gives you that scare effect". Participant C (MS) believes that talking about safety was to scare you into doing the right thing, instead of for education and learning. They are not able to identify how to learn from safety incidents, Instead, they believe they are used to scare students from attempting similar things.

Participant E (EV) mentioned "listening from other people" as a large influence. The common theme from participants A (MG), B (MV) and E (EV) is that these experiences need to be non-judgemental and collaborative, they all benefited from the open discussion with other people about safety.

Documentaries

Participant F (ES) discussed how they found it easiest to learn about safety through documentaries on previous engineering safety incidents. These had a more profound effect on them than learning because they could "emotionally relate" and they found it hard to relate to PowerPoints or lectures at UWA.

Company Norms

Although a company cannot force their employees to associate their engineering identity with the company's safety culture, social identity theory suggests that over time employees will start to associate with the values of their work colleagues and those of the company (Loui, 2005). As discussed, the survey by Novak et al. (2017) found that a high level of safety outcomes in a corporation correlated to a high employee individual commitment. The findings provide evidence of this.

Participant E (EV) said, Company G, a Large Engineering and Design Consultancy presented them with one video about safety inductions while when they moved to Company A they undertook three days of safety inductions, they believed the extended safety induction changed their understanding of safety.

Participant B (MV) had work experience at two large mining companies, Company A and Company B. Company B had a reactive safety culture, which Company A had a preventative safety culture. When discussing the safety culture at Company B compared to Company A they said:

> *"It was different [At Company B] because the plant was so old that stuff just happened, so the way they managed the risk was a lot different." … "The safety culture [At Company B] wasn't preventing the incident; it was solving them after that happened."*

Participant A (MG) discussed Company A's focus on safety. It becomes clear that Company A had significant safety practices, however, Participant A (MG) was frustrated by the safety impacting their productivity and performance.

> *"it's all about safety. You can cut down on your productivity, but you cannot cut down on your safety process." … "We as a business may tend to sort of fall back on targets and might sort of create a lag in the workflow".*

Participant A (MG), B (MV) and (EV) had all worked at Company A and noted that this company had a stronger focus on safety than their other experiences. The company culture and norms at Company A impacted their understanding of safety. In the safety culture definitions, two of the four participants that worked at Company A easily recited Company A's definition of Safety Culture, showing that the definition was repeated enough that they picked it up. It is evident that Company A was in a later stage of safety culture development out of the different stages of safety culture, pathological, reactive, calculated, proactive, generative (Hudson, 2001).

Participant C (MS) worked at company D, an air-conditional installation company with a poor safety culture which impacted Participant C's individual safety culture. The following comment' show that Company D has a low level of safety culture development (Hudson, 2001). The participant made multiple comments that have been shown below for impact.

> *"What I've experienced when they know that there's a void in the documentation, they don't tell the people higher up because it results in more paperwork that they don't want to fill out."*
> *"You have to do something a little bit jank."*
> *"Getting the job done seems to take precedence over safety. ... They don't care, it costs money"*
> *"Theres like a pressure, to be like it's fine, sweep it under the rug, tick it off".*

According to Social Identity Theory, Company D is influencing the attitudes of Participant C (MS) (Loui, 2005). They do not appear to care about safety, shown by the nonchalant way they said "blah blah blah" while discussing risk.

> *"We're not sticking fingers into places that … Yeah, well, maybe I shouldn't say that sometimes we do. Everything is turned off, everything's isolated, blah blah blah. We know the risks".*

However, Participant C (MS) is aware that the companies' values do not align with their own believes and they want to change their values, this is discussed later.

> *"I want it to be sort of, my identity to be based upon those issues. Like I see the pain and the suffering that all these issues make, and I sort of want to not do that" … "So I want to be better than that".*

It becomes clear that where a person works impacts their understanding of safety. The company a university student does vacation work at during this formative time will impact their association with safety and safety culture.

When do Engineers in the mining industry start to associate it with their Engineering Identity?

Transformative Experiences

Students require a transformative experience to associate safety culture with their engineering identity, Tyng, Amin, Saad, and Malik (2017) found emotion has an impact on learning and creating memorable experiences. This experience will help them understand the importance of safety and safety culture. The three transformational experiences identified in the study are detailed in Figure 3.

Figure 3 - When do Engineers in the mining industry start to associate it with their Engineering Identity?

Site Experience

Visiting or working on a mine site was a transformative experience for participants A (MG), B (MV), D (EG) & E (EV). Participant A (MG) discussed their first project as a graduate engineer.

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After investigating a incident on a ramp where the chocks were not properly in place they found that the ramp was also not rated for the weight. “There were more questions to be asked about how that can be improved and how that can be prevented.” Participant B (MV) identified learning about safety in university, but they only started to understand the implications of working in a safe environment when they saw it themselves, they stated that:

> *“When I started out [at company b] I was, you know, I was aware that I had to be safe, but walking around the site for the first time being like Oh my God, all this stuff could actually like really injure me. It is when you start thinking well. How can I protect myself? How can I protect those around me from being injured?”.*

Meeting Others

Participant D (EG) mentioned that meeting others who had safety incidents was pivotal in their safety culture learning.

> *“There’s lots of guys I worked with who were missing fingers because there are a lot of pinch points in a coal mine and just resting their hand or something, it gets squashed. So just stories like that, or there was an electrician who got severely burnt. Also meeting people like that, that was really, I think shaped how I think about it.”*

Safety Incidents

Another transformative experience was being involved with a safety incident. Although ideally these situations are avoided by companies, they still have a profound impact on those involved. Participant B (MV) explained how she was on site when a mayday call came through the radio about a casualty, she heard the whole interaction play out.

> *“That's very real and you're like oh my God, this is happening. We were just sitting in the car and you know, it's very almost confronting, like realizing you know, people do get hurt. It's one thing to read about it … but seeing an incident happen in front of you … you realize that you know this does happen, these are real concerns that need to be managed.”*

Do participants associate safety culture with their Engineering Identity?

Participants A (MG), B (MV), D (EG) & E (EV) all associated safety culture with their Engineering identity and identified transformative experiences that were pivotal points for them. Participant C (MS) had trouble defining safety culture and listing attributes that made a good engineer. Both C (MS) and F (ES) do not currently associate safety culture with their Engineering Identity. When asked if they associated safety with their engineering identity C (MS) stated:

> *“I want it to be sort of, my identity to be based upon those issues. Like I see the pain and the suffering that all these issues make, and I sort of want to not do that” … “So I want to be better than that”.*

Participant F (ES) said:

> *“it sounds like it's a lot of fluff, it's just like people talking and bullshit, so they can do the job and pretend to be doing something useful but, like they might be doing something useful, but they won't prevent a disaster”.*

No Vacation Experience

According to the constructivism theory of learning, students build on their past experiences (Zulkarnaen, 2019). Participant C (MS), a final year student did not have any course-related work experience when they studied the unit Risk and Reliability. They had no previous experiences to build on which led them to feel “disconnected” while studying the unit. When talking about a case study on Piper Alpha, an Oil Rig in the North Sea, the participant said

> *“I don't see me ever working on an offshore rig, like I don't see that. I mean I could I? But I don't see the lessons I meant to learn from it, that seems a bit too not relevant”.*

The student was not able to relate to the case study.

"Wow, a lot of people died. Not exactly sure how that Implicates me about how to do stuff better. I mean, I understand the processes and stuff that went wrong, but I've not done any work that like relates to it".

This lack of engineering vacation experience is hindering their formal learning of safety culture at university. Meanwhile, other students taking this unit may have been exposed to work like this in a vacation program which means they were able to relate to the content.

Participant F (ES) didn't consider personal wellbeing as being part of safety and believed that managing dehydration and heat stress was "pointless" it didn't "directly related to the job" and "I wouldn't care". They had a limited definition of safety and focused more on safety in terms of engineering design than human factor and behavioural factors and said "I would think safety is more to do with stuff". This shows the importance of having these transformative experiences early so that students learning is not impacted.

Significance of Findings

This study builds on the study by Payne (2020) and confirms their findings that Engineers do associate their professional identity with safety culture and experience and mentoring have an impact on a person's individual safety culture. The findings about how safety culture is taught are consistent with those in the literature such as safety moments by Jamieson and Shaw (2019) and mentoring by Dehing et al. (2013).

The study is significant and different to previous research as it identifies how students learn about safety culture, it also identifies that a transformative experience is required for engineers to associate safety culture with their engineering identity. Furthermore, it captures what happens if a student is not exposed to these transformative experiences early in their engineering studies. It confirms that there is a discrepancy between the understanding of safety culture students gain from university and the safety culture understanding professional engineers have. The contributions and the impact of this research is significant as there is currently limited research on how safety culture is currently learnt in Australia. This study can be used to inform engineering education as not all students are graduating with the same understanding of safety and safety culture.

Limitations and Further Studies

This project was limited by the number of participants that were interviewed. The study was also limited to Engineers working in Western Australia that had studied at the University of Western Australia, further research into a larger scope of participants is recommended for future research.

Further studies branching off this study could investigate how safety culture is currently taught at university and what is the most effective way to teach it. One participant mentioned learning better from videos than PowerPoints, could Videos or VR could be used to teach safety in the future?

Conclusion

Safety culture is not a miracle, it is easy to have inflated expectations of what safety culture can achieve. Students learn about safety culture in university or work but require an emotionally transformative experience to associate it with their engineering identity. If a student does not have these transformative experiences, they are not able to relate to the content taught at university effectively which may hinder their learning.

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Emotions in Engineering Education: Preliminary Results from a Scoping Review

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ABSTRACT

CONTEXT

There is today a broad consensus that emotions influence all forms of teaching and learning, and scholarship on *Emotions in Engineering Education* (EEE) is an emerging and rapidly growing field. However, this nascent research is currently very dispersed and not well consolidated. There is also a lack of knowledge about the state of the art, strengths, and limitations of the existing literature in the field, gaps, and future avenues for research.

PURPOSE

We have conducted a scoping review of EEE research, aiming to provide a first overview of the EEE scholarship landscape. We report here on preliminary findings related to (1) the status of the field, (2) geographical representation of authors, and (3) emerging hot spots and blind spots in terms of research approaches, contexts, and topics.

METHODS

The scoping review is part of a larger, systematic review of the EEE literature. Using an inclusive search strategy, we retrieved 2,175 items mentioning emotions and engineering education, including common synonyms. Through abstract screening and full text sifting, we identified 184 items that *significantly* focus on engineering education *and* emotion. From these items, we extracted and synthesized basic quantitative and qualitative information on publication outlets, author origins, keywords, research approaches, and research contexts.

PRELIMINARY RESULTS

Surprised by the large number of EEE publications, we found that EEE is a rapidly expanding, but internationally dispersed field. Preliminary results also suggest a dominance of research on higher education, often exploring students' academic emotions or emotional competences. Research on emotional intelligence and anxiety is particularly common while studies focusing on cultural and sociological aspects of EEE are largely absent.

CONCLUSIONS

The EEE literature is expanding exponentially. However, the field is not well consolidated, and many blind spots remain to be explored in terms of research approaches, contexts, and foci. To accelerate the development of the field, we invite current and prospective EEE researchers to join our emerging, international community of EEE researchers.

KEYWORDS

Emotions, engineering education, systematic review, scoping review

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Introduction

Engineers often identify their work as rational, beyond emotion, and engineering is often characterized as purely scientific, involving technical solutions to real world problems (Cech, 2018). However, many real-world problems, such as the 17 United Nations Sustainable Development Goals and the emergence of the Industry 4.0 era, require attention to human factors, including emotions, since technical issues are only part of the problem (World Economic Forum, 2021).

During the past two decades, engineering programs, professional societies, and accrediting bodies have increasingly acknowledged the importance of emotions in engineering education and practice—which is supported by research on, for example, engineering ethics, social justice, risk management, problem solving, student development, and retention (Hess et al., 2020; Kellam et al., 2018; Roeser, 2012), as well as the wider educational literature (Pekrun & Linnenbrink-Garcia, 2014). In fact, research interest in EEE is increasing rapidly (Lönngren et al., 2020) and in April 2020, the authors gathered at an international symposium to formulate a research agenda for this emerging field. However, we realized that we first needed a comprehensive overview over *existing* research, which did not exist yet. Thus, we decided to undertake a scoping review and a systematic review of the EEE literature. Here, we report on preliminary results from the scoping review.

Purpose

The purpose of this scoping review is to provide a first overview of the existing landscape of EEE scholarship. In this paper, we report on preliminary findings related to (1) the status of the field, (2) geographical representation of authors, and (3) emerging hot spots and blind spots in terms of research approaches, contexts, and topics.

Research team positionality

The disciplinary backgrounds of our review team include engineering education, science education, psychology, and professional development for university faculty, and we employ a wide range of theoretical and methodological approaches. Our cultural understandings are colored by our backgrounds in Australia, Denmark, France, Germany, Ireland, Malaysia, Portugal, Sweden, Switzerland, the United Kingdom, the United States, and Venezuela. We acknowledge that we are not able to represent African, Eastern European, and Middle Eastern perspectives.

Background

Emotions are commonly distinguished from *affect*, which is an omnibus construct that encompasses emotions, feelings, moods, and non-emotional constructs, such as motivation, interest, and attitudes (Pekrun & Linnenbrink-Garcia, 2014). Emotions are studied in many different disciplines, leading to a wide range of definitions (Bellocchi, 2019). Many scholars subscribe to *componential theories* (Scherer, 2005), which outline four dimensions of emotions: they (1) are represented by linguistic labels, (2) are *about* something, (3) involve physiological changes, and (4) may involve expressive gestures (Turner, 2007). We restrict our discussion to this componential approach because it is consistent with perspectives used in many of the items in our review. In making this choice, we acknowledge the broader range of theories and perspectives (e.g., social constructionist, feminist) that are not considered here.

Methods

In this paper, we report on preliminary results from a *scoping review* (Grant & Booth, 2009), which is part of a larger systematic review project and we therefore follow "transparent, methodical, and reproducible procedures" (Borrego et al., 2014, p. 46). More specifically, we

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follow Siddaway et al.'s (2019) description of six stages in conducting systematic reviews: scoping, planning, searching, abstract screening, full text sifting, extracting and synthesizing information.

Scoping

The scoping stage focuses on formulating research questions, considering the breadth and depth of the review, and becoming familiar with the literature that is to be reviewed. Since there was no previous review of the EEE literature, we did not know in advance what we would find in the literature. We therefore decided to start off with a broad scope and narrow our focus in an iterative manner. To get familiar with the literature, we conducted several pilot searches in different databases and with a variety of search term combinations. Based on those searches, we formulated the following research questions:

1. What is the status of EEE research in terms of numbers of publications, publication outlets, and publication trends?
2. Who publishes EEE research and how do authors collaborate internationally?
3. What are some emerging hot spots and blind spots in terms of research approaches, contexts, and topics in the EEE literature?

Planning

The planning stage involves operationalizing the research questions by formulating search terms and in-/exclusion criteria. We formulated, tested, and refined our search terms until we were confident to achieve an adequate "balance between sensitivity (finding as many articles as possible that may be relevant) and specificity (making sure those articles are indeed relevant)" (Siddaway et al., 2019, p. 757). As recommended by Siddaway et al. (ibid.), we initially prioritized sensitivity to ensure that we would not miss anything important. For example, we included the broader terms "affect" and "feeling" in our database searches since we suspected that some authors may unintendedly use these terms as synonyms of "emotion". By including these terms, we also assumed that we would retrieve items that focus on specific emotions, such as "anxiety" or "shame", even if the term "emotion" is not used.

To formulate preliminary in-/exclusion criteria, we took inspiration from two frameworks that are widely used to develop search strategies for systematic reviews: the primarily quantitatively oriented *PICO framework* (Population, Intervention, Comparison, Outcome) and the more qualitatively oriented *SPIDER framework* (Sample, Phenomenon of Interest, Design, Evaluation, Research type) (Borrego et al., 2014; Cooke et al., 2012). Since our review covers quantitative, qualitative, mixed-methods, and non-empirical literature, we combined elements from both frameworks and added criteria for non-empirical scholarship.

Searching

We searched a broad range of databases to capture as many EEE publications as practically feasible. We included general databases (*Scopus*, *Web of Science*, *Academic Search Complete*), educational/social science databases (*ERIC*, *IBSS*), a psychological database (*APA PsycInfo*), an engineering database (*Engineering Village*), and databases specialized on eBooks and theses (*eBook Central*, *Dissertations & Theses Global*, *Open Thesis*). Prioritizing sensitivity, we included synonyms and related terms. We also used truncation symbols to capture different word forms. The search string used—adapted to the syntax of each database—was:

((emoti* OR affective OR feeling*) AND ("engineer* educat*" OR "technology educat*" OR "engineering stud*" OR "engineering instruct*" OR "engineering facult*")).

Where possible, the fields searched were "Title", "Abstract", and "Author Keywords", and the search was limited to peer-reviewed items.

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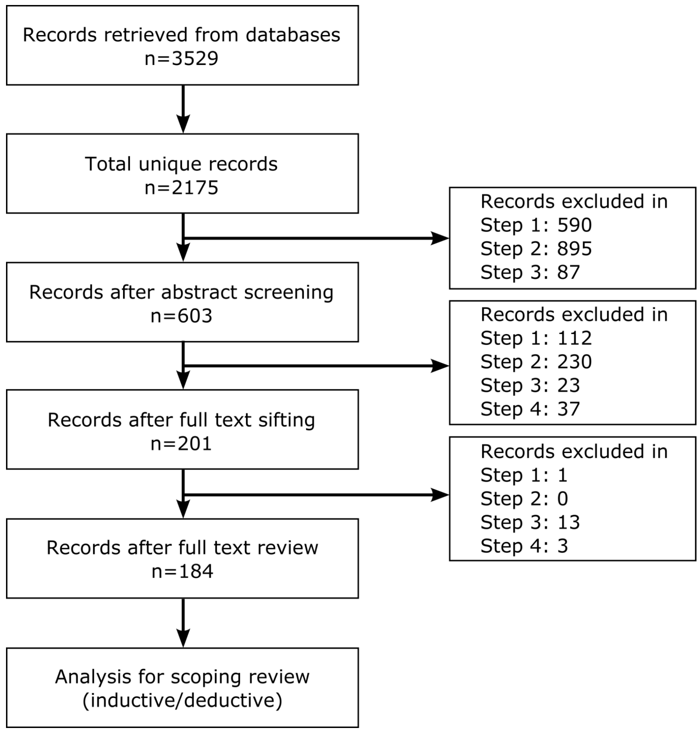
Each database was searched independently by two reviewers and the results cross-checked. The searches were completed in late August 2020, yielding 3,529 items. The items were added to the reference management software *Zotero*. We also used Zotero to remove



duplicates, leaving 2,175 unique records for abstract screening (see Figure 1).

Figure 1. Overview of the selection process for the review.

Abstract screening

For abstract screening, we developed a detailed code book based on our preliminary in/exclusion criteria. It included 41 criteria, applied in three steps: (1) sample and/or setting must be *related to engineering, technology, and/or computer education*; (2) phenomenon of interest and/or outcomes must be *related to emotions*; and (3) must be a *scientific publication*. All reviewers participated in a training session and all items were screened independently by two researchers (inter-rater agreement 75%) and disagreement was resolved by a third researcher. 590 items were excluded in step 1, 895 in step 2, and 87 in step 3, leaving 603 items for full text sifting.

Full text sifting

During full text sifting, Siddaway et al. suggest that the focus should “shift from sensitivity to specificity”, aiming to “see if each [item] is indeed appropriate for inclusion” (2019, p. 764). Therefore, we adapted our code book to increase specificity. The revised code book included 37 items, applied in four steps: (1) content must be *relevant for engineering, technology, and/or computer education*, (2) must have a *substantive focus on emotions*, (3) must be a *scientific publication*, (4) *full text must be accessible* through our library resources and written in a language that at least one member of our international research team can read. Again, all reviewers participated in a training session, all items were sifted independently by two researchers (inter-rater agreement 74%), and disagreement resolved by a third researcher. 112 items were excluded in step 1, 230 in step 2, 23 in step 3, and 37 in step 4, leaving 201.

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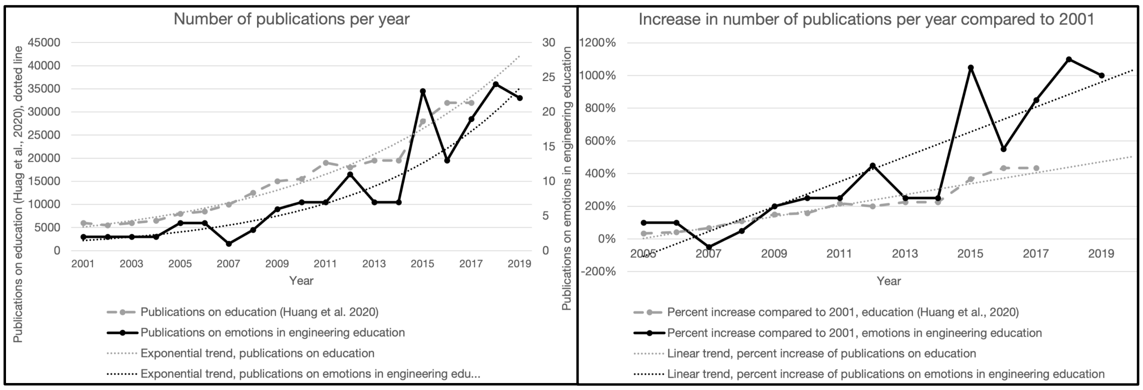
Extracting and synthesizing relevant information

From the remaining 201 items, we extracted information about publication outlets, authors' origins and keywords, use of common emotion-related concepts, research approaches (types of research, research methodologies, data collection methods), and contexts (e.g., educational context, pedagogical approaches used). Each item was read by one reviewer, who also entered the extracted information in a shared spreadsheet. As we read the items more closely in this stage, we identified 17 additional items that did not meet the inclusion criteria for full text sifting, one in step 1, 13 in step 3 and four in step 4, leaving 184 items for analysis in this preliminary scoping review (for the final results, we will include additional items after hand searching reference lists and journals). For items with predefined



categories, we extracted descriptive statistics through deductive analysis. Free text answers were analyzed inductively through thematic clustering and creating new categories as needed. Authors' keywords were analyzed deductively, categorizing keywords according to terms included in the EER taxonomy (Finelli, 2020).

Figure 2a. Number of publications per year. Figure 2b. Increase in number of publications per year, compared to 2001. Statistics for publications on education from Huang et al. (2020).

Preliminary Results & Discussion

EEE is an emerging and rapidly expanding field

When we decided to do this review, we expected to find a relatively low number of publications (n<50). This expectation was based on our observation that many EEE publications (including some of our own) start with a claim that there is a lack of EEE research. Thus, we were surprised by the overwhelmingly large number of publications retained in our review. Our surprise indicates that the field is not well consolidated since authors often do not seem to know about others' EEE research. At a later stage, we will perform a citation analysis to explore the extent to which authors draw on others' work.

Despite this apparent lack of consolidation, the EEE literature seems to have grown exponentially in the past two decades. Only three items were published before 2001, while 22 papers were published in 2019 alone. At a first glance, this growth seems to mirror the development of the broader educational literature (Huang et al., 2020; Figure 2a). However, the *percentage growth*, compared to the number of publications in 2001, seems to indicate a faster growth rate for the EEE literature (Figure 2b).

Although the number of publications is increasing, many items are published as conference papers (45%) rather than journal articles (40%), books (0,5%), or book chapters (3%), indicating that EEE is still an emerging and developing field (Figure 3a). We also found a relatively large number of theses (23%), which may be explained by the growing interest in the field. It may also indicate that EEE research is easier to perform in long-term projects that allow researchers to explore the complexities involved in theorizing, measuring, and

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analyzing emotions. Compared to funded projects, most thesis projects are relatively open, allowing students to focus on what they find most interesting rather than what is most easily funded. Thus, the large number of theses in our review may also point to difficulties in obtaining funding for EEE research.

Finally, we analyzed how central emotions are to the items in our review. Despite our full text sifting criteria to only include publications with a *substantive* focus on emotions, we found that many publications (33%) did not have emotions as their *primary* focus. This suggests that emotions are a topic that often emerges in, or is added to, research focused on other topics: emotions are often only a secondary focus.

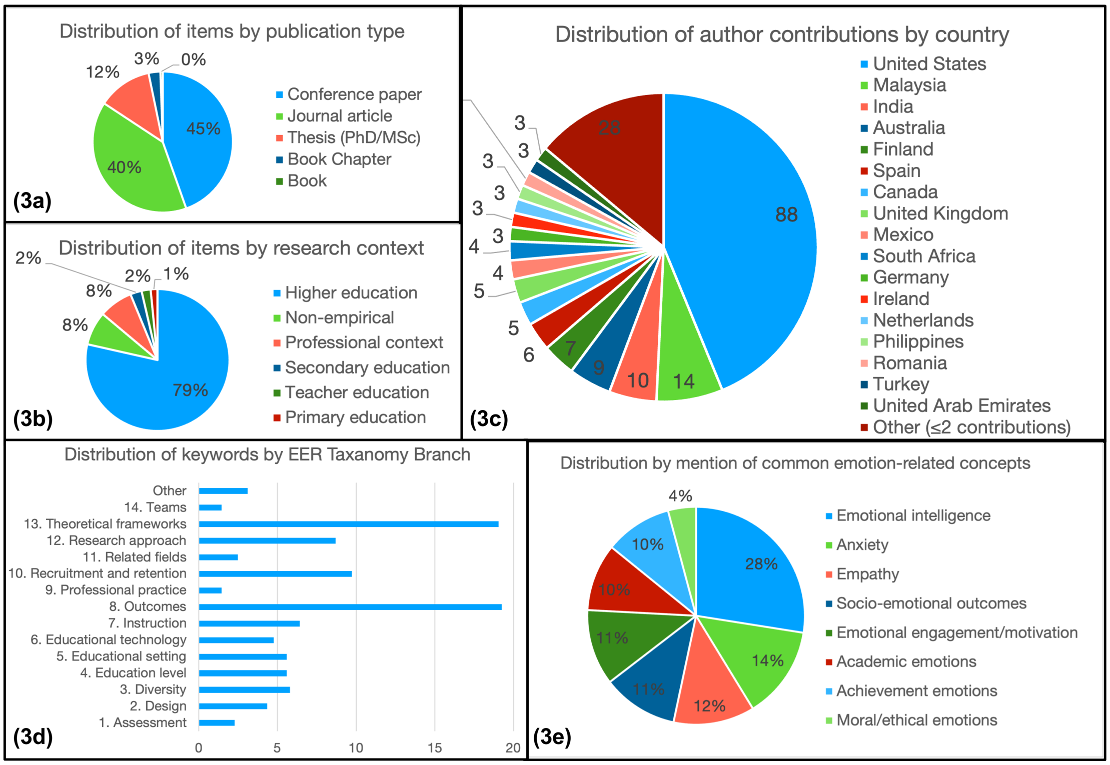

Figure 3a. Distribution of items by publication type. Figure 3b. Distribution of items by research context for empirical data collection. Figure 3c. Distribution of countries where authors are based. Countries are counted only once per item, even if several authors from a country contributed to it. Figure 3d. Frequency of keywords by EER Taxonomy branch. Figure 3e. Percentage of publications that mention common emotion-related concepts.

EEE is an internationally dispersed field

445 authors from 39 different countries contributed to the 184 papers in our review. There is a strong dominance of authors based in the United States, contributing to 88 papers. However, we also found substantial contributions from authors based in Malaysia (14 papers) and India (10 papers). Figure 3c provides an overview of countries from which authors have contributed to at least three papers.

International collaborations are relatively rare. While authors from 17 countries have collaborated with at least one other author internationally, only 13 items (7%) were written in international collaborations and they were all co-authored by at least one author from the United States (n=7) or the United Kingdom (n=6).

The authors who contributed to most publications are Walther (n=7), Karanian (n=5), Kellam (n=5), and Villanueva (n=5) from the United States; Muhamad (n=5), Sahari (n=5), and Saibani (n=5) from Malaysia; and Riemer (n=5) from Australia. We only found two groups of

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authors that frequently publish together (Walther, Kellam & Villanueva in the United States; Muhamad, Sahari & Saibani in Malaysia). 396 authors (89%) only contributed to one item in our review, indicating that the field is highly dispersed and that many researchers explore emotions as a side topic—rather than making emotions their primary research focus.

Emerging hot spots and blind spots in EEE research

Research approaches

To develop an overview of research approaches used in the literature, we categorized the publications as conceptual (e.g., essays, literature reviews, conceptual discussions, and scholarship of teaching; n=35), quantitative empirical (n=78), qualitative empirical (n=28), mixed-methods empirical (explicitly adopting a mixed-methods design, with reference to mixed-methods literature; n=23), or multi-method empirical (utilizing multiple methods, but without reference to mixed-methods literature; n=10). As shown in Table 1, quantitative studies clearly dominate our sample.

We also categorized the 149 empirical studies according to research methods, distinguishing between *artifacts* (e.g., written documents; n=12), *observations* (n=10), *physiological measures* (n=8), and s*elf-reports* (reporting on one's own emotions in, e.g., questionnaires or interviews; n=78). 20 publications reported using a combination of methods. Self-report methods are used most often. Self-report methods are also regularly used in single-methods studies, while the other method types typically are combined with self-report methods.

Table 1. Article categories in the corpus and methods used in empirical studies

	Article Type					
Methods	*Conceptual*	*Mixed Methods*	*Multimethod*	*Qualitative*	*Quantitative*	Total
Artifact		4	0	7	1	12
Observation		3	2	4	1	10
Physiological		0	7	0	1	8
Self-Report		23	10	28	78	149
Combination		5	9	4	2	20
Total	35	25	10	35	79	184

The dominance of self-report methods is not surprising since these methods are consistent with cognitive and psychological perspectives on emotions—which have dominated the educational emotion literature for several decades (cf. Bellocchi, 2019; Pekrun & Linnebrink-Garcia, 2014). In short, self-report methods are well suited for research based on an understanding of *emotions as mental constructs* that are made available to researchers through participants' own descriptions. Research using physiological measures (which has emerged more recently and is not yet widely used) is based on an understanding of *emotions as internal to individual's bodies or minds*. Observational studies, on the contrary, are often based on an understanding of *emotions as social and relational phenomena*. The low number of such studies suggests that social/relational perspectives are underrepresented in EEE. We suggest that future research should engage with a broader range of emotion theories, including socio-cultural, feminist, critical, cultural theory, and distributed perspectives. For example, critical discourse analysis could be used to uncover the role of emotions in maintaining—or challenging—unequal power relations in engineering education (c.f. Zembylas, 2007).

Our analysis of the use of *artifacts* is preliminary. We currently use it as an umbrella term for different types of artifacts, ranging from reflective writing, to teaching plans or meeting notes. We acknowledge that this category is broad and that some artifacts could be counted as self-report measures instead. We will further explore this category in our ongoing analysis.

Research contexts

We also coded all items according to the contexts in which the research was undertaken. Each item could be coded with multiple research contexts. By far the most common research context was *higher education* (79%), followed by engineering learning in professional

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contexts (8%). Primary (1%) and secondary (2%) education accounted for very few research contexts. Although this probably reflects the fact that engineering education is primarily carried out in higher education, our search string included the term *technology education*, which is commonly used to describe engineering education in schools. The comparatively weak focus on research on emotions in primary and secondary education seems at odds with the broader research on emotions in engineering (Uitto et al., 2015).

In 40% of the publications, the research was carried out in the context of teaching interventions, utilizing a wide range of pedagogical approaches. The most common approaches were problem-/project-based learning (15%), labs/workshops/exercises (6%), seminars/group discussions (5%), written assignments (5%), lectures (4%), case studies (3%), online education (3%), assessment (3%), and language learning (3%). Given that lectures and assessment are widely used in engineering education, their relatively low representation in our review suggests that emotions may be considered more relevant and/or problematic in active learning situations, such as problem-based learning, than in traditional lecture-based education. This is unfortunate since research has shown that emotions are important even in those formats (e.g., Quinlan, 2019; Tormey, 2021).

Research foci

To develop an overview of foci in EEE scholarship, we analyzed authors' keywords. We found 382 unique keywords (after removing obvious terms, such as 'engineering education', 'emotion', 'engineering', and 'education'), which we coded using the Engineering Education Research (EER) Taxonomy (Finelli, 2020). The taxonomy has 14 thematic branches, each of which is further divided into subcategories. Figure 3d shows the frequency of keywords by EER Taxonomy Branch. Only 40 keywords were used in more than one publication and 90 publications lacked keywords.

Our preliminary analysis suggests a dominance of research on *emotional intelligence* (n=46), which was used as a theoretical framework (branch 13) and/or in data collection instruments (branch 12). Mental health-related keywords, particularly *anxiety*, were also dominant (branch 10, n=31), mirroring a trend in the broader research on emotions in education (Pekrun & Linnenbrink-Garcia, 2014). Many of the keywords coded as educational *outcomes* (branch 8) were related to *communication*, *ethics*, and *entrepreneurship*, indicating that emotions are considered more relevant/problematic in teaching targeting these types of outcomes than in teaching of purely technical content. Our analysis further suggests a dominance of research on *academic emotions*, while non-academic emotions (e.g., *humor*) were rarely explored. Keywords related to *faculty* and *instructors* were also rarely used, suggesting a lack of research on teachers' emotions. Finally, the initial analysis suggests a lack of research based on sociological and cultural conceptualizations of emotions, as keywords such as *emotional culture*, *emotion rules*, or *emotional capital* were lacking.

We also coded all publications for eight emotion-related concepts that we expected to be used frequently. The results from that analysis (Figure 3e) confirm preliminary findings from the keyword analysis: *emotional intelligence* (28%), *anxiety* (14%), and *socio-emotional outcomes* (11%) are frequently used. The results further suggest that *empathy* (12%), *emotional engagement/motivation* (11%), *academic emotions* (10%), and *achievement emotions* (10%) are frequently mentioned in publications, but seldom chosen as keywords.

Conclusions

We have presented preliminary results from a scoping review of the EEE literature, finding that EEE is an emerging and rapidly expanding, but internationally dispersed field that could benefit from more international exchange and collaborations. We also found that most EEE research so far is conducted in higher education contexts, employs quantitative research approaches, self-report methods, and a limited range of theoretical conceptualizations of emotions. The blind spots we identified indicate many promising and important directions for future research. Finally, we invite current and future EEE researchers to join our international

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EEE community, which aims to create spaces for international and interdisciplinary scholarly conversations about emotions in engineering education.

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Identifying and developing the factors necessary for the creation of functional groups

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ABSTRACT

CONTEXT
In 2020, research was carried out into three, group-work based engineering and IT undergraduate subjects each with approximately 600 students. The research was focused on students' experience of online group work, and what emerged were several factors that contributed to developing a capacity for successful group work online. These factors included common expectations amongst group members, students' confidence in themselves and fellow group members, and a strategic approach to task completion.

PURPOSE OR GOAL
Students frequently find group work assessments challenging and unenjoyable due to reasons unconnected to the assessment itself. Tensions within the group may result in students not participating in the task, disengaging from the group work, and in extreme cases dropping out of the subject. Meanwhile, other students have to pick up the slack and complete the remaining work. Factors such as group trust, individual attitude and aligned motivation have been identified as indicators of successful group work. We aim to further understand the conditions necessary to creating functional groups and to use this knowledge to develop tools and activities to help create functional groups.

APPROACH OR METHODOLOGY/METHODS
Over three semesters, focus groups of first- and second-year students in subjects requiring group work discussed factors contributing to their group's success or failure. Focus groups were also run with tutors to determine features they considered important in creating successful groups. The data was analysed for themes that indicated the factors that support and inhibit the development of functional groups. These results have been used to adopt tools and develop activities to improve group dynamics which will be used in future classes.

ACTUAL OR ANTICIPATED OUTCOMES
This research provides further indications of the elements contributing to group achievement. It has given insight into conditions that need to be avoided for groups to succeed. The literature suggests that confidence, attitude, and motivation are fundamental to collaboration. Analysis of focus groups has supported this and suggests that developing student agency may help students achieve these. The research has guided the implementation of tools and activities that can be used to help students to improve their ability to work in groups.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
Success in group work depends on developing student trust in their own abilities and the abilities of their groupmates and these are supported through development of student agency. The research has presented tools and activities that promote and develop individual agency in a group context and foster students' confidence in themselves and fellow group members, and a strategic approach to task completion.

KEYWORDS
Group work, teamwork, online

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Introduction

This paper builds on work presented at last year's AAEE conference on the transition of three group work-based subjects of approximately 600-1000 students each to online tutorials. In this research, we identified factors that enabled or inhibited the success of online groups and adapted activities to facilitate successful group work. To further this research, interviews were carried out with tutors, the following cohort of students, and the tutors who taught them. The aim was to understand the effect of our efforts to mitigate the difficulties of working in groups online.

Focus groups confirm the research of Wildman et al. (2021), which states that the change to online learning had psychological effects on students. These repercussions included perceived increased levels of hesitation in decision making and forgetfulness. Wildman et al. (2021) and Du et al. (2018) reported that online groups are prone to greater levels of non-participation from group members.

Dulebohn and Hoch (2017) observed that poor communication and low participation is not just an issue for university students, virtual teams in industry often suffer from lower levels of engagement and a lack of trust between team members.

Du et al (2018) suggest that a key factor in successful group work is trust based on responsibility and a motivation to achieving common goals. This in turn helps develop mutual understanding and greater cooperation. Xu et al. (2014) note that control of emotions is more difficult when the emotional cues of a face-to-face meeting are absent. Trust between tutor and student and student and student is an essential element of any learning experience but is much more difficult to establish online.

This paper analyses the experiences of tutors and students in their attempts to create and work in online groups. We investigate how the conditions for successful groups can be established and evaluates the methods tried so far. We use Lencioni's (2002) '5 Dysfunctions of a Team' as a lens for team-work issues affecting students. The paper makes recommendations on improvements and areas that can be developed in the future.

Background

This paper is centred around tutor and student experience in their second and third semester of online classes due to the onset of COVID-19. Not surprisingly the situation was less fraught than during the first semester. This was indicated by a significant decline in the drop-out rate and a reduction in student requests in later iterations of the subjects. Everybody became better at coping with the 'new normal'.

Previously, we identified the following factors in predicting successful group work. Firstly, motivation, students needed to be engaged for functional student groups to exist. Wade et al. (2016) indicate that motivation was partly facilitated by icebreakers, and a high degree of tutor interaction with tutors checking in with each group each tutorial. Another factor was students' willingness or otherwise to speak and have their cameras on in groups. The more group members got to know each other, the more they would develop confidence in their teammates. In addition, the setup of the group and the division of work was seen as a factor in group success. Groups who gave thought to how they worked together and used a skills-based approach to divide work tended to be more successful.

During the second and third semesters of online groups, the three subjects developed new materials and techniques designed to increase self-efficacy, encourage motivation, and improve the quality of group work.

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Teaching strategies and tools

Pre-work

Online quizzes to encourage students to complete pre-work

Even when these subjects were in-person, it was difficult to get students to engage with pre-class work. In an online environment, when students have a shorter attention span, pre-work was more important. In groups, where few students had completed pre-work, not enough people had the knowledge to participate in team tasks. Whilst tempting for the tutor to spend class time going through pre-work, this was counterproductive as students soon believed there were no consequences for not doing pre-work.

To encourage students to engage with the work, students were given weekly multiple-choice quizzes on the pre-work. This accounted for 10% of the final mark. These quizzes were successful in that most students did enough to pass them. However, they still may not have achieved the required depth of understanding to fully contribute in class.

Although there is a tendency to try to cover more material by adding to pre-work, it is important not to over-burden students. This runs the risk of students giving up. Moreover, for students to value the tasks, there must be explicit link between pre-work and class work.

In-class

Greater use of icebreakers and group and whole class activities

Feedback from first semester 2020 identified that some students became disconnected. More effort was made to introduce icebreakers to help develop relationships within the tutorial. In the first tutorial, ‘getting to know you’ exercises were used to build understanding and empathy. Quizzes on character and personality traits were used to create functional project teams in week 3. These activities helped students understand their teammates’ personalities, ways of working, strengths, and weaknesses. This prefaced activities to get groups them to think about how they would work together. Other ‘lighter’ team activities were used to maintain group relationships throughout the subject.

Icebreakers influence group cohesion, but other factors also influence. There were still students who did not engage with the subject or their group.

The use of Mural

Mural could be described as an online platform for butchers' paper and post-it notes. It allows students to brainstorm, add ideas anonymously to a collective online board. This was used for both whole class and group activities. The advantage of Mural was that students could present their ideas anonymously without fear of judgement. It also allowed teams to formulate their projects, as notes and ideas were moved around and built upon each other.

Informal feedback from students and tutors was positive. As tutor’s expertise developed, more innovative ways of using Mural were discovered improving student interaction.

Regular group check-ins with tutors

Tutors checked in with each group each week. The group summarised their project progress and the areas on which they were working. These check-ins gave each group the opportunity to discuss issues and to be guided to keep their project on the right track. This worked well in that the tutor was well-informed on group progress. However, too often the tutor would struggle to get groups to communicate directly. Some students preferred to communicate through text without cameras. In addition, it was often the same voices representing the group each week.

Tutors and subject coordinators had weekly meetings to establish teaching team identity and cohesion, as well as share ideas and provide feedback for agile response.

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Drop-in sessions for students

Each of the subjects organised weekly one-hour voluntary drop-in sessions for students with the subject coordinator. These sessions gave students an opportunity to ask questions about the subject. Although there was a noticeable upsurge in attendance around assignment deadlines, these meetings were generally not well attended.

Methodology

The project took a qualitative approach to investigate the phenomenon of online group work. Data points were collected including semi-structured student focus groups, tutor focus groups, student feedback survey comments, and student self and peer-feedback results.

One group of four students and one group of three students were asked to elaborate on prompts on their experience of group work. The students had either just completed first year or second year group work subjects. Students' results in these subjects ranged from credit to high distinction. These results were broadly reflected in their Weighted Average Mark (WAM)

Two tutor focus groups were held who had taught on one or more of the three subjects. Tutors were asked to respond to prompts about their observations of online teams, activities to help students engage, and factors determining success. These discussions were compared with the results of the student focus groups.

Each semester students complete a feedback survey and relevant comments were isolated for analysis.

In all three subjects, students were asked to evaluate their own and their group members' performance. Comments around this were analysed to understand how groups functioned.

After data collection and with ethics approval, multiple data points for the same participant were collated for review. All data was analysed for common themes using thematic analysis. Four researchers reviewed and analysed the data and each other's findings, and discussions reviewed commonalities and differences between those findings before a final set of themes were developed. In particular, the data was investigated to see whether greater experience of being online allowed students to develop greater understanding and new strategies for learning.

Students have been given pseudonyms to protect their privacy.

Findings

The themes that emerged from the data indicated that our adaptations to activities and use of tools impacted on the effective functioning of groups. However, there were additional factors that influenced group success, such as familiarity with the online environment. A few emerging factors correlate to the negatives in the five levels of dysfunction described by Lencioni (2002). Lencioni's pyramid is introduced to students mid-semester as a group reflection exercise (see Figure 1). Groups are encouraged to assess whether any of these stages are applicable and if so, to take steps to remedy the issues.

Time

Not surprisingly, tutors and students were more familiar with working online. This is demonstrated by the reduction in email queries after the first semester. All students in our focus groups had at least one year of online experience. As students and tutors became more familiar with expectations, feelings of unease dissipated. That is not to say that they liked it better.

> *Online learning makes it harder for everyone to interact more. It seems rather limited. (Student comment from SFS survey)*

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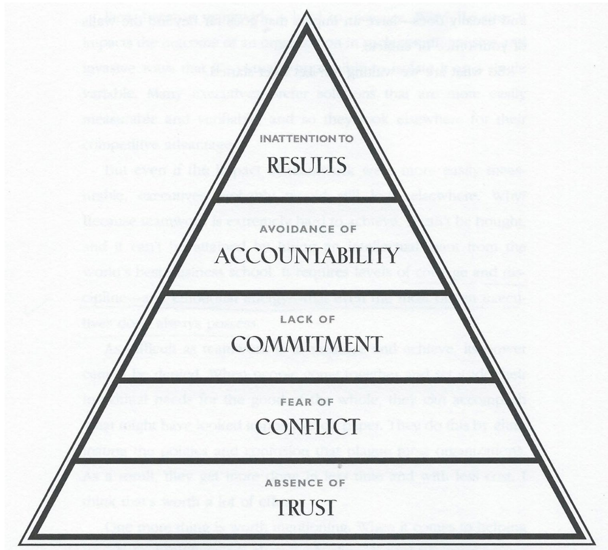

Figure 1: Lencioni's pyramid of five levels of dysfunction of a team (Lencioni, 2002)

Trust

Developing trust is an essential element of successful group work. Tutors and students both find it difficult to work in an environment where there is no rapport, cohesion or immediate feedback. When students' cameras are switched off it is impossible to gauge peer reaction. Tyler (2019) states that for trust to be achieved there needs to be transparency and honesty within the group. This means being willing to display vulnerability in front of your group members (Zartler, 2017). This is unlikely to occur in an unfamiliar environment where reaction is uncertain.

> *The students who are in their early twenties or late teens are judged all the time so they will look silly in front of peers. So no matter how many questions you ask in class you don't really get a response. (Kevin, tutor)*

Methods to develop a collegiate spirit within classes included greeting each student at the start of class, messaging students who did not contribute to check everything was ok, and using online polls to encourage student feedback. Strategies were introduced to encourage group members to be more accountable to their peers.

> *EngCom and CITP spend the first few weeks trying to establish the principles of good teamwork amongst the team, there is understanding of what the team roles are, there is understanding how to plan, there are some ice breakers. (Rob, tutor)*

The building of a community both within the class and within online teams is essential. A lot of this comes down to attention to individual students paid by tutors.

> *Pushing for them to at least have their cameras on, at least get to go through some icebreaker activities so that they have a structure to know each other becomes crucial. (Wendy, tutor)*

> *I think the students knows that when you notice them, and their contribution is missed or appreciated. (Jane, tutor)*

Fear of Conflict

Fear of conflict is connected to lack of trust. If group members are unable to be vulnerable in front of each other, it is unlikely there will be open discussion. Groups that discuss issues

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openly enjoy each other's company and will frequently go off task. Our tutors were aware of this and would let these conversations continue.

> *If I was dropping in on a call to see how they are and they are laughing and talking about something, I would take myself out and not interrupt because there was some value in that engagement. (Charles, tutor)*

It was the groups that were silent that were more of a concern. Tutors would try to contact a group to find they were offline or there were only one or two members present. Fear of conflict would seem to be linked with lack of communication.

Commitment and accountability

In university group work, commitment is equally as important as trust as a catalyst for successful groups. Students in groups with commitment to the task, both enjoy the subject and are successful.

> *I have a subject where I'm in a group and we're actually doing things fine because everyone wants to work. (Peter, first-year student)*

It is easier to avoid commitment in an online environment. Students could disappear if they hadn't completed a task. It is more difficult to let someone down when you must face them in-person.

> *It is easier to get to know people face to face than it is online, and you've gotten to know them., You have kind of, I think, you feel more pressure to do well for these people that you know, rather than these random people on the screen. And so, there's more accountability within the group. (Florence, first-year student)*

Inextricably, linked to commitment is motivation. This manifests itself when there is misalignment of motivation within groups. To mitigate this, newly formed groups develop a group charter outlining how they will work together. Groups negotiate their expectations, norms and ways of working, including the grade they hope to achieve. Despite these efforts, there remains a disconnect between students wanting to achieve a high grade and those who want a pass.

> *"Teamwork is a mixed bag. You can get people who really work with you and want to get an HD [High Distinction], but then you also get people who are still trying to understand whether they want to do this subject or whether they have the right amount of time commitment." Tony (second year student)*

Online tutorials make it easier for uncommitted students to avoid accountability.

> *"It is easy now I get to be a passive learner; I get to kick back and listen to everybody else and let people who want to talk can talk." Charles (tutor)*

Student focus groups suggest that many students make little effort to engage with the subject or their group and rely on other people to get their mark for them.

> *"At University if someone's not pulling their weight you have to just keep on carrying them." Calum (2nd year student)*

Students in the focus groups recognised they had conflicting goals. They understand that group work is an essential skill for their career, and that it is a major aim for the subject.

> *'Group work is a skill that throughout university we have to develop so that we can actually apply it when it comes to work.' Peter (First year student)*

However, students find it difficult to apply these skills when working with less engaged group members. It was often easier to take on the extra work themselves allowing less productive group members to avoid accountability.

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‘From a personal perspective, I work hard, and you need to get good marks, so while I think teamwork is important for the long term. I can't help but be caught up in the short-term rationale.’ Polly (first year student)

Although it is understandable that students want to protect their marks. They are not practicing the skills found in a functioning group and are allowing the less committed student to avoid any accountability.

‘If someone didn't do it then we would then allocate their bit to everyone else to try and get that done.’ Florence (First-year student)

Attention to results

Whether students display a lack of attention to results depends on how results are defined. Most students define a successful result as the grade at the end of the subject with many students seeking the highest grade possible. Given that students need to pass the subjects to proceed with their degree, motivation to pass is high.

A successful result is seen by tutors and some students as learning the skills required to work in groups.

You get to meet other people who are more likely to be interested in the same field as you are. They may be from different backgrounds and have different views on certain things in the same topic so It's good to be in a team with different people rather than just like-minded friends. (Philip, first year IT Student).

On the other hand, not all students see the need for working in diverse groups, believing that their future career will either involve working alone or in teams of people similar to them. Both tutor groups state that it is important to explain why group work is a skill that is worth learning.

‘You have to explain to them. You will be communicating with other people in groups for a living. Whatever you thought the job was it is probably not. You have to talk to a range of stakeholders. You have to get along with people that you may not like, and you have to talk to people that may have different levels of technical expertise.” Charles (Tutor)

Consequently, initial lectures and activities are developed to highlight how communication skills and the ability to work in teams will be important to their future career. In the last semester more effort has been put in to explaining how the tasks are relevant to their university studies and their future career.

Leadership

It was interesting to note that although groups were not required to have leaders, many teams chose de-facto leaders. This was reported in the self and peer-assessment and in focus groups. It seems that groups found it necessary to have someone specifically tasked with organising and keeping track of their project.

“…..took the leadership role, was really good at organising everyone and making sure everyone got their work done.” Student comment on teammate on SPARKplus.

Some students reluctantly took on the role of leader, because they were frustrated by the lack of progress.

"I think I was the dominating one because, you know I wanted to do well and everyone else did want to do well but I feel I just cared a bit more so.” Polly (first year student)

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What worked well and how we can build on it.

Icebreakers

Teams that functioned successfully were inclusive. They developed through building student trust, especially early on through icebreakers. It was found that inclusive tools such as Mural were successful in that they allowed students to present ideas visually and build upon them. Problem solving activities were popular as they are low stakes but appealed to students' creativity and at times competitive instincts. In the next iteration of the subject, activities will be introduced at the first weeks that will necessitate students using their cameras. The intention is to set inclusive norms early to become a habit when students are working in smaller break out rooms (Castelli and Sarvary, 2021).

Greater attention to group formation

Despite the issues, most of the student groups functioned well. Self and peer-assessment comments on fellow group members were mainly positive. Compared to last year there was a greater understanding that different skill sets would contribute to the task in different ways. This was reflected in the way groups decided to work and how tasks were divided to suit student strengths.

> *"I do believe students have different strengths. They definitely should play to their strengths, that's how you can achieve a better mark." Anthony (2nd year student)*

To develop this understanding greater attention was paid to group formation. In pre-work before groups were formed, students took quizzes to better understand their preferred learning styles, personality and character traits. In class, students shared this information with their group members and used it in dividing tasks and developing working styles.

> *"I think getting to know earlier on what their strengths are, so everyone has a unique way of contributing. Some of the subjects we have been teaching focus on learning styles or personalities to see they have the language to express what they are and just to give some personality to individuals in a particular group." Jane (Tutor)*

The goals and ways of working were documented in the group charters, which were completed in the first team time session. In future iterations of the course, it may be useful to have teams revisit and revise this contract at regular intervals.

In the next semester, a series of scenarios based on real group issues will be introduced to newly formed group for discussion. It is hoped that by discussing these issues early through case studies, students will be aware of the risks, and build capabilities to address, and avoid them.

Regular reporting on progress to increase accountability

As it is easy for students or groups to go missing in online tutorials, regular check-ins were especially important. Tutors would focus on facilitating group work and would make efforts to hold group members accountable by having them explain their ideas. Groups were particularly motivated when they were asked to present to other groups (social accountability). These groups were then tasked with giving feedback to a specified group. In addition, external 'Design Guides' questioned students on their designs during selected tutorials and gave suggestions on improvements.

> *"When groups check in, it means that they sense check their progress regularly. And they will quickly find out if the group is stirring in the wrong direction, because perhaps, they have listened to a more dominant member of the team who has misinterpreted a certain bit of the assignment.' Keith (Tutor)*

It was noticed that in these reporting sessions, the same students reported every week. For the forthcoming session, it is planned to have a timetable for students to report, this ensures that every student needs to be connected enough to understand the group plan. To further increase feedback on tasks and reduce student uncertainty, students will submit a draft of their final report. They then present this draft to another group, give feedback to that group on their draft, and summarise the feedback they receive. This has been made a graded assessment to encourage students to be more active in the feedback process (Nicol and Selvaretnam, 2021).

Leadership

Our findings indicate that groups will appoint leaders or that team members may be compelled to take the leadership position. This semester there will be a section in the group charter where students discuss whether they want team roles (including a leader), and what they want from that leader. They can then make a more informed decision as to who that leader should be and the qualities, they should have to help the group function efficiently.

Conclusion

Lencioni's model works well in describing the conditions that need to be in place for online teams to be successful. However, in an online university context, commitment is probably of equal importance to trust. If students are not committed to the task, trust cannot exist. The building of relationships, rapport, and cohesion between students and between tutor and students is essential for establishing successful groups. These relationships can be facilitated through icebreakers, regular tutor check-ins, assurance and group accountability.

Students need to be encouraged to reflect on their groups' requirements for success and how these conditions can be brought about. The idea of leadership and what it means within these online groups needs further investigation.

Students become better at online learning with more experience. However, group work is much easier to facilitate in-person, especially with first year students, as it is easier to counteract the five disfunctions and build social cohesion.

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Perspectives on Engineering Education Research in the UK: what is being done, why, and for whom?

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ABSTRACT

CONTEXT

Engineering education research (EER) continues to be an emerging field of research in many parts of the world. Unlike other countries within Europe, the UK has a long history of EER, with effort focused on advancing a technological workforce during the post-war era. Despite this, there currently exists a lack of engagement in EER activity within the UK and it does not share the same level of prominence as other countries including the USA and Australia.

PURPOSE OR GOAL

In a UK context, there is a lack of information pertaining to: who identifies as an engineering education researcher or is involved in engineering education research; how they define engineering education as a field of research; who they consider their audience to be; and the factors that inform their research questions, methodologies and whom they choose to collaborate with.

APPROACH OR METHODOLOGY/METHODS

The research is based on the qualitative analysis of semi structured interviews with individuals who identify as engineering education researchers, and who are involved in EER within a UK context. Invitations to participate in the interviews were sent to members of the UK and Ireland Engineering Education Research Network (EERN). The interviews were transcribed, coded, and thematically analysed.

ACTUAL OR ANTICIPATED OUTCOMES

The findings suggest that UK EER is primarily conducted by intrinsically motivated teaching focused academics. Research questions tend to be of personal interest and focus on the participants' local context. It is uncommon for those involved in EER to collaborate, especially with colleagues external to their own institution, or with education researchers and social scientists. There is a preference for disseminating work at conferences as opposed to within journals and an acknowledgement that UK EER is not yet of the quality needed for either funding or publication in some journals. There is a distinct lack of professional development and informal mentoring opportunities, as well as funding, time and recognition for partaking in EER.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Our preliminary conclusion is that although EER is not yet considered to be a recognized research field within the UK, the perceived need for both an emerging research agenda, and a consensus in quality criteria. are indicative of a move toward the establishment of EER as a bone fide field of research. More investigation and utilisation of quantitative approaches are needed to enable us to reach fully evidenced conclusions and will form the next stage of our investigation.

KEYWORDS

Engineering education researchers, researcher identity, researcher agency, UK.

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Introduction

Previous work has highlighted a lack of clarity around the goals, identity, and status of Engineering Education Research (EER) (Jesiek, Newswander, and Borrego, 2009). There have been several publications which focus on EER within different contexts, including the U.S.A. (Froyd & Lohmann, 2014); Portugal (Sorby et al., 2014; van Hattum-Janssen et al., 2015); Ireland (Sorby et al., 2014); Australia and New Zealand (Godrey &Hadgraft, 2009); Europe (Bernhard, 2018); and within the Nordic Countries (Edström et al., 2016). Elsewhere, work has considered EER within a global context (Jesiek et al., 2010a; 2010b; Streveler, & Smith, 2010) and compared approaches taken by researchers in different locations (Borrego & Bernhard, 2011). These studies highlight the relative lack of EER within the UK.

EER in the UK stretches back to the end of WWII (Bosworth, 1963; 1966; Heywood, 1969; 1970; Heywood & Monk, 1977; Ministry of Education, 1945; 1956). Despite this long history, more recent studies have found that UK academics dedicate little time to EER; the field is marked by low levels of publication, and a lack of resources and financial support (Shawcross & Ridgman, 2013). A later study, which focused on research conducted within the UK between 2000 and 2017, showed that most of the published work was single authored, or from single institutions (Nyamapfene & Williams, 2017). These studies highlight a lack of consistency in research questions addressed. However, neither of these studies provide qualitative information pertaining to engineering education researcher identity, and factors informing research questions, collaboration, and dissemination.

Focussing on a UK context, this work-in-progress study set out to investigate who identifies as an engineering education researcher or is involved in EER; how they define EER as a field of research; who they consider their audience to be; and the factors that inform research questions, methodologies and whom they choose to collaborate with. The study follows the approach taken by Borrego and Bernhard (2011), which focuses on answering the w-questions (what, why, to what end, where and who) of education. It is hoped that, in light of the "persistent state of déjà vu" (Wisnioski, 2015, p. 244) experienced by engineering educators, that this study will help reveal factors needed to support the development of UK EER and inform conversations about its future.

Methodology

This study aims to provide a snapshot of the state of EER in the UK. The nature of the research question necessitated the use of a purposeful sampling approach to identify those involved in EER in the UK. A call for participants was distributed via the UK & Ireland Engineering Education Research Network mailing list. The authors also sent emails to colleagues within their own institutions. Email recipients were asked to identify as "an engineering education researcher or (be) involved in engineering education research". Eleven individuals initially consented to participate. Through a snowball sampling approach, a further three were recruited. Participants came from eleven different universities with eight having previously worked in industry. Further participant information is given in Table 1.

Table 1: Participant information

	Engineering/STEM	Non engineering/STEM	Total
Teaching Specialist	9	1	10
Research & Teaching (Traditional Academic)	3		3
PhD (Engineering Education)	1		1

A semi-structured interview protocol was developed to encourage a conversation about topics including: participants' career path, job role and motivations for taking part in EER; the factors that informed their research questions, methodologies and choice of collaborators; the means by which their research was disseminated; the ways in which their work was

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recognized and rewarded; and the extent to which they engaged in EER conferences, networking and professional development opportunities. The research methodology was approved by the Swansea University College of Engineering Ethics Committee.

Interviews lasted between 45 and 60 minutes and were conducted, recorded, and transcribed by the authors. The researchers met following their initial interviews to adjust the interview protocol. The transcripts were sent to the participants for approval before analysis. A thematic analysis (Braun & Clarke, 2006) was undertaken with an initially inductive and semantic approach taken to identify themes. The researchers coded the data independently, and then compared themes and sub-themes. The transcripts were re-read and re-coded following agreed theme identification. Both authors agreed that the data obtained during the final interviews did not lead to identification of any significant new themes.

Findings

Who is doing Engineering Education Research and Why?

Ten of the participants interviewed were on a teaching pathway. This, despite the limited sample size, would suggest that these individuals make up a large proportion of those engaged in UK EER. One participant noted that it was not until "you are somebody designing and reassessing courses" that you consider EER. Another participant suggested that the narrow technical specialisation within UK engineering education meant that "people who are studying engineering are not then particularly interested in engineering education research". This is consistent with Figueiredo's view (2014, p.27) that "most of those who decide on the future of engineering education are already one-dimensional engineering scientists in a process of fast convergence towards self-perpetuation".

Conducting EER was generally intrinsically driven by a motivation to improve teaching. The majority of the ten teaching specialists described a preference for teaching, with one saying they had not wanted a role "heavily involved in research and with minimal teaching" Another said that EER is, "never going to become my full career because I really like teaching". The same was true of academics on a traditional academic pathway, as indicated by one such participant's claim that technical research was "not necessarily satisfying all the curiosity".

Three of the participants had moved from a traditional academic 'teaching and research' role to a 'teaching and scholarship' role. One claimed to have a "wider interest in research" which they described as "making solutions, improving things, making something better". They considered that this, alongside being "fascinated by education" and wanting to help in "supporting others to also learn and understand", was what drove their EER. These findings point toward participants taking an engineering-centric problem-solving approach to EER, which was then primarily viewed as a 'tool' for solving perceived problems in teaching.

These findings suggest that EER is primarily conducted to support teaching. This is consistent with previous research in which it was found that EER is viewed as a "teaching activity" as opposed to a "viable research area" (ASEE, 2009, 2012; Olds et al., 2012).

What is considered as Engineering Education Research?

EER was viewed as existing on a continuum which includes scholarship. One teaching specialist did not consider themselves a researcher because their work was "more about observation and action research around my own practice rather than saying I'm going to start out with a research question" and that their findings were instead "emergent from practice". This distinction was even less clear for some, with one teaching fellow saying that scholarship "can be reading journal papers… can be presenting at conferences… that could just be engaging with the literature". These findings suggest that the participants felt uncomfortable referring to their work as research, possibly because they viewed it as somewhat less rigorous than technical engineering research.

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What are considered as research questions and how are they informed?

Research questions were primarily focused on issues of personal interest. In general, research topics tended to focus on issues to which individuals were "really drawn to on a personal level", as stated by one of the participants.

There were perceived shortcomings in research questions that focused on local context. Research questions tended to focus on the local context, with typical research activity focused on teaching. One interviewee suggested that "the university expects it (EER) to be within the university at that level". This contrasted with the participant's desire to engage in wider research, "looking across the department or looking across universities".

There was a move toward asking wider research questions and creating a research agenda. One participant suggested that EER needed to focus on wider issues like "where engineering needs to move… what do we need to do to change the sector", with another participant suggesting that there needed to be an "ongoing conversation to refine and agree what our real benchmarks are". Another participant felt "emerging agendas are a good thing …people who could come together and identify their common interest". One teaching fellow believed this would "make it (EER) into something bigger than just the individual people doing that." The emerging shared belief in the need for a common research agenda to underpin the growth of UK EER is consistent with views of historian Michael Mahoney (2004), that a common research agenda can help foster disciplinary unity in emerging research fields.

How are skills in Engineering Education Research developed?

There was a lack of formal development opportunities for those engaged in EER. Participants thought EER was "different from the kind of research that they would do" and that "people don't really know how to go about it". They saw a "need to find a way to bridge this gap and help people in that scenario to actually have the skills, but also the confidence".

The difficulties faced during the transition to EER indicated a need for wider support. Those who had begun to develop such skills had varying experiences, with one educator saying that "it's quite hard to admit (you don't have the expertise) and work in a space where you're a complete beginner". Another, who had obtained an MSc in Research Methods said that having "come from the positivistic backgrounds…it really opened my eyes to how important the qualitative research was". This gap in knowledge was, according to one participant, worsened by early subject specialisation in the UK education system, with decisions to study engineering being made "at 18" when you "to some extent…stopped writing essays."

Some teaching specialists were unsure of their ability in EER with one saying, "I don't see myself as an engineering education research person because I'm not embedded in the social sciences enough" and another saying, "I just don't feel like I know the politics enough to be able to navigate the system to make the case for it". They questioned whether this was because they were on a teaching pathway and excluded from the Research Excellence Framework (REF), which is used to determine the allocation of "quality-related" government research funding within the UK. These findings suggest a need for wider support which focuses on identity development and increasing the confidence of those partaking in EER.

Academic development departments played a role in introducing participants to education research but there was desire for discipline focused training. Three interviewees spoke of obtaining a teaching qualification, with one saying it "got me more excited again about pedagogy". A different participant claimed that teaching support was "way too generalist… not very impactful" with another saying that it "didn't really go into any depth when it came to engineering specific education research… I don't think I even realized it even existed".

Who did participants work with and how were collaborations formed?

Collaborations were generally informal, with limited sustainability. Collaborations were predominantly formed between engineers who taught on the same programmes. One

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participant spoke of belonging to an institutional EER group but said “things change quite rapidly” and had “kind of gone back to the beginning” when a key member left.

The role played by education researchers varied across institutions. Working with social scientists and education researchers was considered a form of development for engineers. However, one participant said that their education department had “never been particularly interested in the overlap” with EER and another considered that the education department “train the schoolteachers” and that very few were involved in “proper research”. Participants had varying levels of engagement with internal education research networks, with one teaching specialist saying that they “don't necessarily feel invited” and that collaboration relies on “individual relationships” and ‘luck’. However, another participant, who had co-founded an institution wide education network, claimed it is “valuable because it means we're bringing together people who have different perspectives and different expertise”.

There was some evidence of an increasing effort to engage in external collaboration. Those with external collaborators were either senior research professors, or those who had transitioned from industry and had “kept those contacts going”. It was less common for participants on a teaching pathway to collaborate externally, with one interviewee saying that they had “spent two years finding my feet and teaching” and that they needed to “go and do a bit more networking”, and another that they “just don't feel like I have the external contacts or the time to develop them”. A different interviewee described finding collaborators by looking “for more teaching fellow type people” on “the staff pages” of other universities.

Where do participants share their work and access networking opportunities?

Conferences were viewed as opportunities to receive feedback from like-minded people. Participants viewed conferences as an opportunity to meet “networks of likeminded people”, and, to a lesser extent, to facilitate collaboration. Almost all of those interviewed valued the annual conference held by the UK and Ireland Engineering Education Research Network (EERN) with one saying “it's very friendly, it's really small. It feels very supportive.” This seemed particularly important for those who lacked support in EER in their own institutions. The opportunity to “get feedback” was reiterated by several participants, with one teaching specialist indicating that they were “craving that interaction and discussion…that feedback”. Participants also felt that conferences were more accessible than journal publication as, in the words of one interviewee, “you don't have to jump through the same hoops,” as publishing, with another saying, “it's less daunting … and less daunting in terms of time”.

Desire to grow the EER community was considered to lead to a compromise in research quality. Some interviewees acknowledged that “we want the community to grow” and that “almost anything is accepted”. This was seen to result in “very little cohesion or consistency or themes that allow you to dig into any depth”. It was also considered that there was “too much I made this change to my module, and this happened”, and “a lot of scholarship”. Interviewees were also critical of the more general higher education conferences and symposiums, with one individual stating that they “ended up talking about the paper in a room with three people” and considered it “ridiculous. It was pointless…so I published a paper that's been lightly peer reviewed to speak to three people. I'm not doing that again”.

There was considered to be a lack of information about which conferences to attend. Several participants said that they did not know which conferences to attend, with one saying that they “just picked one that seemed to have a theme that looks interesting or relevant” and another saying, “it’s a bit random.” One interviewee questioned “who am I supposed to find out from, where’s the list of conferences that are acceptable or not”.

Where is Engineering Education Research being published?

Few of the participants had experience of publishing their work, with the barriers seemingly being associated with their roles as teaching specialists. Perceived barriers to publication included a lack of time to conduct and publish research and high teaching workloads, with one interviewee saying that “the people who are often well placed are those of us that are on

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teaching focused pathways… are quite time poor when it comes to do this kind of work, because… you have a huge teaching load". One participant said that they were "rubbish at writing my research and publishing it" and another that they had "lots and lots of part written papers". In some cases, this appeared to be associated with a lack of confidence, with one participant saying that they did "not feel very competent about" the use of "language". One participant, who was a senior research professor, acknowledged that those mainly involved in EER were teaching specialists, some of whom had "never done research". This was viewed as a potential obstacle to publication as they may not "understand what world leading means…don't understand what the world stage is" and "don't read widely enough".

Some participants highlighted the variation in journal standards and criteria. From the participants' perspective, the two main journals for EER publication were the Journal for Engineering Education (JEE), and the European Journal for Engineering Education (EJEE). Of the two, participants felt that the JEE was the more difficult to publish in, with one interviewee suggesting that that whilst the JEE was "the place that they (the university) would look on", publishing in it would be like "taking on a bit of a Goliath". This was considered implicit from the relatively small number of "papers from Europe they publish" and was put down to the fact that UK EER studies were typically either qualitative or were based on small sample sizes, with one interviewee saying that the UK and USA had "very different perspectives on what we're expecting from research". Another participant instead suggested that "one of the key places that perhaps at the moment most of us should be publishing is the EJEE." However, they added that whilst they had presented at SEFI conferences that has "a very mixed track record with getting things into the journal".

What is considered as 'quality' Engineering Education Research?

Those who had experience of research in other disciplines saw a need for high quality EER. Where to publish EER was linked with conversations about criteria for quality. It was noticeable that the majority of those who spoke critically about the quality of EER were those with successful research careers. One professor who had "sat on four research assessment panels" and had reviewed EER articles, considered it "the brutal reality" that "nobody in the education REF panel will take the slightest notice of EER because they don't think it's sociologically valid…nor is it going to be believed by the engineering panels, because they think it is copping out because it's not quantitative enough and it's not hard enough". In contrast, a teaching specialist said "you can do the smart things, but unless you read a lot of literature to say why you're doing it, you're not allowed to publish based on common sense".

Who is Engineering Education Research considered to be for?

There was a perceived mismatch between the intended target for EER and the current mediums for EER dissemination. Some participants felt that their target audience were fellow engineering education practitioners. However, there was a general feeling that they were "not talking to those people", partly because this target audience did not read the targeted EER journals or attend EER conferences. One participant commented that they "have no expectation that anyone will ever read" the papers published in highly technical journals, and it would be "a retrograde step to start worrying too much about only writing for the big journals." Another participant observed that the way in which EER was written and the use of "sociology language" can put "your target audience (here considered to be engineering educators) off", saying that it "comes in how you write it". Such findings support Jesiek et al. (2009) who questioned whether the development of EER was consistent with the promotion of practical interventions or if researchers risked isolating themselves from practice.

Who is funding Engineering Education Research?

Lack of funding for EER was considered to limit research quality. The ability to publish in "the big journals" was linked to securing funding for EER. One interviewee suggested that "we need to show that we've got research credentials to be able to get the stuff we need." Another participant agreed with this sentiment, saying that "it's kind of a bit chicken and egg."

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One participant believed there was “a lot of expectations from the funding bodies, that the institutions should be funding this work and the institutions say like go and find your own funding'”. They described this as “an impossible situation”. One participant believed that “unless you were kind of leading the field...it'd be a very hard sell”.

The EER community is not yet recognized within the Higher Education System. Although one participant thought that “it is helpful that there is a stream of teaching only people…because it means there is an identifiable community that needs funding”, another teaching specialist countered this view, saying those involved with EER “don't exist for the research councils”. Another expressed a lack of optimism in EER researchers' chances of securing research council funding, saying “the proposals just won't look very impressive alongside you know really rigorous studies that people want to do within their discipline”. Another interviewee said that “the educationalists want to ring fence” education research funding and that you would be “an outsider …in terms of terminology and track record”.

Funding opportunities were generally considered to be inconsistent and limited. One participant considered that “industry will support you…. so, if it's something to improve …improve the graduate quality, you tend to find the local industry are quite interested”. One interviewee who had been successful in obtaining some external funding attributed this to “fitting with the opportunity because that is where the funding was”. The Royal Academy of Engineering was considered as a potential source of funding but was understood to be a closed shop, having a “approved list of suppliers ... a small number of authors they go to as consultants to produce their reports, …they're buying the reliability of a known supplier”.

How is Engineering Education Research supported and recognized?

There was a perceived opportunity cost associated with partaking in EER for ‘traditional’ research and teaching academics. One academic queried "if you've got 40% of your time to work on research. Do you put that into engineering education research where the impact factor is going to be relatively low? Or do you put it into your disciplinary research, where you can get a higher impact factor and so will advance your career because you're going to get good metrics that are going to enable you to get promoted?”. One professor believed that “if you're looking for respect from all your colleagues, you're not going to get it if you go into education research”. It is notable that all the participants who showed least concern about the value of education research were all professors who were well established within their fields of technical research. Similar findings were discussed in the context of Australian higher education, where early career researchers were claimed to be “more vulnerable” (Gardner & Willey, 2018) and the USA where it was suggested that some consider EER to be a “hobby” or “as a side activity”, conducted “later in [one's] career” (Jesiek et al., 2009).

There was a perceived disparity in recognition for teaching focused staff. One teaching specialist described a “real disparity” between teaching and research staff because “you can't get promoted without doing this work (EER), but you're not being given time… you have to be able to commit more than you're contracted.” Another perceived disparity was that traditional academics were likely to “have a pot of money”, which allowed them to share work externally and via open access. This meant that “somebody who's able to publish something open access is likely to get more citations... than people who are prevented from doing that.”

*The level of institutional support for EER was perceived to be variable and inadequate. S*everal participants alluded to support being dependent upon chance, with one saying that they were “quite lucky” to have a line manager who supported their involvement in EER. In comparison, another said, “my line manager is not interested in the teaching” and had refused to fund their EER research. One teaching specialist said that EER is "not supported or resourced” but was “tolerated”, whilst another believed that their institution supported EER “on paper” and that “whether the resources, the time, the processes are well designed for scholarship…that's another matter”. This lack of institutional support was perceived to be due to the belief that the “institution doesn't understand what it means by scholarship.” A recognized effect of EER being a developing field was that “we're all just on our own”. There was a lack of mentors, one participant claiming that “this is one of the most frustrating things and I just don't feel like I have any one more senior to rely on or call on for support. “

Conclusions

This work-in-progress study highlights multiple factors that are needed to support sustainable growth and development of UK EER. Our preliminary finding is that although EER is not yet considered a recognized research field within the UK, findings which highlight the perceived need for an emerging research agenda and a consensus in quality criteria indicate a move toward the establishment of EER as a bone fide field of research. This research has several implications for the development of EER within the UK. There is a need; to assess workload of teaching specialists in relation to promotion criteria and expectation for scholarship and EER; for sector wide discussions about the funding of EER; for the development of training opportunities for staff involved in EER; and for increased opportunities for collaboration.

The nature of the research question meant that this study only reflects the views of a small number of self-selected participants who “identify as engineering education researchers, or who consider themselves to be involved in EER”. The study is therefore subject to selection bias. The email invitation made it clear that “the growth of EER within the UK has been somewhat stifled” and that this study provided an opportunity to gather data which may “inform ways in which the growth of EER may be supported”. It may therefore be reasonable to propose that those who took part empathised with this message and wanted to contribute towards the growth of EER. It is possible that such participants would focus more heavily on negative aspects of EER within the UK, thus biasing results. Future work may benefit from a quantitative approach that includes a sample that is more representative of the EER community, as well as the audience of the research, researchers within humanities, social sciences or education or other stakeholder parties, for example, funding bodies and journal editors. It would also be of interest to explore the views of those from contexts in which EER is better established. Hence more investigation is needed to enable us to reach fully evidenced conclusions and will form the next stage of our investigation.

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Understanding Australian and United States Engineering Education Research (EER) contexts through the eyes of early-career EER researchers

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ABSTRACT

CONTEXT

Core to a successful international collaboration is the consideration and understanding of cultural and contextual differences. Although previous research has identified a range of challenges stemming from these elements, Engineering Education Research (EER) specific recommendations tend to focus on European-U.S. contextual differences. As the Australian EER landscape continues to expand, particularly for early-career researchers, it is important to broaden comparative EER efforts, particularly because international collaborations are increasingly an important consideration for career promotion indicators.

PURPOSE

This research focuses on how engineering education researchers familiar with both the Australian and U.S. contexts experience and undertake EER in both contexts. This research aims to provide greater insights into the similarity and differences of the systems EER operates within across the two countries.

METHODS

Semi-structured interviews were conducted with engineering education researchers at U.S. and Australian tertiary institutions to gather their perceptions of EER in both contexts. Interviewees were selected for having significant experience in both contexts and falling into early-career categories. An iterative process of thematic analysis was undertaken to analyse interview transcripts using open coding.

ACTUAL OR ANTICIPATED OUTCOMES

Interviews with early-career engineering education researchers illuminated the structural differences across contexts that ultimately impact and lead to differences in how EER functions in both contexts. These contextual differences are also impacted by sociocultural differences that influence how international collaboration does and does not work.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This work contributes to the literature that explores what is different about EER across contexts by pointing to why we may see these differences. It is imperative that we consider organizational and sociocultural contexts when exploring differences across EER contexts and capacities for collaboration.

KEYWORDS

Engineering education research, international collaboration

Introduction

Engineering Education Research (EER) is a growing field that is becoming increasingly connected around the globe through international collaborations. The benefits of collaborations in EER are well reported and include, for example, improving diversity of thought on projects, reducing the risk of "reinventing the wheel" by leveraging regional developments, increasing research quality, and increasing funding opportunities (Borrego & Bernhard, 2011; Borrego & Newswander, 2008; Xian & Madhavan, 2012). Of particular note, as contextual and cultural differences are fundamentally important in much of EER because of its roots in the humanities and social sciences (Beddoes, Jesiek, & Borrego, 2011), international collaborations offer an opportunity to consider these contextual differences so that different systems of education may learn from one another. Similar to the benefits, the challenges that need to be navigated while undertaking international research collaborations are also well reported in literature including factors like differences in disciplinary paradigm, language, reward structures, and cultures (Borrego & Bernhard, 2011; Hakala, 1998).

Familiarity and understanding of the contexts involved in an international collaboration has been suggested as key to success (Lucena et. al., 2008) with Borrego and Bernhard (2011) suggesting a need for EER practice, perspectives, and values to be bridged between international contexts. Previous research has suggested that scholars can gain this knowledge through implicit cues like reading literature situated in the chosen context or participating in domestic and international conferences likely to draw attendees from both contexts (Beddoes, Jesiek & Borrego, 2011). However, the former does not necessarily ensure contextual understanding can be achieved beyond basic awareness, and the latter is reliant on privileges not necessarily afforded to all researchers. Drawing on peer experiences may assist with understanding contexts and cultures; however, again may be limited to a privileged few when it comes to international research collaborations in EER.

There is a noticeable lack of specific manuscripts in the current literature discussing contextual and cultural factors of different EER contexts. Most papers reporting on EER contexts have historically focused on classifying and describing EER. These prior studies include descriptions of the research areas, research strategies and funding sources (Borrego & Bernhard, 2011; Berhnhard, 2018; Jesiek et al, 2008; Jesiek et al, 2009; Osorio, 2005; Wankat, 2011; Xian & Madhavan, 2014) as well as methodologies, methods, and contributions (Borrego, 2007). These descriptions typically have arisen from a form of documentary analysis of publications from key conferences and journals (e.g., American Society for Engineering Education Annual Conference and Journal of Engineering Education, respectively) (Borrego, 2007; Jesiek et al, 2008; Jesiek et al, 2009; Xian & Madhavan, 2014), and have also included conceptual papers (Berhnhard, 2018; Borrego & Bernhard, 2011). The perspectives of researchers themselves with respect to how they experience and understand different EER contexts are lacking in the current literature. This lens is significant as it provides insights of the experiential difference between contexts in a practical sense that can be useful in understanding factors important to consider in successful collaborations. Regionality has been acknowledged in literature in comparisons of the United Kingdom, Australia, and India (Jesiek et al, 2009), the United States and Europe (Borrego & Bernhard, 2011) as well as globally (Jesiek et al, 2008). To the extent of the authors' knowledge, no research compares Australian and United States contexts for EER, despite studies noting Australia has a strong tradition of publishing EER internationally (Jesiek et al, 2008; Jesiek et al, 2009) and the engineering education systems being noted as sharing many similarities (Borrego and Bernhard, 2011; Grenquist & Hadgraft, 2013; Patil and Codner, 2007; Prados, Peterson and Lattuca 2005) that potentially sets the stage nicely for opportunities for potential collaborations.

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Purpose and Research Questions

The perspectives of engineering education researchers on how they experience and understand an EER context different to the one in which they are trained is currently missing from the literature. There is also a current gap in literature comparing the United States and Australia EER contexts from the perspectives of researchers in the field. Our research explores engineering education researchers' comparative understanding and experiences of the U.S. and Australian EER contexts. To that end we ask the research questions:

1. How do early-career researchers, who had significant research experiences in Australia and the United States, perceive differences in EER between Australia and the United States?
2. What are the opportunities and challenges of collaborating in EER across Australia and the United States?

Methods

We conducted semi-structured interviews with three early-career engineering education researchers who have experience conducting EER in both Australia and the United States. Qualitative research methods, such as interviews in the case of our study, allow for the exploration of social phenomena from the perspective of those who experience them (Miles, Huberman, and Saldana, 2014).

Sample

The data discussed in this paper are from a subset of a larger qualitative study. The larger study includes interviews with participants at a variety of levels along the professional pathway (i.e., early-career professionals as well as those who have received academic promotions within the field). This paper discusses findings from three early-career participants. We selected early-career participants because of a commonality of the external influences that early-career academics face, such as key performance indicators and success metrics associated with gaining tenure and rank based promotions. Future publications will analyse data from professionals further along in their careers.

To meet selection criteria, participants must have had significant experience conducting EER in the United States and Australia. Given the unique requirements for participants, we implemented purposive and snowball sampling to identify participants. Because of the small sample size and the small nature of the communities under investigation, we do not offer pseudonyms or participant IDs to protect participant anonymity and instead offer the following collective positionality of our participants.

At the time interviews were conducted the three participants in this study were early career professionals. Each participant received formal training in a traditional engineering discipline, both inside and outside of the United States (but not in Australia), prior to receiving formal training in engineering education in the United States. During each participant’s training they experienced EER in Australia. Participants have had a variety of experiences in the Australian context including conducting research, attending conferences, working, and living in Australia.

Data Analysis

We used thematic analysis to synthesize and interpret data, a method for systematically identifying themes across a set of data (Braun and Clarke, 2012). We followed Braun and Clarke’s (2012) six-phase approach to thematic analysis. In Phase 1 we familiarised ourselves with the data by reading through transcripts. In Phase 2, we identified an initial set of codes. Open coding allowed for the data to drive our analysis as opposed to imposing a framework or theory onto our data. Initial codes were then reviewed and revised in an iterative process. Phases 3 and 4 involved identifying and reviewing patterns or themes across the codes we identified. Phase 5 brought about the finalizing of our identified themes. Lastly, Braun and Clarke (2012) advise that phase 6 include producing a report, such as this one, where we address our research questions and order the themes in a way that connects logically and meaningfully.

Positionality

The research team for this study consists of four scholars, three of whom are from the United States and one from Australia. Two authors are Ph.D. candidates in Engineering Education at a U.S. institution where they are receiving formal training within the engineering education field, one is a PhD candidate in Engineering at an Australian institution working on an engineering education dissertation and receiving training in social sciences and humanities, and one is an Associate Professor in Engineering Education at a U.S. institution who earlier in his career worked at an Australian university. Particularly relevant to this paper, three of the authors are early-career researchers who have been navigating international collaboration. The senior academic on the team helped ensure interpretations summarised in this paper were based on collected data instead of the team's own experiences navigating early career research collaborations. This research was enabled by a grant from the U.S.-based National Science Foundation that allowed researchers to compare EER and systems of education between the U.S. and Australian contexts.

Limitations

The interviews in this study were conducted by U.S.-based researchers, meaning that no one with an Australian perspective conducted interviews. Further, the snowball sampling approach taken in this study can lead to a biased sample. Finally, this paper only represents pilot work with a limited sample size, so theoretical saturation was not reached. Future work will include a larger sample size.

Results and Discussion

The major influences on EER in both the United States and Australia, as illuminated by our research, are university structures as well as funding sources. These structural components impacted and informed the function of EER in both contexts. We also found that the structural components interplay with the cultural dynamics within each context to inform different functions within the EER environment, such as collaborations. Although opportunities to collaborate between contexts exist, they do not come without challenges.

Structure and Function of EER

Structurally, participants noted the influence of funding and university structures on their research. Participants noted differences in the institutional roles that engineering education researchers hold in each context. In the U.S. context, engineering education departments or centers were commonly mentioned as a collective base for engineering education researchers. Participants also noted engineering education specific graduate training programs in the U.S. context as an entry point into EER. On the other hand, participants noted that established academics in the Australian context come to EER out of interest from a technical engineering discipline, often concurrently undertaking research in said technical discipline. One participant noted awareness of a PhD student undertaking an engineering education project in the Australian context noting the difference to the U.S. context:

> *We did have one PhD that graduated but she was a civil engineer and her dissertation was in engineering education. So, she basically says that she has a PhD in engineering education because there [in Australia], your PhD is your dissertation. But in order for a model like ours to be successful there, we need to have the resources and we need to have ... You need to be recognized as a field… I think for them, the model of having one expert in a traditional department works very well.*

Participants spoke of engineering education researchers being housed in technical engineering departments in the Australian context and the challenges of lacking a community of support:

> *I do think that engineering education can be successful in a distributed model. I think it would be helpful, though. So, my experience in Australia as being the only engineering education researcher that I knew at the university was pretty lonely … But I don't think that being the only one at [Australian University] is sustainable, because after a certain point, I was like, "No one here understands what I'm doing. I can't connect with the grad students because they're all civil engineers, and they're not interested in my research. I don't have any research community."*

In summary, participants noted that EER was structured and housed within engineering schools differently between contexts. In the United States, EER was described as its own department with dedicated graduate programs and academics whose research portfolio focused on EER. Comparatively, in Australia, EER was described as undertaken from within technical engineering departments, typically by academics trained in a technical field that maintain concurrent research in their technical field of interest. Participants also discussed possibilities of undertaking graduate research in EER in Australia. While these experiences parallel the authors' observations, continued research is needed to further understand these realities.

One participant speculated that the propensity for EER departments in the U.S. context may be driven by the availability of EER research funding:

> *I think it would be hard to support a department if there's not research funding, like a research-based department, if there's not research money available. So, I think that's a huge contributing factor, not just in Australia, but in most other countries outside the U.S. Because from what I can tell, most places don't have anywhere near the amount of funding that we have in the U.S., so I think that's why we haven't seen a lot of engineering ed departments showing up at other places. Some places have the centers which are often supported by the university, but I don't know of a lot of other engineering education specific departments elsewhere.*

Further, participants contrasted the recent challenges in obtaining research funding in the Australian context with the relative availability of funding in the U.S. context. Having consistent funding sources via the U.S.-based National Science Foundation is a fundamental differentiator between the two research communities.

> *When I went for my postdoc [in Australia], they had that Office of Learning and Teaching, OLT.... But now that that funding isn't available anymore, in my last position, it was hard to identify where to get funding, how to get funding, because it wasn't like the [NSF] equivalent in the Engineering education sense. They did have the CSRO grants, that's [a] different type of thread of research, engineering research.*

> *I think it comes down to the resources that maintain the system. I think our [U.S.] model works very well for many reasons. One is obviously money. We receive funding from NSF or all other places. So we can have a department that can offer scholarships, we can afford grad students and the grad students have the main resource that we have and that they are the ones that keep these department going and our research on top of things. That's the true. I think that will be very difficult to implement in Australia.*

Participants observed that the differences in structure informed the function of EER in their environment by encouraging them to focus more on teaching related research topics.

> *But I think being in a traditional engineering department [in the Australian context as opposed to a stand-alone Engineering Education department in the US context] did force me to focus more on the, how do we actually teach and learn engineering a little bit more and think about what is necessary as an instructor, what type of things would an actual instructor of these traditional engineering courses wants to know, and what would they be willing to try?*

This primary focus on teaching related EER in the Australian context, unlike the U.S. context, was also evident in participants' reflections on structural incentives for undertaking research.

Participants reflected on being able to connect EER activities to improving teaching and learning practice as being more important in the Australian context than more traditional research metrics for academic career progression, such as number of research publications. Thus, the structural incentives to publish and obtain funding for EER are different in each context:

> *There is not that pressure around getting money or even publishing [in Australia]. I think it's more important for you to do important things and meaningful things that you can translate back into a classroom. I think that's a huge deal.*

Participants also noted differences in the logistics of the university environment between the two contexts. For example, one participant noted the challenges in learning "the infrastructure of the institution," including "basics" like ethics approval processes.

Participants pointed to direct differences in the way that EER is structured in both contexts and identified ways in which those structural differences result in differences in how EER functions in both contexts, and vice versa. Many of these structural and functional differences can also be linked to cultural differences and how that, in turn, impacts opportunities for collaboration across borders.

Culture and Collaborations

Participants discussed a number of cultural differences that they noticed as they moved between contexts, and we found that these cultural differences also interacted with the structure and function of EER and opportunities for collaboration across contexts. One participant noted the importance of inclusion and diversity to their work in the United States and reflected on cultural differences in how inclusion and diversity were treated in Australia:

> *The second challenge, changing context was that [in the U.S.] I really spend a lot of time educating myself about inclusion and diversity [..] [It is] part of my research, part of my identity. Arriving [in Australia] and seeing that they don't care about those things was really difficult. I even joined a committee for inclusion and diversity and the whole thing was like, how can we bring more women? Wait, what? And that was entire conversation. The first survey that I did, [...] they came back and say, no, no, no. You don't ask these questions [about race]. So that was a challenge because it was part of my research. I wanted to understand those things and it was really complicated. So that part was a challenge.*

Similarly, another participant noted that although both populations focus on student attendance, the root causes for the questions being asked are different between contexts:

> *We complain about attendance, but they have a completely different attendance questions because they have students who are trying to deal with public transportation and work. A lot of their students are working full-time or part-time far more than our students are, so it's just different contexts to figure out and then understand what are the important research questions in that context because they're not the same, necessarily, as the ones we focus on.*

Structural, functional, and cultural differences, including differences in terminology (e.g., "placements" in Australia versus "internships or co-op" in the United States, as noted by one participant) can make it a bit challenging for collaboration or finding common ground across contexts. For example, researchers in the U.S. and Australian contexts often have a different knowledge base and entry into engineering education, which can make it harder to find shared language. As one participant said:

> *I think the hardest thing was figuring out how to communicate with people who weren't engineering education people. And, honestly, that just involved becoming more confident in myself. I'm so used to having a discussion about, what research questions do we want to pursue, and I would ask, "So, what research questions are you interested in?" And they would just look at me like, "Well, you're supposed to tell us. You're the engineering education expert." So, yeah, there was a different expectation in terms of what my role was on a project.*

However, differences in funding structures or terminology do not mean collaboration is impossible. A number of opportunities for collaboration were identified by participants. First,

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they found opportunities for improving teaching and learning noting that teaching interventions were easier to implement in the Australian context:

> *I think there are opportunities for collaboration that we need to take advantage of in terms of teaching intervention because of the flexibility that we have to implement things really fast. It's really easy to revamp an entire course and it is really easy to implement whatever you think would be effective.*

Leveraging topics with structures in place to support related efforts is one way that participants thought to make collaboration feasible. Next, participants also saw opportunities to collect data across countries to conduct research on more diverse data sets:

> *Well, I think the biggest thing would be to be able to collect data on a big scale for multiple countries. Right? So, the problem with a lot of our research is that it is all U.S. based, and like I said, our universities are structured differently. Our curriculum looks different because we have more liberal arts stuff built in, even though we all complain about how we're cutting liberal arts stuff, Australia has even less, and other places are similar. Some places are similar to Australia, some places are maybe more similar to us, but I think they can't just take everything that we find in our studies if we do them all in the U.S. and apply them in Australia or other contexts where their system just looks very different.*

Here the participant points out the value of collecting data across borders to not only garner more information between contexts but also further validate findings.

While the cultural differences identified are interesting to note, further research is necessary to understand the root causes of these differences and how they have manifested within the structure and function of EER. For example, researchers can explore the process of legitimization of EER between both contexts (i.e., what is the legitimacy in facilitating EER or what is considered legitimate EER).

Conclusion and Implications

Our results indicate the importance of considering organizational and sociocultural contexts when exploring and making meaning of differences in national EER environments. Existing work often focuses on differences in research methods and topics between national contexts, but because EER is an applied field embedded within organizations and a larger sociocultural context, these critical contextual factors cannot be ignored. Contextual factors can significantly influence what is considered valid work, how researchers go about doing that work, and with whom. This study aims to add to prior research which has answered *what* is different about EER by context by illuminating some of the fundamental reasons *why* we may see differences in topics and methods.

This work points to the need to think more about context. Beyond understanding why EER varies by context, considering organizational and sociocultural context in other aspects of EER may help us understand why we have not seen the change that we have sought in engineering education. Further, this work speaks to the importance of funding international opportunities for engineering education researchers, which can build collaboration capacity and prompt researchers to recognize how organizations and sociocultural contexts influence all aspects of their work.

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Defining Academic Engineering Education Roles within the United States

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ABSTRACT

CONTEXT

Engineering education is an interdisciplinary research field where scholars are commonly embedded within the context they study. Engineering Education Scholars (EES), individuals who define themselves by having expertise associated with both engineering education research and practice, inhabit an array of academic positions, depending on their priorities, interests, and desired impact. These positions include, but are not limited to, traditional tenure-track faculty positions, professional teaching or research positions, and positions within teaching and learning centers or other centers. EES also work in diverse institutional contexts, including engineering disciplinary departments, first-year programs, and engineering education departments, which further vary their roles.

PURPOSE OR GOAL

The purpose of this preliminary research study is to better understand the roles and responsibilities of early-career EES. This knowledge will enable PhD programs to better prepare engineering education graduates to more intentionally seek positions, which is especially important given the growing number of engineering education PhD programs. We address our purpose by exploring the following research question: How can we describe the diversity of academic or faculty roles early-career EES undertake?

APPROACH OR METHODOLOGY/METHODS

We implemented an explanatory sequential mixed-methods study starting with a survey (n=59) to better understand the strategic actions of United States-based early-career EES. We used a clustering technique to identify clusters of participants based on these actions (e.g., teaching focused priorities, research goals). We subsequently recruited 14 survey participants, representing each of the main clusters, to participate in semi-structured interviews. Through the interviews, we sought to gain a more nuanced understanding of each participant's actions in the contexts of their roles and responsibilities. We analyzed each interview transcript to develop memos providing an overview of each early-career EES role description and then used a cross case analysis where the unit of analysis was a cluster.

ACTUAL OUTCOMES

Five main clusters were identified through our analysis, with three representing primarily research-focused day-to-day responsibilities and two representing primarily teaching-focused day-to-day responsibilities. The difference between the clusters was influenced by the institutional context and the areas in which EES selected to focus their roles and responsibilities. These results add to our understanding of how early-career EES enact their roles within different institutional contexts and positions.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This work can be used by graduate programs around the world to better prepare their engineering education graduates for obtaining positions that align with their goals and interests. Further, we expect this work to provide insight to institutions so that they can provide the support and resources to enable EES to reach their desired impact within their positions.

KEYWORDS

Engineering Education Scholars, Career pathways, Mixed methods research, Higher education

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Motivation

Over the last few decades, engineering education research has gained academic recognition (Froyd and Lohmann, 2014). This development can largely be attributed to the community's 'pioneers,' or the first faculty members to bring to the forefront the possibility of an academic position within engineering education research. These individuals are recognized as significant contributors to (or shapers) of the field (Atman, Turns, & Yasuhara, 2021) specifically one that explores ways to develop, understand, support and engage engineers of all backgrounds and levels of education. Ultimately, recognition of engineering education as a viable academic career path led to the creation of programs and departments with a focus in this area (Benson et al., 2010).

Graduate students pursuing PhDs in engineering education now have a variety of career paths they can follow. Examples can include teaching or research focused positions at institutions of varying research intensities (high research intensity to primarily teaching institutions) alongside staff based positions (McCave et al., 2020). However, many students lack clarity on the types of roles and responsibilities that exist within engineering education academic positions and how to select the position that would be the best fit for them personally. Similarly, though academic institutions are aware of the value that an engineering education researcher can bring to a department or program (Benson et al., 2010), they lack clarity on how to support Engineering Education Scholars (EES), individuals who have expertise in both engineering education research and practice, and what resources EES need to have their desired impact (Coso Strong et al., 2021).

For these reasons, it is important to study how EES define their roles and responsibilities and how these definitions may extend beyond the boundaries of the specified job description. This knowledge will enable programs to better prepare engineering education graduates to more intentionally seek positions, which is especially important given the growing number of PhD programs being established that graduate EES. We address this goal by exploring the following research question in our preliminary research study: How can we describe the diversity of academic or faculty roles early-career EES undertake?

Background

Faculty roles typically encompass a distribution of responsibilities between teaching, research, and service. Despite these defined "buckets," faculty define their roles depending on their professional and personal goals (Kuntz, 2012; Reybold and Alamia, 2008). Modifying job roles and responsibilities to achieve intended desires and goals from a position is not unique to academic environments and is known as "job crafting" in the organizational behavior literature. Berg, Dutton, and Wrzesniewski (2008) found that individuals who modify their positions through job crafting do so in three distinct ways: 1) altering the boundaries of their jobs, 2) changing the relationships they have at work, and 3) altering how they perceive the tasks that are associated with their position. Reybold and Alamia (2008) found that female faculty members who are focused upon their own professional advancement tend to specifically align their roles and responsibilities with what is needed to help them advance in their career. Although, as female faculty progressed further in their career and grew broader awareness of the expectations associated with an academic position, they could feel less need to meet others' expectations. For this reason, it is possible for two individuals in the same position to perform very different tasks depending on their specific goals. This research also supports why prior literature has shown that how individuals describe their roles and responsibilities may not align with their job description (Wrzesniewski and Dutton, 2001).

Methods

To understand how U.S.-based early-career EES describe their roles and responsibilities, we implemented an explanatory sequential mixed-methods research study with equal weight

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provided to the quantitative and qualitative strands of data (Creswell and Plano Clark, 2011). We first collected survey responses (n=59) that were analyzed using hierarchical cluster analysis to identify groups of EES who take similar actions in their roles. We then conducted semi-structured interviews (n=14) with two to four early-career EES from each main cluster to further distinguish the clusters and understand the nuances associated with how individuals define their roles and responsibilities. Our mixed-methods approach aligns with the recommendations of Wrzesniewski and Dutton (2001), who suggest that survey items alone cannot easily capture job crafting. To ensure reliability in the research findings, Walther et al. (2013)'s Q3 framework was applied throughout the qualitative data collection and analysis process.

Quantitative Data Collection and Analysis

We developed a survey instrument to capture the general day-to-day responsibilities of early-career EES through a qualitative analysis of reflection data collected from six early-career EES (Smith-Orr et al., 2019). The final survey focused on three key areas: 1) faculty impact, 2) strategic actions, and 3) influencers. For this study, we focused on the strategic action items (n=18)—i.e., intentional actions taken towards professional goals—because they provided the most detailed information about the actions EES take within their roles. These items prompted participants to report how often they participated in specific activities related to research, teaching, advising, service, and administration in an academic year. Each item was measured on a seven-point scale from never to more than once a week.

We initially sent the survey to 95 U.S. based early-career EES in October 2018. This list was generated based on publicly available data of engineering education PhD graduates, membership in American Society for Engineering Education (ASEE), and the faculty directories within engineering education centers and programs. We also distributed the survey through the ASEE Educational Research Methods (ERM) division listserv to mitigate selection bias in our initial sample identification. We received 53 responses (~56% response rate) alongside our 6 responses (total n=59). The demographics of the sample are summarized in Smith-Orr et al. (2019).

We used hierarchical cluster analysis to group participants based on their strategic actions. We selected hierarchical cluster analysis because it is a more exploratory clustering approach that does not require the researcher to predefine the number of expected clusters (Kaufman and Rousseeuw, 2005). We ran the cluster analysis both with and without data scaling; used Euclidean and Gower proximity matrices as they are recommended to be used with categorical data; and tested both Ward's and complete methods. The cluster analysis was run in R using the anges function for agglomerative nesting in the Cluster package (Maechler et al., 2021). Based on fit indices, we selected the agglomerative clustering solution that used non-scaled data, Gower proximity matrix, and Ward's cluster method.

The final clustering solution included eight distinct clusters that showed variability in a subset of strategic actions (refer to Table 1). To characterize the clusters we pulled the responses to each strategic action item for every participant and calculated an average score for each item. We also looked at the demographic information provided by the participants in each cluster to look for patterns among position types. We decided to focus our further investigation on five main clusters. The three clusters that were not included in further analysis were small (three individuals or less) and distinct in that they included participants who had been in the field longer than other participants or recently started new positions.

Table 1: Strategic Action Survey Items Showing Differences Across Clusters (where R= Research, T= Teaching, and S= Service)

Item	Item Text
R1	Conducting Engineering Education Research
R2	Creating or Maintaining Research-Practice Partnerships
R3	Writing Journal Articles, Conference Papers, Books, etc.
T1	Advising or Mentoring Undergraduate Students
T2	Advising or Mentoring Graduate Students
T3	Advising or Mentoring Post Graduate Fellows
T4	Creating or Modifying Curriculum
T5	Implementing New Pedagogical Strategies
T6	Designing Course Material
S1	Participating in or leading student programs (outreach, study abroad, service learning, etc.)
S2	Giving education-related advice to colleagues
S3	Discussing engineering education research with local colleagues

Qualitative Data Collection and Analysis

We recruited 14 survey participants to participate in semi-structured interviews. At least two EES from each cluster were recruited and we aimed to have a diverse sampling by race, gender, engineering education training, and current institution. Two researchers conducted the interviews. Multiple prompts were included in the interview, but for this preliminary study analysis was focused upon, “What are the responsibilities associated with this position?”.

Three researchers conducted the data analysis, developing memos for each participant that described the following categories: Role Description, Goals, Meaning Making, Strategic Actions, and Impact. To develop these memos, the researchers first coded the transcripts to identify words, phrases and paragraphs that aligned with each category. Three of the fourteen transcripts were coded by all three researchers. Each researcher was then assigned a category and was tasked with drafting that portion of the memo based on the coded transcripts of all three researchers. The researchers wrote the initial memo section based on their own coding of the transcripts and then went back and added additional codes or comments that were not accounted for from their own coding of the transcript. The researchers also highlighted any discrepancies seen across all three versions of the coded transcript. Meaning Making and Impact were written collectively by the three researchers to complete the preliminary memo for three participants. These three memos were then shared across the entire six-member research team for consensus and any questions or comments were discussed by the group.

Having established clarity around the codes and memo writing process, each researcher was assigned four of the remaining transcripts to serve as the primary coder and four as the secondary coder. Both researchers read and coded each transcript before coming together to reconcile overlap or differences in coding. The primary coder was then responsible for drafting the full memo, which was also reviewed by the secondary coder.

During the analysis portion, there were two transcripts that were removed from the sample: one due to the inaudibility of the audio recording and the other due to a change in positions between the survey and the interview.

Limitations

Given that the survey was based on the qualitative analysis of our own reflections on our roles within our institutions, we may have different interpretations of roles and responsibilities related to EES positions from survey respondents thus influencing the clusters that were

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derived. We also acknowledge that we are capturing self-report data on faculty members' perceptions of their actions and approach to their positions, which can be influenced by the time of the semester.

Results

Quantitative Results

Through our cluster analysis, we identified eight distinct clusters representing the different actions taken by early-career EES. However, as previously stated, we focused our analysis on five main clusters. Across the clusters, all participants reported frequently spending time teaching undergraduate and/or graduate students and completing general administrative tasks. All participants reported spending little time presenting research outside or within the institution, and contributing to national and international reports. Details about the differences between clusters can be found in Table 2, along with reference to their ratings on specific items from the survey (summarized in Table 3).

Table 2: Differences between clusters. (Descriptions of Institution Type - R1: Doctoral Universities – Highest research activity; R2: Doctoral Universities – Higher research activity; R3: Doctoral Universities – Moderate research activity; PTI - Primarily Teaching Institutions.)

Cluster	Position Track	Institution Type	Research Quantity	Teaching or Advising	Service or Administration
1	71% Tenure; 29% Non-tenure	86% R1; 14% R2	Significant amount	Primarily mentor grad students	Minimal curriculum involvement, provide EngEd advice to colleagues
2	All tenure	50% R1; 25% R2	Significant amount	Mentor grad students and postdocs	Minimal curriculum involvement, involved in supporting student programs
3	87% Tenure	67% R1; 6% R2; 27% R3	Significant amount	Mentor undergrad and grad students	Involved in curriculum initiatives, provide EngEd advice to colleagues
7	75% Tenure	25% R1 12.5% R2; 12.5% R3; 50% PTI	Minimal amount	Mentor undergrad students only	Significant curriculum involvement, some involvement supporting student groups, provide EngEd advice to colleagues
8	61% Tenure; 23% Non-tenure; 16% No tenure	23% R1; 15% R2; 23% R3; 39% PTI	Little to no research	Mentor undergrad students only	Some curriculum involvement, provide EngEd advice to colleagues

Table 3: Average Item Scores for Clusters (where 1 = Never and 7 = More than once a week)

Cluster # (Sample Size)	Research			Teaching or Advising						Service or Administration		
	R1	R2	R3	T1	T2	T3	T4	T5	T6	S1	S2	S3
Cluster 1 (n=7)	6.86	5.14	4.86	4.00	6.29	1.00	4.57	3.43	3.57	2.86	4.57	5.14
Cluster 2 (n=8)	6.00	4.75	4.50	4.00	6.38	4.13	3.75	3.75	3.50	4.50	3.75	3.63
Cluster 3 (n=15)	6.60	4.93	4.87	5.93	6.80	2.20	5.40	5.07	5.53	2.67	5.47	6.20
Cluster 4* (n=3)	7.00	7.00	7.00	5.33	5.67	2.20	5.67	6.00	6.00	4.00	6.33	6.67
Cluster 5* (n=2)	1.50	1.00	1.00	6.00	1.00	6.00	5.00	2.50	4.50	1.00	4.50	2.00
Cluster 6* (n=3)	5.67	5.67	3.00	2.33	2.00	1.00	2.67	2.33	2.00	2.67	3.67	3.00
Cluster 7 (n=8)	4.38	2.50	3.00	5.50	1.50	1.33	6.75	5.25	6.88	4.00	5.00	4.50
Cluster 8 (n=13)	5.77	3.69	3.23	5.17	2.08	1.08	4.31	4.38	5.15	2.92	4.23	4.38

*Indicates clusters that weren't considered as part of further analysis

Qualitative Results

Across clusters, participants discussed their position, roles, and responsibilities in terms of teaching, research, and service. Yet, how the interviewees within each cluster described what they did to fulfill these criteria differed. For clusters 1-3, EES focused primarily on research activities. The slight differences observed were based on the approaches they took towards their teaching, advising, and service roles and responsibilities. Whereas, EES within clusters 7 and 8 described roles that are more focused on teaching compared to research.

In cluster 1 (n=3), research EES activities were focused on writing grants, receiving grants, and fulfilling grant funding requirements through research activities, which included mentoring graduate and undergraduate students funded through these grants. In discussing service responsibilities, many of the EES within cluster 1 focused on graduate program development and service within their department, university, and field. One such area of service was in faculty development. One participant noted,

"*So individual faculty members that want to try something new in their class, having a couple of days in the summer where we can kind of run them through what that means, what that looks like, how they should collect data to know if it's working or not. And then kind of how to publish, you know, how to do it in a way that you could then potentially publish from that...*"

EES in cluster 1 mainly taught graduate-level courses, however one participant discussed how their teaching load could also include teaching large, first-year courses. They also reported teaching a maximum of two courses a semester, with variation being based upon other responsibilities. For example, one participant discussed their reduced teaching load,

"the standard load was gonna be two courses per semester. What a course was is something we always talk about here, the teaching first year, but we hadn't really worked that out at the grad level. So it was just gonna be two courses a year, and then for the first two years, I did have a 50% reduction. So it was one and one, but again, those were new courses that weren't developed."

EES interviewed from cluster 2 (n=2) discussed their teaching responsibilities more, including curriculum and course development being a larger portion of their positions and roles. While both participants talked about teaching a full load, the first described teaching three courses a year on a semester system and the second reported teaching six courses a year on the quarter system. This discrepancy between the number of courses taught a year highlights the fact that EES interpret full loads of teaching differently. Many of the courses EES in this cluster taught were focused on education, but could also include outreach and workshops related to the K-12 educational space. Both EES discussed that initially research was not the focus of their position and teaching took priority,

"*research work that is hard to fit in, especially those first couple of years when, like I mentioned, the teaching seemed to take more time*".

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When discussing research, their actions included obtaining research funding, conducting project work, and publishing the results. Both participants talked about mentoring and advising their research students, one specifically stating,

"*...as an advisor, you kind of work them through that whole process. Oftentimes they work for you if you have a project that funds them, and they work in conducting the research that you are funded to do. And also just kind of giving them hopefully professional development advice and, and direction toward their career.*"

Lastly, participants in cluster 2 discussed their service responsibilities, noting that much of their service was in departmental level committees focused on curriculum and then field-level service through reviewer functions.

Similar to faculty in both cluster 1 and 2, cluster 3 EES (n=3) focused their time on research activities such as grant writing, bringing in funding, publishing, advising graduate students and undergraduate researchers, and utilizing their summer for research activities. For example, one EES commented about the summer saying,

"*the rest of those two months are spent catching up on everything that I don't get done on campus… a lot of the research ends up getting pushed backwards towards the summer months.*"

While EES in cluster 3 are mainly focused on research, they also spend time teaching. Their teaching included graduate course development and mentoring student teams within classes. Multiple EES in cluster 3 noted they started their positions with a reduced teaching load while they focused on building a research program. Some continued with a reduced teaching load due to research funding. Lastly, EES in cluster 3 discussed their diverse service responsibilities, which included departmental, college, and university level service. More than one EES in the cluster described their departmental service as including graduate program service and search committees and their university service including a position as a program assistant director.

EES interviewed in cluster 7 (n=2) held teaching focused positions at primarily teaching institutions. While these EES did some research, their main responsibility was to teach. They teach full loads of 3-4 classes a semester. Along with teaching, cluster 7 EES spend a good amount of their time meeting with students and holding office hours. Beyond their teaching responsibilities, they have numerous service responsibilities that span departmental activities up to university level service. The breadth of the service they do depends on their position and the needs of their department, college, and university, however both of the EES noted that departmental service is where most of their service related activities occur. For example, one EES talked about their service related to student recruitment and advising within their small department,

"*since there's only two engineering faculty on my campus, I do a lot of the recruitment stuff, a lot of advising…*"

In cluster 8 (n=4), the EES interviewed were split across tenure-track and non-tenure track positions but all EES were in positions where teaching was their main responsibility. Many of these EES were teaching full loads and doing major curriculum development for the courses they taught. Two EES mentioned that they would teach a summer course periodically. Three EES in this cluster noted that they had negotiated a reduced teaching load due to administrative roles they had taken on. For this cluster, service was a large part of their positions either through administrative roles or departmental, college, or field-level responsibilities. For example, one EES describes their service responsibilities as,

"... work outside of our normal kind of responsibility. So the academy research council chair position I have is a service position. You know, I'm contributing to the academy in other ways. I'm an officer in charge of the [student organization]."

Some of the service responsibilities that EES talked about included search committees, student outreach and recruiting, student organization advising, and professional society positions. Many of the EES within cluster 8 discussed that they conducted some form of research, specifically in getting grants funded and managing multiple projects. Cluster 8 EES

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noted that they published their work at conferences rather than journals and needed to dedicate time in the summer to their research endeavors.

Conclusions

Our preliminary work has demonstrated that early-career EES undertake a variety of roles and responsibilities depending on their institutional context. As was identified in McCave et al. (2020), there are many types of jobs that EES can pursue, but how EES structure their work within these positions can vary depending on the resources and support they are provided (Coso Strong et al., 2021) and the institutional context.

Although clusters 1 through 3 could generally be described as research focused, the manner in which each of these EES described their positions varied. Cluster 1 was observed to be focused on graduate program and faculty development with teaching responsibilities most commonly at the graduate level. The high priority these EES put on research activities aligns with their positions being primarily situated in high research intensity institutions (R1). In contrast, EES from cluster 2 were more involved in curriculum development and teaching as it related to education within science and engineering as well as K-12 settings. The emphasis these EES placed on describing teaching elements associated with their positions, although in primarily research-based roles, is reflective of their positions representing a diversity of institutional contexts. Finally, cluster 3 EES commented on how research was a key focus of their positions but noted that it was not always possible to get all the work they would like done during the academic year due to their teaching responsibilities. It is possible that since cluster 3 EES represent a broader cross-section of research institutions than cluster 1, they are not provided with as much teaching load release to allow time to focus on research related efforts. Cluster 3 EES also noted that they spent time mentoring student teams within classes, which was not mentioned by EES in either of the other two clusters.

In contrast, EES from clusters 7 and 8 were found to have primarily teaching-based responsibilities. The difference in role focus may be related to their institutional context with no more than 25% of positions in either cluster being located at high research intensity institutions (R1). Cluster 7 EES described how they were heavily involved in departmental service activities including recruitment and retention. They were expected to conduct research although the time for doing so had to be worked around their other responsibilities. Cluster 8 differed from cluster 7 based on position types with a split between tenure and non-tenure track based roles. These EES noted how they occasionally take on summer teaching and administrative assignments to lighten their teaching load.

This preliminary study has shown that the reality of the roles and responsibilities of early-career EES in academic environments vary based on institutional context. The survey responses and follow-up interviews indicate that although positions may appear similar there are often key differences in roles due to institutional contexts and job crafting approaches that faculty members may take. The amount of job crafting an individual can undertake is often a factor of the interdependence of tasks and the freedom available to modify responsibilities (Wrzesniewski and Dutton, 2001). As such, the enactment of a role is influenced not only by an individual's goals but also the institutional context and ability to job craft. Future work will further explore how early-career EES make meaning in their positions based on their goals, desires, and intended impacts, which will help identify the way in which EES craft their roles differently than how their position is described.

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Institutionalizing Engineering Education Research: Comparing New Zealand and South Africa

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ABSTRACT

CONTEXT

Engineering Education Research (EER) is often written about as a global phenomenon, and yet it takes on quite different forms in various countries. In this study we are interested in the process of institutionalization, whereby a distinct identity and meaning of EER develops in a country and becomes embedded in organizational structures. We draw on neo-institutional theory to look at the broad relationships between national forces such as research funding and accreditation; university-level strategies such as PhD programs, centers and departments; and the emergence of scholarly associations, conferences and journals.

PURPOSE

This study builds on a previous comparative case study of EER in Australia, China and the USA and extends this work to look at New Zealand and South Africa, two national contexts that might be considered "peripheral" in terms of their size and global prominence in EER, but each of which have distinctive and energetic EER communities.

METHODS

Using a comparative case study approach, our study draws primarily on review articles that describe or analyze the field of EER in each country, supplemented by our engagement with expert informants. Analytically, using the process model of institutionalization, the cases are organized around (a) the prior structures and environments in which the organizational EER field emerges, (b) key events that create conditions for this development, (c) how political will and resources come to play, and (d) the emergent belief systems and identities.

OUTCOMES

Both South Africa and New Zealand show trajectories of institutionalization of EER that are strongly linked to institutional imperatives to improve engineering education teaching and curriculum. In the South African case, this is further promoted by an intense national imperative to transform the post-apartheid university system. While some SA researchers have accessed national research funding, this is not the most significant driver of the field. The respective regional contexts explain why NZ EER researchers align themselves with the Australasian body, AAEE, while the SA researchers have established their own structures.

CONCLUSIONS

This study offers further evidence of the very different forms through which EER is institutionalized in different national contexts. South Africa and New Zealand offer further exemplars of context where the main imperative for the field is focused on institutional reform of engineering education, rather than external research funding as has been seen in the USA.

KEYWORDS: Engineering Education Research, institutionalization, comparative case study

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Introduction

Over the past 30 years, Engineering Education Research (EER) as a field has developed as a distinctive domain, with a notable growth in recent years of departments and degree programs, publication outlets, research agendas, and meetings (Jesiek et al., 2009). While EER has advanced across the globe, there have been different trajectories of development in different national contexts. This paper builds on a previous paper which compared the institutionalization of EER in Australia, China and the U.S. The results of that prior study challenged the assumption that there is only one ideal form for the institutionalization of EER. In contrast, it showed that EER thrives in a symbiotic relationship with its host disciplines and institutions, in a broader context of national priorities and structure (Klassen et al., 2020) In this paper, we explore the different ways that EER has been institutionalized in two different countries, South Africa and New Zealand. We aim to determine how (and if) unique aspects of each country make the national fields of EER distinct.

Our study draws on existing literature, which we sourced by engaging with key informants in each national context. South Africa has a distinct history with regards to Higher Education and EER in terms of how the key elements of its history have shaped how the field looks today, particularly in relation to the transition from apartheid to the democratic dispensation. There is already a rich literature on EER in South Africa. New Zealand, on the other hand, has been much less studied and is usually considered together with Australia. Our study aimed to explore whether there was a distinctive New Zealand institutionalization of EER.

Prior studies looking at the development of EER as a field considered many aspects such as the formation of national scholarly groups, national-level strategies such as conferences that are held, university-level strategies like PhD programs and models and other factors such as accreditation and the availability of internal and external funding (Collier-Reed & Case, 2017; Crawford, 2016). Our study also explores a similarly wide range of factors but differs in its use of neo-institutional theory in order to understand the development of organizational structures in relation to wider social forces (Lounsbury & Yanfei Zhao, 2013).

Theoretical Framework: Neo-institutional theory

This study draws on the following definition of institutionalization: “A structure that has become institutionalized is one that has become taken for granted by members of a social group as efficacious and necessary” (Tolbert & Zucker, 1999). Neo-institutionalism explores how institutional structures, rules, norms, and cultures constrain the choices and actions of individuals when they are a part of an institution (Breuning & Ishiyama, 2014).

For this paper, we are interested in seeing how EER has been institutionalized in the South African and New Zealand contexts, viewed through two distinct units of analysis. The first unit is the EER organizational research units that are formed at universities and the second unit of analysis applies to the broader organizational field at a national level, which is a collection of the EER organizational research units and related support organizations. An organizational field is defined as a set of organizations sharing systems of common meanings and interacting more frequently among themselves than with actors from outside the field, thus constituting a recognized area of institutional life (Machado-da-Silva et al., 2006).

To further operationalize institutionalization we draw on the conceptual framework put forward by Zapp & Powell, (2016), who traced the institutionalisation of educational research in Germany, also over a 30-40 year period. Their model consists of four main elements: *Prior Structures & Environment, Innovation/ Shock and Idea, Political Will and Resources and Belief System and Identity*. This is not a prescriptive model, but rather, a set of theoretical concepts that help to build narratives of how institutionalisation is formed in different contexts.

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The four elements are described as follows:

- **Prior Structures & Environment:** Existing organizational actors (prior structures)
- **Innovation/shock & idea:** Key events (innovations or new policy ideas) which create contradictions in organizations' environments and thus lead to new opportunities
- **Political will & resources:** Key actors leverage existing resources to create new institutions or transform existing ones.
- **Belief System and Identity:** Often take the form of normative networks (e.g., professional associations) which shape organizational fields by creating a sense of meaning and identity for local actors

Methodology: Comparative Case Study

Our study is focused on the following research questions:

1. In what ways has the institutionalization of EER proceeded in the two different countries in the study?
2. How can we explain these different trajectories of institutionalization in the light of national contexts?

To answer these, we draw on tools from comparative case study methodology in particular the horizontal and transversal axes of comparison (Bartlett & Vavrus, (2014). The horizontal axis of comparison deals with how similar policies unfold in distinct locations (across the two countries for our study), and how they might be connected. The transversal axes studies across and through levels to explore how globalizing processes connect people and policies through different time scales (Bartlett & Vavrus, 2014).

Our data collection followed guidance for scoping studies (Levac et al., 2010) to locate articles that focused on the field of EER in each country. We searched leading EER journals for articles including New Zealand or South Africa, filtering for those focused on the structure of the national EER field, and also searched the conference proceedings for the two national EER societies. Papers focused on the wider field of EER, and its institutionalization, were hard to locate, so we used reference tracking and citation tracking to trace the few relevant papers we did find. In general, more literature was available for South Africa. Writing on EER in New Zealand is largely combined with EER in Australia so it was initially hard to tell a distinctive story for New Zealand.

We expanded our search by reaching out to key expert informants to help us obtain more information. Our author team includes a breadth of experience living, studying and researching engineering education in both countries. We used our personal networks and a review of EER society websites to reach out and speak to 3 informants in each country (6 total). We selected the informants based on (1) a track record of EER writing themselves, (2) active roles (past or present) in building the national field of EER, and (3) a balance of historical knowledge of field origins with an accurate picture of the current state of the field. We also sought a range of institutional perspectives, so each informant was from a different university. We used a semi-structured interview protocol to prompt the informants to talk about EER in their country, and also importantly to share relevant articles, books and conference papers on the topic that weren't captured by our scoping study. We constructed draft case reports for each country using our theoretical categories below and sent these to the informants for review. Below, we report on the two cases and conclude with a comparative analysis.

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Findings

South Africa

Prior Structures & Environment

Before the 1990s, the higher education system in South Africa looked very different to the way it does today. The apartheid system involved a highly unequal schooling system and racially segregated university provision (Collier-Reed & Case, 2017). The universities that served white students were far better resourced than those designated for others; in fact, the older established universities had all been designated as “whites-only” (Case et al., 2016). All except one of the eight universities and five of the twelve ‘technikons’ offering engineering qualifications were restricted in access for the white population (Case & Jawitz, 2003), even though they only constituted 10% of the population. Racialized patterns of students access were mirrored in academic staffing: during this period, almost all of these engineering programs were staffed almost exclusively by white academics (Case & Jawitz, 2003).

Innovation shock/idea

The first real signs of change came in the 1980s as the racial restrictions on access started to be lifted. This accelerated during the 1990s into the post-apartheid period which also saw massive policy shifts which resulted in a rework of the entire institutional landscape (Case et al., 2016). The racially separate institutions were reworked into a unified system which involved a number of institutional mergers leading to the consolidation of 26 public universities. Student enrolments grew rapidly in the post-apartheid period, with an overall doubling of the student population in first two decades, and significant shifts in student demographics at most of the institutions (Mabokela & Mlambo, 2017).

The important White Paper on higher education of 1997 consolidated the idea that education, and higher education specifically, needed to be a key driver for the transformation of the post-apartheid society (Department of Education, 1997). Thus, issues of equity and access remained at the forefront of political priorities. This was a fertile environment for the growth of Academic Development in universities, which had started at the historically white English universities in the 1980s but which now became a centrally funded national imperative for all institutions.

Political Will & Resources

One of the key groups that had a significant influence on shaping EER as a field in South Africa was the Centre for Research in Engineering Education (CREE). CREE was originally established in 1996 with the aim that Engineering Education could be recognised as a sustainable research field (Fraser, 2008). CREE initially focused its attention on the students who had been educationally disadvantaged from the apartheid education system and who were struggling academically (Kloot, 2021). This focus shifted to incorporate researchers who worked in science disciplines and laid the groundwork for establishing a national network and organizing the first two national conferences in Engineering Education in 1997 and 2000 (Jawitz, 2001). CREE was limited in national scope and role given its home in a single university, University of Cape Town (UCT). The national void was ultimately filled by Engineering Council of South Africa (ECSA), whose primary role was based around the accreditation of engineering programs and the regulation of the practice of registered persons. ECSA initiated plans for a new organization that could coordinate events such as national conferences and this had led to the formation of the South African Society of Engineering Education (SASEE) in 2010 (Collier-Reed & Case, 2017).

Another factor influencing EER as a field in South Africa was the availability of funding to support Academic Development efforts for curriculum development and student support. Significant industry funding came in for bridging programs during the 1980s and in the post-

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apartheid period, government funding came in to support these foundation programmes and academic development efforts directly. Many EER researchers were employed in such programmes. Another important route of government funding supporting EER academics came through the University Capacity Development Grant (UCDG) established in 2018 (Moyo & McKenna, 2021) which supported institutions to build internal efforts to improve their teaching and learning.

With the establishment of SASEE and the growth of national funding, a number of other universities became very active in EER, including the University of Pretoria, the University of Johannesburg, and the Cape Peninsula University of Technology. In these universities, EER scholars have often been able to access internal funds to support their work and to present this at conferences. However, most of the work tends to be centred on key individuals and the convening of informal research groups. Some EER research have successfully obtained funding from the National Research Foundation (NRF), a body which funds research across the spectrum of all disciplines in South Africa. More recently CREE and SASEE have also made some funding available to researchers.

In 2019, a team of CREE researchers with funding from the Department of Higher Education and Training established a programme to support PhD students in EER.

Belief Systems & Identity

The establishment first of CREE and then SASEE were key structures around which the EER community coalesced. Papers published in the conference proceedings of these bodies have always been peer-reviewed, thus building legitimacy for the field as EER researchers were able to support their universities in attracting research subsidy. A significant recent development in this regard is the establishment of the Southern Journal of Engineering Education (SJEE) recently launched by SASEE. This is a new scholarly forum for the publication of original research that is relevant to the international engineering education community. This will be an open access publication which will value critical perspectives on the unique challenges facing engineering education in South Africa and the Global South (Chance, 2021). This will allow for a significant further consolidation of the EER community in South Africa given the requirement for academics to be publishing their research.

New Zealand

Prior Structures & Environment

New Zealand only established independent degree granting universities in 1961 (previously all operated under the umbrella of a body called the University of New Zealand) and until the late 1980s these public universities were regulated through the University Grants Committee (UGC), which allocated funding and managed the system's accountability (Crawford, 2016). Academics in permanent positions at universities have always been involved in both teaching and research and the PhD model was established to follow the UK, involving original research and dissertation to be conducted, with limited organization-based course work.

The Institution of Professional Engineers New Zealand (IPENZ), now rebranded to Engineering New Zealand, was established in 1982, evolving from earlier entities that were invested in the regulation of professional engineering qualifications. By the 1980s concerns had started to surface in the profession about the overall numbers of engineering graduates, and particularly about the number of women graduating out of these programmes who made up only 2.5% of graduating engineers in 1980 (Godfrey, 2003).

Innovation Shock/Idea

In 1989 there were three key developments that were the impetus for the development of EER in New Zealand.

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At the level of the overall higher education system, a significant reform in 1989 created a new unitary statutory framework for all tertiary education, also advancing marketization with each university given the freedom to set their own fees. Another major shift came in 2001 with the implementation of the Tertiary Education Advisory Commission (TEAC), established to map out a new direction for tertiary education. Along with creating a new government agency to allocate government funding, the TEAC had specifically proposed to separate research funding from funding for teaching and learning specifically (Crawford, 2016). Overall, these changes meant that universities had to make sure their curricula fitted into the overall qualifications framework, and had to be more accountable for the quality of their teaching and learning.

A second key development also took place in 1989 with the founding of the Australasian Association for Engineering Education (AAEE). From the outset it involved both Australian and New Zealand engineering educators, even though AAEE is a special interest group of Engineers Australia (this is its main "home" although it also functions as a technical society for Engineering New Zealand). AAEE describes itself as a professional association of academics, support staff, postgraduate students, librarians, professional engineers and employers who all have vested interest in fostering excellence and innovation in engineering education (*AAEE*, 2021). AAEE started holding national conferences in 1989, and established a journal in 1991. Much of their early work focused on describing teaching innovations and practices (Klassen et al., 2020). Emerging EER researchers in New Zealand became involved in AAEE quite early on, recognized the value it poses and brought this knowledge back to New Zealand. In doing so, this influenced other researchers interested in the field and hence some of these key individuals were also a big driving force of the emergence of EER in New Zealand. These researchers also presented their work at American engineering education conferences such as ASEE and FIE. Notably, Elizabeth Godfrey developed an international reputation early on for her work on women in engineering (Godfrey, 1992).

A third development in the same year, 1989, was the establishment of the Washington Accord, a global system for the accreditation of four-year engineering degrees, of which IPENZ was a founding signatory. IPENZ was also instrumental in facilitating the Sydney and Dublin Accords which accredit the other engineering qualifications. In 2017 IPENZ was rebranded as Engineering New Zealand.

Political Will & Resources

New Zealand has struggled to establishing a critical mass of EER researchers, given the smaller size of the higher education system. Some of the key institutions involved in EER in New Zealand are the University of Auckland (UoA), University of Canterbury (UC) and the University of Waikato, those with the most longstanding engineering programmes. The Faculty of Engineering at the University of Auckland drew on the framework of the Scholarship of Teaching and Learning (SOTL) in building institutional structures to support staff development in engineering education (Godfrey & Rowe, 2007). SOTL has now been engrained as a part of the faculty performance reviews and as a necessity for promotions, with growing expertise on describing course objectives and building constructive alignment in the curriculum. Similar work is also being carried out at UC. The University of Waikato is home to the Engineering Education Research Unit (EERU) which focuses on improving learning outcomes for engineering students (Waikato, 2021).

In terms of funding, from the 2000s onwards, following the TEAC, the government has provided extra performance-based funding to tertiary education providers based on whether they meet their specific targets in alignment with government expectations (Crawford, 2016). Engineering faculties have thus prioritised building the quality of teaching and learning and in cases have internally supported engineering education efforts. This has tended to be a bigger impetus for EER than external research funding, although some faculties of Engineering built collaborations with faculties of Education in order to obtain external grants.

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Belief Systems & Identity

It can be seen therefore that nationally there is only a small group of researchers in New Zealand doing work related to EER, mostly driven by institutional imperatives related to improving teaching and learning. As a small group they have struggled to find their own distinctive identity compared to EER being carried out in Australia, and have thus tended to align with AAEE since this organisation gives the scale that is needed, rather than trying to run their own national conference.

At some points New Zealand participants have expressed the need for their own national event (Swan & Godfrey, 2013). It has also been proposed that EER researchers might align themselves with Ako Aotearoa, a government-funded organisation committed to supporting the country's tertiary sector teachers, trainers and educators to be the best they can be for the learners' success (Swan & Godfrey, 2013). There are currently no graduate programs specifically targeting engineering education in NZ and because of that, doctorates in this field have been few. However, through the interests of enthusiastic individuals, this is slowly starting to change and appointments at the Full professor level based on achievement related to scholarships in Engineering Education, have also validated engineering education as a career pathway (Godfrey & Hadgraft, 2009). This said, most EER scholars also carry significant technical research interests, which have often been easier for securing funding. In this regard, a significant new development in 2020 is the establishment of "Engineering practice and education" as a new Field of Research which opens up eligibility for distinct research funding (https://aaee.net.au/for-codes/). To date EER researchers either have to apply through Engineering or Education without a distinct niche for the field.

Discussion and Conclusion

This study has sought to identify the forms of institutionalization that have emerged to support EER in two countries, South Africa (SA) and New Zealand (NZ), building on an earlier study that examined Australia, China and the USA. Moving beyond these larger and potentially more prominent players in the global field, we are able to further develop the argument about how the evolution of EER is intimately connected to the national context and the opportunities and constraints it affords.

Our first research question sought to describe the different trajectories of institutionalization in each country. Here we identified some key features for each context. In South Africa we noted the establishment of key structures around which the community cohered, firstly CREE located predominantly in one university although aiming for national reach, followed by SASEE which more readily made that ambition possible. South African EER researchers have had regular national conferences since the late 1990s. In New Zealand, EER researchers have mostly aligned themselves with the Australasian body, AAEE. In both countries EER has a strong practice focus, helping universities respond to national imperatives for curriculum and teaching reform.

In terms of the forms of EER institutionalization that have emerged in these countries, we see similar forms at the university level where the work is tightly embedded in the institutional commitments of a few key universities. The role of individual champions has been significant. Thus, EER academics in both contexts are located within disciplinary departments and/or faculties of engineering. PhD students have mostly attached themselves to individual academics as is possible in the British style research-based PhDs. A very recent development in South Africa has seen government funding allowing for the establishment of a cohort style model for supporting PhD students in EER.

Our second research question sought to explain the differences in these trajectories. There are some key differences between SA and NZ which provide challenges in conducting this comparative case study. A key dimension is scale, with the NZ higher education system being much smaller than that of South Africa, even though it enrolls a greater proportion of

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its youth cohort (but coming off a significantly smaller population base). Regionally there are also significant differences, with South Africa having a very different trajectory to the surrounding countries on the continent and thus a much more advanced infrastructure for engineering education. NZ has very close ties with its regional neighbor, Australia, and there are many similarities in their higher education systems.

Both SA and NZ have significant political imperatives driving efforts to improve teaching and learning, particularly in engineering which has a key economic focus for the country. Both have seen significant reform of the higher education system, although South Africa's was arguably more impactful given the need for an entire overhaul of the apartheid structures.

A key difference in explaining the different trajectories is that South African EER researchers have benefited from distinct resources coming their way, firstly with industrial funding for academic development from the 1980s, through to targeted funding from the post-apartheid government South African EER researchers have also managed in some cases to obtain research funding for their efforts, and this has arguably opened up routes to promotion based purely on EER outputs. Publications are a significant aspect of promotion in South African universities and are directly linked to research subsidies to institutions, and in this regard EER researchers have made their mark. In NZ, the systems for funding and assessment of research mean that it is very challenging for an individual academic to focus their research purely on EER, and thus most adopt a hybrid approach including technical research in their portfolios.

Our approach in this study has inherent limitations and thus we also consider these findings to be preliminary pointers for future work. There is definite scope for a follow-up study which seeks to obtain perspectives from a broader range of participants, especially in relation to the South African case where the field has become relatively institutionalized.

Overall, this study offers further support for the thesis that EER takes very different forms in different contexts. This is a key consideration for the global community in the field, to be sure that outputs from one context are not simplistically judged against those from another. The countries under consideration in this study are potentially more useful comparators to many other emerging EER communities around the globe than the USA and China. We note the value of regional communities such as in Australasia, but at the same time a national system that is big enough with targeted resources can sustain national bodies such as South Africa. A really crucial point relates to scale of analysis. At a university level, EER researchers in South Africa and New Zealand operate in relatively similar structures. However, at the next level these contexts function very differently. This is also a crucial point for consideration of global bodies such as REES/REEN that aim to draw together representation from national structures.

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Indigenous Knowledges and Perspectives in Engineering Education: Team Reflections on a Series of Faculty Workshops

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ABSTRACT

CONTEXT

Indigenous Peoples, and their languages, cultures, Knowledges, beliefs, and values have been historically silenced through systematic colonial suppression in Canada for centuries. Since 2008, the country has been engaged in a national effort to learn these truths and practice reconciliation, called for by the Truth and Reconciliation (TRC) of Canada. Education, used as a tool to eradicate Indigenous Peoples in Canada, is one mechanism by which Canadians can right these historical wrongs. As such, four engineering faculty members in a large research university in Western Canada in a year-long internally funded project designed a series of engineering-specific faculty workshops/events to bring Indigenous Knowledges and perspectives into engineering education.

GOALS AND PURPOSE

The project goals were for faculty members to experience a shift in perspective by seeing engineering education through Indigenous worldviews, and to support faculty in integrating Indigenous Knowledges, perspectives, and design principles into engineering curricula. The purpose of this paper is to explore the impact of this work from team members' perspectives.

METHODS

Team members' Reflections After Events are inductively analysed for overarching themes.

OUTCOMES

Three themes emerged from team members' individual critical reflections: *challenges, culture,* and *change*. There were differences in team members' responses to the themes and in the tones of their reflections. It is anticipated that this paper will stimulate both intertextual and interpersonal conversations with Indigenous Peoples and allies working to make space in engineering education for Indigenous Peoples and their ways of being, knowing, and doing.

CONCLUSIONS

Overall, 1. This work requires many people; 2. mistakes are made; 3. students are vital in forwarding this work; 4. faculty are in different places; and 5. a paradigmatic shift is required. Through team members' critical reflections we have stimulated deeper understandings on the impact of this work and how paradigmatic change was observed and can be encouraged.

KEYWORDS

Engineering education, faculty workshops, decolonize, Reflection After Events

Introduction

Indigenous Peoples, and their languages, cultures, Knowledges, beliefs, and values have been silenced through systematic suppression via colonialism in Canada for centuries. Since 2015, the country has been engaged in national efforts to learn these truths and engage in reconciliation, as called for by the Truth and Reconciliation (TRC) of Canada. Education, used as a tool to eradicate Indigenous Peoples in Canada, is now named as one of the mechanisms by which Canadians can right these wrongs, as outlined in the TRC's 94 Calls to Action (Truth and Reconciliation Commission of Canada, 2015). As such, four engineering faculty members in a large research university in Western Canada were awarded a year-long internal Indigenous Initiative Fund (IIF) grant to build good relationships between Indigenous and non-Indigenous engineering stakeholders and enrich engineering education by seeing engineering through Indigenous worldviews. The project involved (1) funding a part-time Elder-in-Residence position to support our Indigenous and non-Indigenous engineering community and guide our project in safe, culturally sensitive and shared ways; (2) offering a series of engineering-specific workshops/events to explore Indigenous cultures, pedagogies, Knowledges, beliefs and values in teaching and learning and integrate these worldviews into engineering education in relevant, genuine, and good ways; and (3) recruiting an Indigenous student leader to advise the project. Our project team designed 12 engineering-specific faculty workshops/events in partnership with several groups, including a team from the institutional teaching and learning centre led by an Anishinaabe-Metis-Dakota Indigenous Initiatives Educator and artist, an Indigenous undergraduate engineering student, and colleagues from the Department of Native Studies. It was supported by the Indigenous Student Centre on campus.

The project was action-oriented toward characterizing the barriers to integrating alternate worldviews into engineering curricula and enacting ways to alleviate those barriers. The goals of the project were for faculty participants to experience a paradigmatic shift by seeing engineering and education through Indigenous worldviews, and to support faculty in integrating Indigenous Knowledges, perspectives, and design principles into engineering curricula. These outcomes were purposed to affect an increase of Indigenous partnership, achievement, representation, and belonging in the Faculty, and support the enhancement of engineering education with Indigenous worldviews in significant, safe, and culturally sensitive ways. The work is aimed to resonate with our engineering students through its translation into engineering curricula and ultimately engineering practice.

The project team comprised of the *Project Lead*, a new tenure-track assistant professor, a white woman settler, born and raised on Treaty 1 Territory and the Homeland of the Métis Nation, with a disciplinary background in visual arts, creative writing, communication, and education; a *Post-Doctoral Fellow*, a Friday-born girl from the Akan Clan in Ghana, with a PhD in Biosystems Engineering; a *Director*, a Métis Professional Engineer and Director of the Indigenous engineering access program (ENGAP) in the faculty; and an *Administrator*, a Professional Engineer with Mennonite heritage and disciplinary backgrounds in engineering and engineering education, who at the time of this project, was an Associate Dean (Design).

The workshops and events were designed using the Anishinaabe teachings of the Sacred Hoop – as taught to us by the Indigenous Initiatives Educator and artist, Leah Fontaine – as an organizational framework to both demonstrate the incorporation of Indigenous ways of being, knowing, relating, and doing into curricula, and connect participants to the power of these perspectives (see Figure 1). The Sacred Hoop is a circular framework in which the four human aspects – Mental (knowledge; cognitive), Emotion (feelings; affective domain), Physical (hands-on, skill-based; psychomotor), and Spirit (history, relationship-building) – are represented to celebrate their connectivity and unity (Fontaine 2010). The Sacred Hoop offers an Indigenous framework from which one can design curricula that align with the knowledge, skills, attitudes, values, and behaviours that engineering educators are required to develop in their students (for more on how the Sacred Hoop in engineering education, see

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Seniuk Cicek et al. 2019). We argue that engineering educators often omit integrating the Emotion and Spirit elements in traditional engineering courses. The Sacred Hoop teachings offer an Indigenous way to design curricula that will holistically activate faculty and students and enhance their learning through the diversification of perspectives. Using Indigenous perspectives to design engineering curricula was chosen to demonstrate to Indigenous and non-Indigenous faculty and students the Price Faculty of Engineering's commitment to honouring a shared history, holding shared values, and developing a shared approach for working towards Truth and Reconciliation in Manitoba and in Canada.

The purpose of this paper is to share project leaders' individual critical reflections on the workshops /events offered thus far, stimulating deeper reflections for the team, and conversations with Indigenous Peoples and allies working to enhance engineering education with the voices of diverse, historically, and presently silenced Indigenous Peoples. Through the processes of critically reflecting and sharing, we aim to learn more on how to move forward in meaningful and impactful ways.

Workshops

There were 12 workshops and events designed using the Anishinaabe teachings of the Sacred Hoop as guided by Leah Fontaine, planned over the four seasons of a year (see Figure 1).

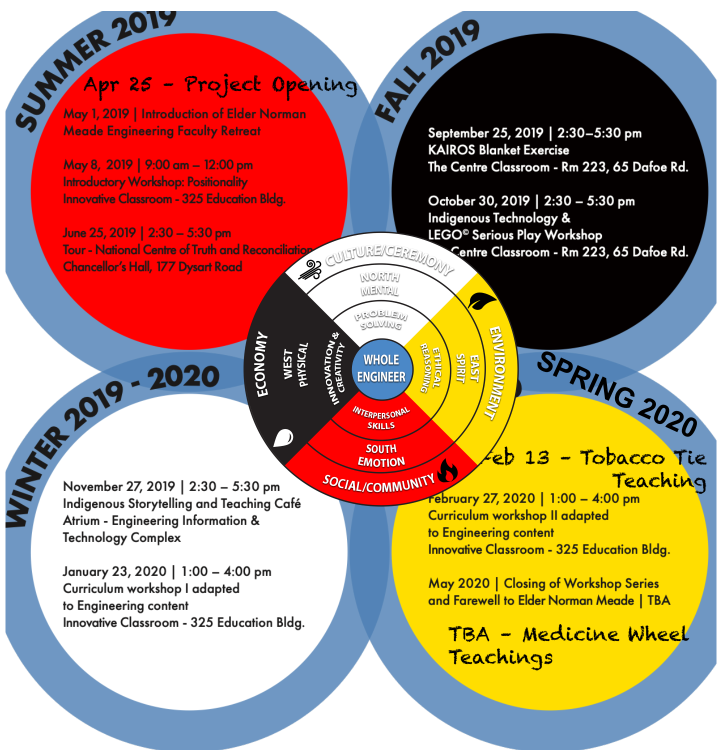

Figure 1: Post card designed using the Anishinaabe teachings of the Sacred Hoop, to communicate to faculty the Indigenous Initiatives Fund workshops & events

Workshops/events included:

Spring/Summer: *Project Opening*: Smudging Ceremony and Feast (April 2019); *Welcome to the Elder-in-Residence* at the Faculty Retreat (May 2019); *Positionality Workshop* where Faculty participants learned of the importance of relationships fostered in knowing What is my Story? (i.e., Who am I? Where am I from? Why am I Here? Where am I Going?) from the centre of the Sacred Hoop (May 2019); Tour of the National Centre for Truth and

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Reconciliation (housed in our institution) in honour of the victims and survivors of Residential Schools in Canada, and their families and communities (June 2019).

Fall: *"Gwayakotam: They Hear the Right Thing, Find Out the Truth" Workshop*, where participants experienced a KAIROS blanket exercise that simulated the histories and stories of colonialism (September 2019); *Indigenous Technologies and LEGO © Serious Play Workshop* where faculty and students learned of the technical designs and innovations of Indigenous Peoples and used LEGO© builds to discuss bridges and barriers to bringing Indigenous ways of being, knowing, and doing into engineering education (October 2019).

Winter: *Teaching Café* with Indigenous and ally academics teaching faculty, staff and students about the history of Indigenous Peoples in Manitoba, the negative impacts of engineering hydro projects on Indigenous Peoples and their communities in Northern Manitoba, and Indigenous perspectives in Science as understood via Indigenous Languages (November 2019); *"Mashkiki Beshibii'igan: Medicine Line" Workshop (Curriculum I)* that introduced how curricula and pedagogy can be intersected with both western and Indigenous perspectives to promote successful teaching and learning in new and innovative ways via the Sacred Hoop framework (January 2020).

Spring: *Tobacco Tie Teaching* offered by Elder-in-Residence Norman Meade (February 2020); *"Mashkiki Beshibii'igan: Medicine Line" Workshop (Curriculum II)* (February 2020); *Medicine Wheel Teachings* by Elder-in-Residence Norman Meade; *Closing of Workshop Series* and feast.

The project has not yet closed as two Spring 2020 workshops/events (*Medicine Wheel Teachings* and *Closing of Workshop Series*) were delayed due to the COVID-19 pandemic.

Methodology

Team members' experiences with the project were explored using critical reflection and inductive analysis. We engaged in Reflection After Events, as described by Boud (2001):

> Much important reflection can occur once the immediate pressure of acting in real time has passed. Some learning inevitably takes time and requires the ability to view particular events in a wider context. …it is important to emphasize that it is not simply a process of thinking, but a process that also involves feelings, emotions, and decision making. We can regard it as having three elements: return to experience, attending to feelings, and reevaluation of experience…

Return to experience offers the opportunity to revisit the event with a wider perspective and experience its full impact (Boud, 2001). Importantly, *attending to feelings* supports experiencing both negative and positive emotions, so the former can be "discharged or sublimated; otherwise, they may continually distort all other perceptions and block understanding" and the latter "can be celebrated, because they enhance the desire to pursue learning" (Boud 2001). Re-evaluating the experience enables "freer evaluation of experience than is often possible at the time" and involves scaffolding knowledge, making connections, and taking ownership of the 'new' knowledge (Boud 2001).

Team members' critical reflections were inductively analyzed. Inductive analysis is recommended if little is known about the phenomenon, and the aim is to move "from the specific to the general, so that particular instances are observed and then combined into a larger whole or general statement" (Elo and Kynga¨s, 2008).

In February 2020, the project lead invited all team members to critically reflect on the project in a Reflection After Events "by writing a reflection from your own perspectives of the project." She explained, "I envision perhaps a paragraph or two where you share your own observations, thoughts, reflections, and evaluations of the workshops you've co-designed or facilitated and/or have observed/participated in, and suggestions for moving forward. Perhaps a 'lessons learned' retrospective." The project lead then inductively analyzed these critical reflections for overarching themes. Themes and the resulting discussion were critically reviewed by all team members.

Project Team Perspectives: Findings

Three themes emerged from team members' individual critical reflections: *challenges, culture,* and *change.*

Challenges. There were diverse, and at times "clashing" perspectives among the team members and the different contributors team members engaged with from across the institution to develop the workshops. These challenges were resolved by "listening to understand", revisiting workshop objectives, and making relevant changes to engage all contributors and audiences. As one team member explains, "It was easy to assume that all Indigenous Peoples had the same negative experiences. I know we read that we can't generalize Indigenous Peoples but that is something that comes so fast as we meet people. That is one of the many things I learned. Listen to understand first."

There were also challenges in finding a "healthy middle" ground to engage engineering faculty and staff interests. We wished to lean towards concrete action while authentically respecting and honouring the processes one needs to engage in with Indigenization, including spending significant amounts of time active listening, reflecting, learning the historical contexts, and engaging with more elusive ideas (such as positionality and the KAIROS© Blanket exercise). There was also the challenge of lack of attendance in the workshops despite the belief that all faculty held a "principled agreement" in the importance of Indigenization for its own sake as well as to "make Engineering more relevant and of better service to society." As one team member reflected: "…the attendance at workshops has caused us to wonder why the principled agreement has not translated to active participation..." Indeed, the participation challenge was mitigated after several workshops by inviting two allied faculties – Agricultural and Food Sciences and Architecture – to attend the workshops, and in two cases, by including students as participants (e.g., in the LEGO workshop and in the Teaching Café). At times this solution was very successful, increasing attendance in the LEGO workshop to capacity (~35 people) and resulting in over 70 people attending at least one of the three presentations during the Teaching Café. However, this was problematic when some of the allied faculty members attending for example, the Curriculum I workshop, were at different places in their journeys to Indigenize the curricula than their engineering colleagues. As a result, they were frustrated by the perceived beginner level of the workshop. There was also frustration with their colleagues' engineering thinking, which is typically more concrete/positivistic than our architecture colleagues.

Culture. The workshop series highlighted the "engineering profession's culture for action." This culture made offering some of these workshops tricky. Workshops that dealt with concrete ideas like historical engineering projects' impacts on Indigenous communities or curriculum initiatives that were purported to support Indigenization seemed to garner more interest. Engineers typically expect concrete solutions to 'problems'. So, for example, some engineer participants came to these workshops expecting to walk away with concrete programming that they could implement in their curricula. When this wasn't the outcome, they were disappointed. This recalls Expectancy violations theory (EVT), which "is an interpersonal communication theory that… distinguishes between positive and negative violations. …[M]ost advice for communicators is to avoid violations of expectations" (Burgoon, 2016). Leaving participants' expectations unfilled can lead to participant dissatisfaction and unrealized project outcomes. At times, some participants found the workshop objectives/titles unclear, both prior to and after attending the workshops. In unclear objectives and expectations, there is evidence of communication barriers. The engineering profession's culture for action, problem solving, and penchant for solutions is something that we must explicitly consider as we move forward with this project. Finally, there is a culture of "ambivalence" and "privilege", reflected on as: "those who have no quarrel with the objective but who sit in privilege, and thus in ambivalence. These are well-intentioned, engaged faculty

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members who do not identify any personal imperative to attend or engage deeply with the issue." Privilege was also felt by our team members – the privilege to feel proud by this work and measure it by colonial counts, and as one team member reflected, the "'all-round rights and privileges' where my choices have never been restricted, where my acquiring knowledge based on different perspectives was an asset and welcomed by my peoples, where I am always connected with my peoples no matter where I am in the world." In this work, privilege and ambivalence requires explicit recognition and disruption.

Change. There was evidence of change via implementation, engagement, learning, and transformations. As one team member reflected: "During the workshops the attendees were engaged and appeared to be learning. Afterward it came to my attention that some of the professors who attended the workshops implemented the things they had learned in the workshop directly into their classrooms." This same team member assuaged their challenge with participation when they recognized the "snowball effect" the workshops were having:

> I was originally disappointed with the turnout for many of the sessions until I realized that there was a bit of a snowballing effect. After I did presentation on Indigenous Technology to what I thought was a small crowd I had at least six professors approach me and ask if I could do my presentation to their students. I gladly accepted and have been able to reach hundreds of students through this initiative.

The work of the Elder was also acknowledged as transformative:

> Also, the Elder, [who is] part of the IIF [project], is housed within ENGAP [Indigenous engineering access program] and there has been a real transformation of the ENGAP space because of this. Some of this transformation was physical as a space had to be provided for the Elder which gave us the opportunity to request additional space for ENGAP students that we had lost due to providing an office for the Elder. This allowed us to secure two additional small rooms that the students are able to use as study rooms or group work rooms. More importantly having Elder Meade in our space once a week has resulted in an emotional and cultural change. I see numerous students and Engineering Faculty taking the opportunity to speak with Elder Meade.

There were changes in perspectives for participants – e.g., "they recognized that it takes a mindset shift" – and for team leaders: "One unexpected learning and finding out of these workshops/events is that this work takes mindset shifts… This happened to me." Another team member reflected on the shifting perspectives they experienced when they embodied the role of workshop participant, and became aware of how Residential schools were not schools in the familiar affable sense, but rather instruments for the genocide of Indigenous Peoples in Canada:

> As a participant, the workshop series gave me the opportunity to better understand the culture of the place through learning about the history of Indigenous Peoples and the meaning of "We Are Treaty People." …our visit to the National Centre for Truth and Reconciliation (NCTR) provided me with the opportunity to learn and have a better understanding of the "residential school" system and the Truth and Reconciliation Commission of Canada's (TRC) 94 "Calls to Action." At the NCTR, I got the opportunity to explore with others the meaning of the "residential school" system. To my surprise, the word "school" and "education" used in the "residential school" system were nowhere near what I had perceived them be.

Finally, it is important to note that the other two themes, *challenge* and *culture* require, *change*: "One observation is that like many initiatives, the workshops tend to attract those already on board and already to some extent educated on the issues. This is coherent with change management, where one seeks to engage champions and allies (10%) and disregard noisy detractors (10%). In this case, it has brought the "ambivalent 80%" into focus…"

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Discussion

Despite the commonalty of the three themes *challenges, culture,* and *change* across team members, there were differences in team members' responses to the themes and in the tones of their reflections. Perhaps these differences were due to their positions on the team, and their power or powerlessness to effect or experience change.

The Post-Doctoral Fellow and Director of ENGAP recognized the challenges but felt motivated/encouraged by the changes they respectively witnessed in personal and community transformation. The Post-Doctoral Fellow celebrated their opportunity to be both a team member and participant in the workshops, appreciating the "opportunity to learn" and acknowledging that the workshops "set my foundation right to move forward in my current position…" The Director had the opportunity to witness how the Elder-in-Residence… afforded "real transformation of the ENGAP space" – transformation described as physical, – gaining space for Indigenous students – emotional, and cultural, resulting from the opportunities to interact with Elder Meade. These transformative changes can be classified as "Decolonial Indigenization" on the spectrum of Indigenization as ascribed by Gaudry and Lorenz (2018). Decolonial Indigenization is the most impactful type of Indigenization that can be achieved according to Gaudry and Lorenz (2018), which could explain the inspiration in the Director's critical reflection.

Differently, the Project Lead and the Administrator expressed that the challenges remained, with the Project Lead more pessimistic and the Administrator more contemplative in their respective responses. The Project Lead witnessed a change in a mindset shift during the second last workshop, and although understanding this paradigmatic shift as remarkable and necessary in the process of Indigenization, and recognizing it in herself, she still wondered if this was enough impact to justify the resources spent:

> One unexpected learning/finding in these workshops is that this work takes mindset shift, perhaps rather than concrete action, or rather first. This happened to me; it's a way of thinking about and learning about Indigenous perspectives and opening up to our own understanding of these as missing from our curriculum. I saw this firsthand with one participant who came to most workshops in the series. At the second last workshop, the Curriculum I workshop, they recognized that it takes a mindset shift. I saw that person bring their own stories (i.e., positionality) to their classroom; I saw them change their approach to teaching, personalizing it more. Personalizing engineering! Is this success? Is one person's changing mindset a victory in all the hours and hours and hours put into these workshops?

The Administrator felt our engineering community "seems to agree in principle that Indigenization is important for its own sake and that it can make engineering more relevant and of better service to society", whereas the Project Lead did not perceive this agreement, and questioned how to garner it:

> How do we encourage the learning about Indigenous Peoples, Indigenous history, Indigenous engineering/engineers, colonial history, residential schools, the truth about Canada as a genocidal nation presently and in history, to continue? How do we make it, communicate it, as really relevant and important to engineers and engineering education? How do we get engineering faculty to understand the importance AND the connection to engineering? Can we change faculty? Or are we better off to work with students, who will demand change and already see the world differently than the older generations who teach them?

The Project Lead was left questioning the work and her role, whether her position as an assistant professor and her identity as a non-engineer made her an effective project lead:

> Is our work a waste? What are the ripple effects? What are the unintended consequences? Are they harmful? Are they good? How do we know we are making a difference? Inroads? Truthfully, I felt tired after all this work… Who should take the lead

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> on this? Where is my role? I'm not even an engineer! Does my/the message get lost because it doesn't come from an engineer? Am I demonstrating 'followership'? Is this my role?

(For a discussion on *followership*, see Hurwitz and Hurwitz (2009), who argue, "the good follower, having seen what direction the leader wants to go in, figures out how to get there quickly, effectively, and without anyone getting hurt in the process".)

The Administrator felt the workshops supported institutional structures: the TRCC's Calls to Action; the university's Strategic Plan; and the faculty's vision and mission, and was encouraged that she did not encounter "any administrative or academic barriers to holding the workshops", whereas the Project Lead felt a fundamental clash with the academy:

> This type of work and evaluation are marred by the structures of the western academy. As an assistant professor, pre-tenured, I must measure and evaluate this work. I must find its impact – which is super helpful and exciting – but motivated by demonstrating my own worth – commodities to apply for personal gain: for tenure. Not for the sake of the work itself. I wasn't motivated to do the work for this reason; and yet I must report on it to support myself in this system.

The Administrator recognized that "it remains a challenge to find a healthy middle that engages faculty and staff members' interest while authentically honouring the issues with which one needs to engage in Indigenization." The Project Lead believes "…engineering students and Indigenous engineers must help us figure out how to move forward with this work. And the administration must embrace it so that this is someone's mandate and we keep moving forward in alignment with the vision for the faculty supported by the power of those in charge." Despite these expressed frustrations in doing this work, there was also recognition by the Project Lead of the fortune in being able to engage in this work. As she reflected: "I am grateful for all the very good and giving people whom I've met and worked with through this work. And humbly acknowledge that I've only put in 3 years – and many – most especially Indigenous Peoples – have put in lifetimes of work. I don't have the right to feel frustrated. Only to figure out the next way forward."

Concluding Remarks

In keeping with the teachings of the Sacred Hoop, we reflect via this framework that this work:

- Takes a lot of people (Ground, Sky)

And in this work:

- Mistakes are made (East)
- Students are vital in forwarding this work (South)
- Faculty are in different places (West)
- A paradigmatic shift is required (North)

And in doing this work:

- We're grateful (Centre)

Through team members' critical Reflections After Events, we have stimulated deeper understandings of the impact of this work and our roles in doing this work; discharged negative emotions and celebrated positive ones; recognized the challenges and cultures at play; and observed paradigmatic change, all of which will inform how we can move forward with this project in ever more meaningful and impactful ways. Further, as stated by one reviewer of this paper: *While this article is not directly about the change being proposed by the program as described and conducted, change of a very major kind is what would be the outcome should the program succeed, as hoped, in the long term. The nature of the change*

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being proposed, and the kinds of resistance experienced - e.g., absence of intended audiences - suggest that attention needs to be paid to the nature of the change proposed and the resistances it will inevitably meet along the way. We are grateful for this insight. Theories of change, particularly Appreciative Inquiry, where hopeful images and positive questions will be explored as the research and this work continues (Coghlan et al., 2003).

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Copyright statement

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Starting the conversation with African engineering educators about student success

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ABSTRACT

CONTEXT

The literature on student success is rich, but most of it is written from the perspective of the Global North. The interventions proposed in the literature may not be practicable or relevant in an African context, or may not be seen by decision makers to be applicable. A preliminary review of the literature shows limited formal African scholarship on engineering student success. We seek to surface and value the expertise on student success that already exists in African engineering institutions, and add it as a contribution to the literature.

PURPOSE

The objective of the larger research project is to expand the literature on student success to include perspectives from sub-Saharan Africa. We aim to understand existing African models for student success in engineering, which can enable practical interventions in curriculum design and in institutional support structures. The goal of this paper is to begin to understand student success in the context of three African engineering institutions.

METHODOLOGY

This paper presents the first phase of the research, in which we explore the perspectives of a small number of experienced engineering educators from a range of countries and institutions in sub-Saharan Africa, through the medium of an online focus group. This initial unstructured conversation gives us an understanding of the current situation in which educators find themselves. The focus group data was interpreted using Bourdieu's theory of practice, which addresses inequalities in education.

OUTCOMES

The focus group data has allowed us to scope the range of contexts in which student success should be considered in sub-Saharan Africa, and identified critical areas for deeper study and further questioning. Based on this, we have developed an interview guide for semi-structured interviews with a wider group of participants, and confirmed that Bourdieu's theory of practice is an appropriate theoretical framework for analysing the second phase interview data.

CONCLUSIONS

In order for engineering education research to contribute to changes in practice, it needs to be relevant for local contexts. This research begins to develop scholarship around student success from multiple African perspectives, recognising the expertise of African engineering educators, and enriching our understanding of how African engineering institutions engage with this topic.

KEYWORDS

Student success; engineering education in Africa; Bourdieu's theory of practice

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Introduction

This paper seeks to begin a conversation about the factors which influence engineering student success in sub-Saharan Africa, with the long-term aim of developing models which can enable practical interventions in curriculum design and institutional support structures that are relevant for the African context.

We began our research into student success in sub-Saharan Africa by conducting a preliminary database search. We looked for sources which mentioned student success in STEM contexts in higher education in sub-Saharan Africa, and obtained approximately 200 sources, in contrast to the thousands of sources on student success worldwide. Three-quarters of sources originated from South Africa, and reported on South African universities, although South Africa is only 1 of the 46 countries in sub-Saharan Africa. The remaining sources represent the rest of sub-Saharan Africa, which contains multiple regions with a diversity of contexts in terms of languages, infrastructure, economic resources and education levels. We acknowledge that an electronic database search is a limited methodology for surveying African scholarship. Nonetheless, the global literature on student success will be enriched by adding multiple diverse narratives from the varied contexts of sub-Saharan Africa.

Research in student success has developed from being primarily focused on student agency to understanding the impact and importance of universities, curricula and lecturers on individual student behaviour, as explained by Tinto in a reflection on his own career in the South African lectures (Tinto, 2014). Tinto (2014) concludes that solutions to student success should be centred on the experience of students on campus and their engagement with lecturers, primarily their experience in the classroom. Boles and Whelan (2017) also identify the teaching and learning relationship between students and lecturers as critical to student success, and emphasise that these interactions happen both inside and outside the classroom.

Many authors also acknowledge the importance of factors that are beyond the control of the classroom, such as financial pressures on students, pre-tertiary education which does not sufficiently prepare students for the technical requirements and values of engineering studies, lack of career guidance, large class numbers, and psycho-social factors for individual students (e.g., Tinto, 2014; Mogashana, 2015; Ahmed, Kloot & Collier-Reed 2015; Boles and Whelan, 2017; van der Merwe and Maharaj, 2018). We note that this array of factors are reported in most contexts in the student success literature. However, an important difference between the African context and wealthier countries is the extent to which these factors affect the majority of students at a university rather than the minority, and also the availability of institutional resources (both budgetary and personnel) which would allow universities to mitigate these factors.

In Africa, most universities which teach engineering and STEM are elite institutions in their countries, but nonetheless struggle with resource constraints. Students come from disrupted and unequal schooling, many with constrained financial resources, and the student body contains multiple dimensions of diversity and inequality, depending on local context, including socio-economic inequality, race, gender and first generation university students. (Mogashana, 2015; Wuhib, 2017; Adjei, 2019).

A number of African studies emphasise stories of success, focusing on how different groups of students overcame structural and cultural constraints, as exemplified by Mogashana’s 2015 study of the agency of Black South African students. Resilience is identified as an element of success in Adjei’s 2019 research on the persistence (“hustling”) of low income STEM students in Ghana. Wuhib (2017) describes how residential communities impact the success of women in STEM in Ethiopian public universities.

We aim to broaden the sources and the types of narratives that are captured, and to situate South African experiences among multiple sub-Saharan African contexts. In this paper we

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report on the first phase of this research, in which we used an online focus group to explore the perspectives of experienced engineering educators from three African universities. Our research question asks *How is student success understood across different contexts in African engineering institutions?* The outcome of this preliminary research is to identify critical areas for our ongoing investigation, and to develop an interview guide for interviews and focus groups with a wider group of participants.

Theoretical framework

The literature on student success agrees that it is a phenomenon where the interaction between structural, socio-cultural, and individual factors is important, and therefore Bourdieu's theory was proposed to analyse the data. This paper aims to evaluate whether the sociological notions of **field**, **capital** and **habitus** are effective for interpreting African engineering educators' discussions of the factors influencing student success.

According to Bourdieu's theory of practice (Bourdieu,1977), social practice is the result of an interdependence between the habitus of the individual, the field in which social interactions occur, and the capital which is valued. The **field** is a space defined by the specific capital which is valued, and by specific rules for obtaining capital. **Capital** may be viewed as the assets (cultural, social as well as economic) which, when possessed, enable membership of the field. The **habitus** of the individual (which is related to agency) is the set of embodied patterns of behaviour that the individual has acquired through all the fields in which they have participated. The habitus is influenced by experiences, values, beliefs, and education, as well as factors such as gender, race and religion.

Student success can be explained in Bourdieu's terms as a product of student **habitus** meeting the **field** of university structures, which value certain forms of cultural and social **capital**. Student habitus is shaped by interactions with the field in the past and present, and shapes the field in the future (Crossley, 2001; Raey, 2004). We can understand this interaction by seeing how lecturers' habitus has been shaped by their past experience of the field as students, and then how their habitus influences the field for future students. Thus, student success is a function of habitus, but habitus is influenced by field. Bourdieu himself has used the notions of field, capital and habitus to study the success of students in Algeria (Bourdieu & Wacquant, 1992), addressing the subject of the reproduction of inequality through education.

Methodology

We selected a focus group because we wanted to open the conversation without too many preconceptions about what the answers would be. We aimed to have a broad, general conversation in a context where there is not extensive literature. The medium of an online focus group, including people with similar levels of experience in the same conversation, allows the participants to make connections and highlight disparities between their different contexts. We obtained ethical clearance for this project from the Faculty Research Ethics Committee at the University of Pretoria, and all participants gave informed consent.

Participants

We recruited three participants to whom we have given pseudonyms of Frida, Lerato and Michael. We contacted the participants via email, in which we explained the project and invited them to participate in a one hour online focus group. We chose the participants using purposeful sampling (Emmel, 2013), with variation between different countries and contexts in Africa. The sampling also has a homogeneous component, as all our participants have played multiple roles in engineering education, with experience of teaching, administration, mentorship as well as research, and all have at least 10 years of experience as engineering educators.

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Frida is a lecturer at a rural university in Uganda, University A, with fewer than 5 000 students. Besides her lecturing responsibilities, Frida gives support to students and staff with the learning management system and library resources, mentors students, takes a lead in guiding students to find internships for industrial training, and is a patron of the student professional association. Lerato is a lecturer at a well-resourced urban university in South Africa, University B, with more than 25 000 students. Lerato supports students to overcome non-academic challenges, and has published research in the field of student success. Michael is a lecturer at an urban university in Tanzania with more than 15 000 students, University C. Michael has played a range of roles, including registrar, assisting students with challenges as part of the registration process, coordinator of student practical training, and examination officer.

Data Collection and Analysis

The data was collected in a focus group on an online platform which lasted one hour. The focus group was recorded via the online platform, and sent to an outside consultant for transcription. Both researchers acted as facilitators during the focus group. The session began by reminding the participants of the overall purpose of the discussion:

> *What are the factors associated with student success in your context, from your perspective and experience?*

The discussion focused on three themes: defining student success, identifying the factors that affect student success, and understanding the impact of diversity on student success.

Initial analysis was done by the researchers based on their informal notes from the session, identifying overarching themes that they noticed during the discussion. The transcription was coded using inductive coding (Braun and Clark, 2006), and the common themes were then developed.

Limitations

This first phase of the planned larger study is necessarily limited by our methodological choice to begin with a single online focus group. The participants in this study come from Anglophone countries in Southern and Eastern Africa. This paper is thus missing perspectives from West Africa, and from Lusophone and Francophone countries. We also do not capture student perspectives.

Results

In this section, we describe the understanding of student success that we gained from our focus group. We then discuss the range of factors that impact this success. Throughout our presentation of the results, we will highlight the multiple categories of diversity that run through this data.

What is understood by “student success”?

When defining student success, the participants spoke of three broad aspects: firstly, the concrete success of passing exams and gaining the qualification; added to that, the deeper success of gaining the requisite knowledge and skills for the profession; and finally, the development of the whole person. Lerato expressed this multi-layered understanding: “So success is more than just about the qualification, success is about what they overcome in the process of becoming.” These interconnected and nested definitions of success are all expressions of the **field**, and what the field values: students move from the field of their pre-tertiary education, through the field of the university, and onwards to the field of professional life. In this paper we focus our understanding on the field of the university, but the values of pre- and post-tertiary fields exert an influence.

Student success understood as passing the exams

The first, and most obvious aspect of student success is that a student who passes the exams and gains the qualification is a student who has succeeded. Valuing this aspect of success can be problematic, with students and the institution focused only on surface achievement, as Michael challenges: "...it leads now the students towards studying to pass exams only."

Student success understood as gaining the requisite knowledge and skills

Michael expressed most clearly the second aspect of student success, "To me student success is when a student is ... able to acquire the relevant knowledge and skills". The idea of what this knowledge and these skills are is broadened by Frida, who notes the importance of students "being able to leave a better person, in terms of how they interact with others, how they look at problems, how their critical thinking is." She references the demands of the post-university environment:

> *... industrial training feedback that we get usually has issues around non-readiness of the student, especially in terms of the soft-skilling aspects – leadership, communication, report writing – as opposed to the technical aspects, whereby somebody is a good programmer but they are not a good team player.*

Student success understood as development of the whole person

Lerato and Frida both emphasised the importance of a holistic understanding of the growth of the individual student, rather than just focusing on their academic performance in understanding student success. Frida identifies success with the student having a sense of purpose, "It's about a student being able to discover who they are in the first place so that they are able to pursue that which is really at the centre of their heart." This reminds us that university studies do not define a person's success. This broad understanding of student success moves away from a focus on the **field**, towards an emphasis on **habitus**: the student's preferences and agency are also important.

Lerato problematises these definitions of student success, pointing out that student perceptions of success are diverse, and related to class and privilege. For students from poor, working class backgrounds, success is often directly related to obtaining the qualification and gaining employment. In contrast, students from middle-class backgrounds may focus more on ideas of excellence, and whether they are at the top of their class. This connects student success with interacting concepts of social, cultural and economic **capital.**

Factors that influence student success

Student success is a complex phenomenon that is sensitive to inequality, with systemic as well as individual contributors. In contrast to Tinto's primary emphasis which is on the student classroom experience (Tinto, 2014), our participants focused on issues outside of the classroom, as Lerato explains:

> *...it doesn't matter if a lecturer does the best tutorial or [has] the best teaching methods or … [has] given the best explanation on a concept. If you are hungry, if you are worried about whether your parents are eating at home or not, if you're worried about where you are going to sleep … if you are worried about who's going to pay your fees, … , it doesn't matter how great the lecturer, the teaching and learning circumstances can be, you can still fail.*

We begin by considering the economic circumstances of the universities, and then focus on the economic circumstances of students, their educational and social backgrounds, as well as psychological factors which affect individual students. We end by identifying the institutional support structures which universities have put in place to address these factors.

Institutional resources

Our participants reported challenges relating to the economic circumstances of their particular universities. Frida and Michael both mentioned limitations experienced with facilities such as labs, access to technology and library resources. They expressed their opinion that student success is negatively impacted by understaffing. Michael perceived his university as having a lower lecturer to student ratio than others in Tanzania. This draws attention to the importance of the diversity of economic circumstances between different universities. It is noteworthy that our participant from University B in South Africa did not comment on resource limitations to student success.

Economic factors for students

A strong emphasis among the participants was the contribution of a student's economic circumstances to their success. Financial insecurity can have a direct impact on academic performance, from the beginning of the semester, when lack of money delays registration, to the end of the semester when uncertainty about financial qualification for final exams affects students' preparation. In addition to lack of finances to pay fees, participants highlighted that some students lack the money to meet their basic needs, including adequate food, hygiene and accommodation. This impacts their wellbeing and indirectly affects their academic performance.

The financial situations of students are diverse within each university, with some students having the resources and the security of a comfortable home as well as access to convenient transport, while others lack the basics. Frida reminds us that, "While some of the ones from the challenging backgrounds will still thrive as well, but maybe their level of effort to get there is really deeper."

Educational background

The diversity of student's pre-tertiary education impacts their alignment with the expectations of engineering study at university. Lerato comments on two parallel education systems in South Africa, with a well-resourced elite sector and a large poorly-resourced public sector. She notes that for students from marginalised backgrounds it is not as easy "to assimilate into this university structure." Frida notes that, "the secondary schools that they come from matter" in Uganda, with students from "really deep, up-country village schools" lacking the exposure of students from urban schools. Michael also addresses the rural / urban divide in Tanzania, when he contrasts the expectations of students from the urban area, who "have that privilege of being ready, or at least they know what they are going for," with those of students from remote, rural areas, who "have a different sense of academic success." This misalignment was partially attributed by our participants to a lack of clear expectations of engineering. Michael points out that "...at the university we don't have a well-structured way of introducing the students to the engineering courses... We fail to prepare the students in terms of career guidance."

Students require particular language, knowledge and skills in order to succeed in their engineering studies. This includes proficiency in Maths and Science at secondary school. Our participants also identified the problems faced by students who are not familiar with computers, or who struggle with a language barrier: "... whereas they are trying to learn the language, they also have to understand the content and there's no extra room for them to be able to learn one thing and then be able to perform it very well as others" (Frida).

Social background

The social background of students, including their socio-economic class, their social beliefs around education, and the educational experiences of their communities affect their expectations of engineering and of university. In Tanzania, students may be selected for

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engineering without knowing what it is, and although they have strong skills, they struggle because they do not have exposure to engineering. In South Africa, race and class are interlinked, but Lerato says that class is now becoming a bigger factor in predicting engineering student success. The children of well-educated black middle class parents have privilege both from their elite education and their cultural and social knowledge of engineering that advantage them over other black students.

Students' success will be impacted by their well-being, which is a function of many factors. We have already mentioned the impact of finances and of educational and social alignment with the university. Students also experience unique circumstances and difficulties related to their health, their personality, social problems, anxiety levels, stigma, and trauma due to life and family events which may interrupt or affect their studies. We see that a student's social background and individual circumstances determine the **cultural capital**, **social capital** and **habitus** they bring to the **field**.

Institutional support structures

Each university attempts to mitigate the impact of financial, educational, social and psychological factors on student success through a variety of strategies. These support structures vary between the three universities. University B in South Africa is able to dedicate resources to formal student support, with dedicated specialists providing psychological, academic, as well as personal services. In contrast, at University A and University C, this type of support is provided by the lecturing staff. At these universities, each lecturer mentors a certain number of students across all departments in the faculty and provides academic guidance as well as pastoral care throughout the course of their study program. Participants also spoke of informal structures such as student associations, which build leadership and interpersonal skills outside of the classroom.

Discussion

In our discussion of the results we explore and identify the ways in which Bourdieu's concepts of field, capital and habitus are important to deepening our understanding of student success.

The notion of **field** is important because it helps us to understand the student's context, as engineering students in a particular university. The university interprets and presents the language and culture of engineering education in a particular way, that is informed by the country and context in which the university is located. The students enter the field of the university from different fields, their pre-tertiary education, the community they grew up in, as well as the society in which they live. For some students, the transition between these fields is happening every day.

The field is not simply the institutional structure, but is shaped and informed by the perspectives and actions of the lecturers. For instance, the different ways in which Frida, Lerato, and Michael understand success may change the field by changing what is valued by the students, although these are in competition with other less mutable structures which also influence student values. The future field that they will enter after graduation also impacts the student perspective of success.

When we talk about the language and culture of engineering, as well as discussing what lecturers and students value, we are expressing the importance of **capital**, which includes cultural capital and social capital (Bourdieu & Wacquant, 1992). The cultural capital which is valued in the field of the engineering university includes background knowledge in science, language proficiency, technical language, norms and implicit expectations. Social capital captures the relationships that students have with the field, and with power, including the respect they receive due to financial resources, or the stigma they experience due to their lack of power or resources, or their perceived difference from the valued norm. From our high level perspective, we see that social and cultural capital are difficult to separate out, and are

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transferable if you have them. Having capital that aligns with the institution is important for student success.

We do not see strong evidence of student **habitus** (agency) in our participant narratives, although it does appear in some particular examples. This is partly a consequence of the high level conversation that we engaged in, which has not allowed us to capture the ways in which the field has affected student habitus. This is an area which should be addressed in future research, through interviews with students. We have however discussed the interaction between field and habitus in talking of the influence of the habitus of our participants as lecturers in shaping the field of their universities. In future research, we need to distinguish between the habitus of the academic, which plays such an important role in the field, and the habitus of the student.

Conclusions and Recommendations

Our research has investigated student success through the perspectives of engineering educators from three different African universities, in different countries and with distinct local contexts. We have explored varying definitions of student success. We have identified factors that affect student success, adding an understanding of how local contextual details nuance the existing literature. We have demonstrated that Bourdieu's notions of field, capital and habitus can give valuable insights into these questions, and will provide an appropriate theoretical framework for the second phase of the study.

We have identified three important areas for questioning in future semi-structured interviews and focus groups: inequalities and diversity; mentoring and other formal and informal engagement between lecturers and students; and the alignment or conflict of lecturers with their university.

This preliminary research has highlighted the need to critically interrogate *inequality* in our future research. Success in engineering education is particularly sensitive to inequality because of how strongly it depends on the capital and habitus of the individual, acquired in the field of their pre-tertiary education and experience. Although the different contexts identified varying sources of diversity, the impact of socio-economic class was present in all the participant narratives. In our investigation of inequality we need to interrogate the meanings of 'rural' vs 'urban' more deeply to understand what is implied by this framing, as well as how this interacts with socio-economic class. We also believe it is important to characterise the inequalities that exist between universities in a country and in the region.

We will examine the formal and informal ways that students are *mentored*, as this is the core of the institutional strategies which our participants reported to improve student success. This will include investigating the training of mentors, and their effectiveness, as well as scrutinising the role of gender in the mentoring relationship. We will also consider the role of student associations in student development.

The habitus of the *lecturers* will be probed, in order to better understand the ways in which lecturers influence the field.

Our future research will include a broader literature review, considering multiple search avenues beyond electronic database searches. Our future research participants should include groups of participants from a single country or region, to understand the importance of different institutional contexts within a shared regional context, as well as participants from a wider range of countries to further investigate the similarities and differences between countries. We will aim for diversity in the gender of our participants, and in their relationship to formal power within the university.

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Curriculum Design in New Engineering Education: A Case Study of Two Emerging Engineering Programs in China

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ABSTRACT

CONTEXT

Cognizant of the burgeoning needs for reforming engineering education to respond to the accelerating development of the new industrial revolution, China launched the "New Engineering" initiative in 2017. Among which, the interdisciplinary Emerging Engineering programs accounted for an essential but entirely new field, with hardly any existing experiences in curriculum design, which was decisive to the construction of these programs.

PURPOSE OR GOAL

This study focused on curriculum design based on a modified Vision-Teaching-Support framework, to investigate the student outcomes, curricular structure, and contributing factors in curriculum design of the Emerging Engineering programs, and therefore share possible lessons and experiences with other engineering programs from practice perspective, as well as contribute to current interdisciplinary engineering education literature.

APPROACH OR METHODOLOGY/METHODS

This study adopted the comparative case study approach, and conducted a three-phase data collection and analysis process to investigate the student outcomes, curricular structure, and contributing factors. Particularly, the "*Internet +*" program at University A and the "*New Engineering*" program at University B were selected.

ACTUAL OR ANTICIPATED OUTCOMES

This study offers preliminary insights towards interdisciplinary curriculum design, results show that general engineering, interdisciplinary innovation, and future-oriented competencies constitute student outcomes in Emerging Engineering programs, and lead the whole process of curriculum design. Therefore, student-centred curriculum with cross-department involvement is designed to achieve these outcomes, and internal supports at university, academic departments, and individual levels along with external supports from industrial partners jointly contribute to designing and implementing these interdisciplinary curricula.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Curriculum design of the Emerging Engineering programs is a holistic project that requires coordination between vision, teaching, and support. Further study is needed to include pedagogical insights based on multiple cases in different countries.

KEYWORDS

Curriculum design; emerging engineering programs; interdisciplinary

Introduction

The globalized world is moving towards the Fourth Industrial Revaluation, with burgeoning needs for engineering education to quickly respond to the accelerating technology trends and educational reforms (Das, Kleinke, & Pistrui, 2020; Sakhapov & Absalyamova, 2018). Accordingly, China launched the “New Engineering” initiative in 2017, with aim to actively respond to the urgent needs for reforming and transforming engineering education towards future (MOE, 2017). The “New Engineering” is regarded as the 2.0 version of the Plan for Educating and Training Outstanding Engineers (PETOE) launched in 2010, therefore, engineering programs under this new agenda can be divided into three categories: the Upgrading Engineering programs that are transformed and upgraded from traditional engineering programs, the newly Generating Engineering programs that are established from multiple disciplines including both engineering and non-engineering disciplines, and the Emerging Engineering programs that are newly emerged towards the emerging industries (Lin, 2017). Among the three categories, the Emerging Engineering programs account for an essential but entirely new field, which emphasize restructuring undergraduate engineering education in an interdisciplinary way so as to cultivate engineering students for the emerging industries. However, hardly any existing experiences can be learnt from to develop such Emerging Engineering programs, particularly, how to design the curriculum of such programs remains to be an ill-defined question. Although many studies have noted that the curriculum should be interdisciplinary, industry-oriented, and support comprehensive competencies training such as interdisciplinary knowledge and skills, engineering leadership, complex problem solving, sustainable development, and et al. (e.g., Lin, 2020; Fan & Xia, 2020; Cai & Ding, 2019), there remains path dependence on traditional curriculum design. The path dependence of the curriculum means that the Emerging Engineering programs have the tendency to follow the curricular structure of traditional engineering programs rather than satisfy the interdisciplinary demands.

Although there exists lots of studies related to the “New Engineering”, and indicated the value and significance of interdisciplinarity in innovating and reforming engineering education in China (e.g., Lin, 2018; Yang & Yu, 2019; Xu & Zhou, 2019), interdisciplinary teaching and learning is still not deeply and systematically rooted in current engineering curricula. As previous study pointed out, interdisciplinarity is often hard to implementation in academic settings (Klein, 2005), as a result, both educators enrolled in the Emerging Engineering programs and researchers who have interests in such programs have not found common ground on the implementation and development of these programs, particularly the curriculum design.

From a process perspective, interdisciplinarity is indicated by academics as a possible way to entail the training of creativity, innovation, systematic thinking, and self-motivated learning (Haynes, 2017; Summers, 2005). From a result perspective, interdisciplinarity is often regarded as a concrete capability of engineering education (Gero, 2014; Lam, Walker, & Wills, 2014). No matter which perspectives, interdisciplinary curriculum is considered to improve students’ learning (Lattuca et al., 2004), especially the intrinsic integrative processes that students might not learn from other disciplinary learning (Borrego & Newswander, 2010). At the same time, the integration process of interdisciplinary curricula required clear learning goals (Gresnigt et al., 2014), teaching and learning approaches (Navarro et al., 2016), institutional coordination and supports (Aquere et al., 2012; Karlsson et al., 2008).

Accordingly, the Emerging Engineering programs at both practice and research levels provided an opportunity for systematically innovating interdisciplinary curriculum design, and meeting the needs from both students and society. Therefore, this study focuses on the learning goals or student outcomes, the curricular structures, as well as the contributing factors in achieving interdisciplinarity. Guiding questions in this study include: 1) What distinctive student outcomes are emphasized by the interdisciplinary Emerging Engineering programs? 2) How the curricula are structured to achieve such student outcomes? 3) What

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are the key factors contributing to future interdisciplinary curriculum design of the Emerging Engineering programs?

Based on the three research questions, we adopted the Vision-Teaching-Support educational processes Van den Akker (2003, pp. 1–10) proposed in researching on curriculum, and modified it to better fit the framework in facilitating interdisciplinary engineering education (Van den Beemt et al., 2020).

Conceptual Framework

Curriculum design is both a process and a system, rather than a result or an independent component, it requires more than just determining which courses to be taught (Fraser & Bosanquet, 2006), but including learning process and content, teaching methods, and learning outcomes (Modo & Kinchin, 2011). Therefore, a systematic approach is essential for curriculum design to integrate student outcomes, curriculum-content, as well as the institutional approaches (Hayes, 1989; Khan & Law, 2015). The Vision-Teaching-Support framework Van den Beemt et al. (2020) applied in interdisciplinary engineering education to identify educational processes does not merely focus on curriculum design, it also provides an integrative approach to investigate the student outcomes, curricular structure, and contributing factors in interdisciplinary engineering programs. Therefore, this paper modified the Vision-Teaching-Support framework to support the analysis of the whole picture of curriculum design in Emerging Engineering programs, with interdisciplinarity as its core character. Specifically, "vision" in this paper serves as the bridge to explore the first research question by describing the basic goals of the Emerging Engineering programs, which can be specifically identified by the expected student outcomes. "Vision" of the Emerging Engineering programs is helpful to identify the reasons behind the emergence of these programs in the field of engineering education. "Teaching" is key to curriculum design because it directly focuses on curricular aspects of the Emerging Engineering programs such as curricular content and structure (Aikenhead, 1992), and connects the overall curriculum with the vision. "Support" refers to contributing factors from the institutions and departments or schools, including the preferential policies and resources for curriculum design. As a result, the modified Vision-Teaching-Support framework (M-VST) in this paper can be illustrated in Figure 1, with emphasis on the teaching dimension, and its connections of the other two dimensions.

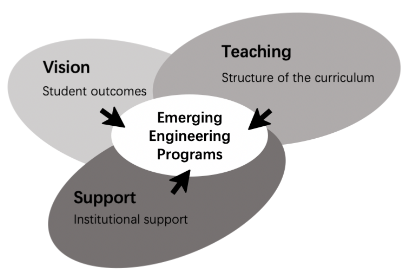

Figure 1. M-VST Framework for Curriculum Design in Emerging Engineering Programs

Methods

This paper aims at theorizing the construction of the Emerging Engineering programs, in order to make sense of the ill-defined questions in interdisciplinary engineering education. Therefore, we adapt the Comparative Case Study (CCS) approach proposed by Bartlett & Vavrus (2016) to characterize the curriculum design of the Emerging Engineering programs, in terms of vision (student outcomes), teaching (curricular structure), and support (contributing factors). The three educational processes of vision-teaching-support well matches the multiple levels of case-based research of the CCS approach (Bartlett & Vavrus, 2017). At the macro level, the programs identified in this paper share a same major policy,

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that is, both were established after the launch of New Engineering inititative under the context of the Fourth Industrial Revaluation. At the meso level, the programs were implemented quite differently in different institutional environment, particularly, one is comprehensive research university with strength in basic science and humanity and social science, and the other is research university with a long tradition and strength in engineering. Therefore, the advantageous disciplines and university policies varied. As a result, the programs were enacted differently at the micro level, especially the student outcomes and curricular structures.

Five including criteria are used to select our programs: 1) at undergraduate level; 2) established at a research university, this aims to reduce the possible variations of the institutional environments which the programs are embedded in (Eisenhardt,1989); 3) established in recent five years, this is because of a four-period of undergraduate learning. According to first three criteria, 23 programs at 31 research universities yielded. Then a fourth criterial was introduced in order to better illustrated the characteristics of the Emerging Engineering programs, that is, 4) it must be an interdisciplinary program rather than a thread of multiple disciplinary curricula or a broader field of discipline. These 23 programs were re-screened on their websites and 18 were excluded because of the fourth criterion. As a result, 5 programs were kept at 3 universities, and can be divided into two categories: single program or “umbrella” program. The authors intend to use the term “umbrella” to clearly identify the institutional factors at meso university level, therefore, a fifth criterion was introduced: 5) it is jointly established by multiple departments rather than only one existing department or school. As a result, 2 programs were finally included in this paper: the “*Internet* +” program at University A, and the “*New Engineering*” program at University B. Both were not accredited by the China Engineering Education Accreditation Association (CEEAA) because of the interdisciplinarity and the short time period after established.

Our approach includes a three-phase data collection and analysis. The first phase begins with seeking out key sources including journal articles and news reports related to the two programs, as a result, 1 journal article and 12 news reports directly were found. The second phase is semi-interviews with both enrolled students and responsible administers to help better identify the curriculum designing and implementing process of the two programs, as a result, the researchers conducted 5 interviews (all around 60 minutes) with 4 faculty/staff and 2 students (two faculty/staff were interview at the same time). Two of the faculty/staffs shared study plan of the programs which constitutes key documents of this paper. The third phase identifies whether follow-up data collection is needed, as result, a follow-up informal interview with one of the students was conducted. Totally, 1 journal article, 12 news reports, 2 study plans, 5 interview records and a follow-up record, as well as other segmented documents constitute the dataset of this paper. Finally, through a thematic analysis approach (Braun & Clarke, 2006), all collected data were analysed in a constructionist way to identify the emphasized student outcomes, curricular structure, and contributing factors. Findings will be reported in next section, and according to the requirements of our interviewees, the university names are innominate while the program names are explicit.

Findings

Vison: Engineering + Interdisciplinary Innovation + Future-Oriented

Three categories of student outcomes emphasized by the two Emerging Engineering programs emerged, we define them as general engineering, interdisciplinary innovation, and future-oriented competencies (Figure 2).

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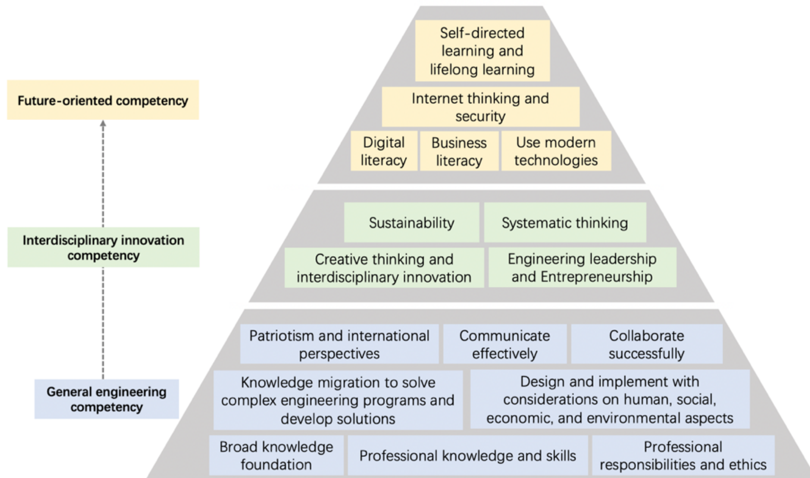

Figure 2. Student Outcomes Identified in Emerging Engineering Programs

General engineering competency includes knowledge from diverse fields, and basic interpersonal skills that directly connect with engineering education and practice. Interdisciplinary innovation competency entails execution intelligence and creativity, and encourage interdisciplinary collaboration and knowledge sharing continuously. Future-oriented competency emphasizes core capabilities necessary for our modern society, especially under the Fourth Industrial Revolution. It is worth noting that although "self-directed learning and lifelong learning" is considered as a common requirement in current engineering programs, we included it in future-oriented competency rather than general engineering competency is due to the accessibility of ICT and online resources, as well as students' "*amazing learning abilities*" in modern society (Mentioned by our all faculty/staff interviewees). In our analysis we noticed that such student outcomes go far beyond than the accreditation standards in CEEAA and the Accreditation Board for Engineering and Technology (ABET), which indicates that the Emerging Engineering programs serve as pioneers in innovating engineering education in China, as well as improving quality of engineering education gradually (Lin, 2017).

Teaching: Student-Centred and Cross-Departmental Coordination

Both programs in this paper can be regarded as "umbrella" program which consists several concentrations. the "*Internet* +" program includes 6 concentrations: Smart Internet of Things (SIoT), Materials Genome (MG), Smart Energy (SE), Artificial Intelligence (AI), Big Data Processing (BD), and Internet Finance (IF); and the "*New Engineering*" program includes three concentrations: Intelligence Science and Technology (IST), Microelectronics Science and Engineering (MSE), and Artificial Intelligence (AI). Therefore, the curriculum of the programs is designed across different departments, and distinct curricular structures are formed (Figure 3, Figure 4).

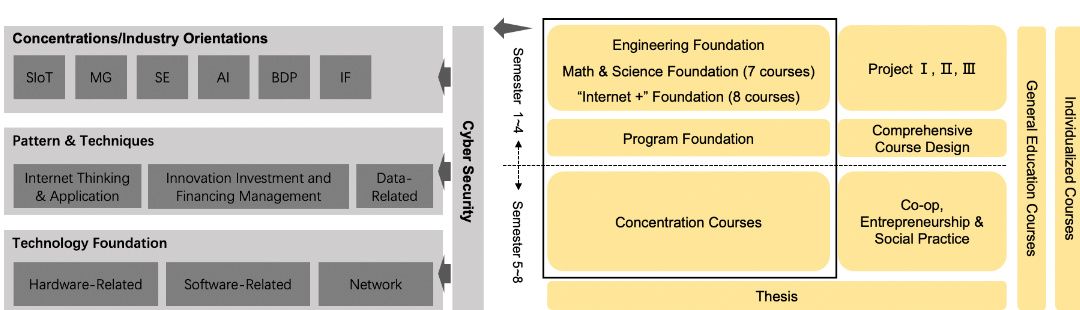

Figure 3. Curricular Structure of the "*Internet* +" program

The curricular structure of the “*Internet +*” program is defined as a “2+2” structure with dual degree (Zhou et al., 2018), that is, one unified learning period (semester 1-4) plus one professional learning period (semester 5-8), and students are encouraged to pursue dual degree under different concentrations. The advantage of the “2+2” structure is the high efficiency to achieve interdisciplinarity. As student Wang noticed:

> *Because it is a mixed structure, I can learn AI along with economics and management, and I would be awarded dual degree when I graduate. That means we not only choose courses within our original programs, but also select interested courses in other departments, and finally, our interests can be support by the dual degree. Wonderful, right?*

The curricular structure of the “*New Engineering*” programs is defined as a “2+X” structure, that is, “2” refers to general education and professional education, and “X” refers to individualized development pathways. These pathways include:1) advanced professionalism pathway connecting with honour degree, 2) interdisciplinary development pathway connecting with minor degree, and 3) entrepreneurship pathway. Honour degree and minor degree are not essential conditions for the first two pathways, students can pursue a regular degree rather than an honour or minor degree under the two pathways via advanced professional course packages. The entrepreneurship pathway is always supported by the course threads such as the “Big” Health thread and the Intelligent Electronic Information System thread. Here, the thread means a list of interdisciplinary courses that designed by faculty from diverse departments, with aim to better serve the increasing entrepreneurship needs of students. Currently, the most common pathway of the “*New Engineering*” program is “X1” (Figure 4). Great benefit of this structure is that different needs and interests of the students can be satisfied via only one study plan, furthermore, students’ deeper interests and curiosity can be easily aroused. As student Yang implied:

> *I think the most beneficial aspect is that we can choose the courses that we are truly interested in, and therefore we will study deeper and learn more related knowledge, as a result, we challenge ourselves rather than only purse GPA. Also, we have more time to enroll into labs or internships.*

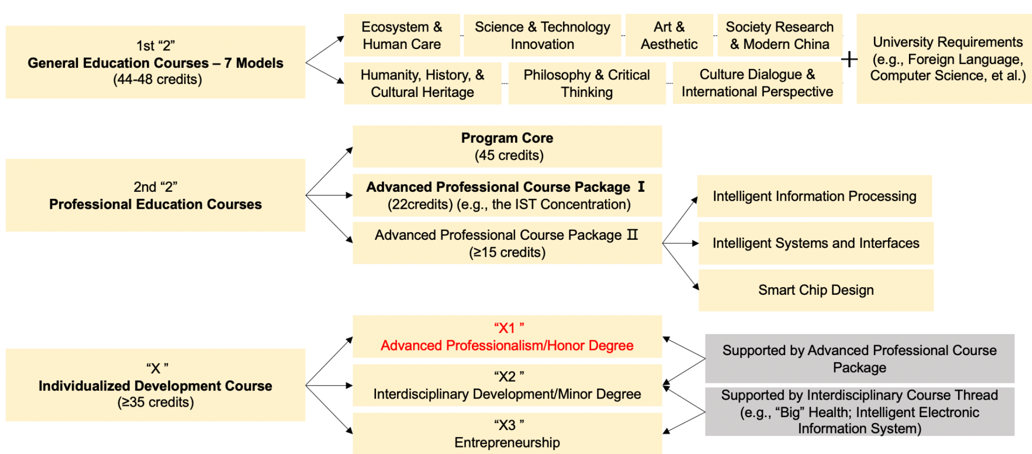

Figure 4. Curricular Structure of the “*New Engineering*” program

Common characteristics of curricular structures between the two programs include the flexibility to serve the student-centred idea, which runs through the whole process of curriculum design, the cross-departmental coordination to guarantee the cutting-edge and interdisciplinary curricular content. We observed that the two features well balance the needs of both students and the industry, and therefore facilitate interdisciplinarity in an innovative method.

Support: Holistic Project with Joint Efforts Internationally and Externally

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The design process of the two programs indicated that interdisciplinary engineering education is a holistic project which can only be achieved through joint efforts at multiple levels including university level coordination and policy support, department level activeness and resource, and individual level recognition and involvement (e.g., dean and faculty). At university level, our analysis finds that preferential policies and resources to the Emerging Engineering programs are the most significant factor to efficient curriculum design and implementation. For example, the "*Internet* +" program is supported by not only resources such as innovation labs, specialized labs and seminar rooms, but also policy convenience such as scholarships, postgraduate recommendation, co-op internships, and overseas study opportunities. Under these supports, individual and professional recognition of the program significantly increased. At department level, active involvement of faculty from diverse disciplines greatly guaranteed the teaching and learning quality of the interdisciplinary curriculum. Along with faculty's integrative participation, the existing course across departments have been utilized by the Emerging Engineering program maximumly. At individual level, faculty is motivated to focus more on teaching and learning rather than merely research, at the same time, their cutting-edge research projects are introduced into curriculum, which further contributes to the integration of teaching, learning and research. For example, the "*New Engineering*" program has attracted researchers in related fields to actively participate in teaching and learning, they not only introduce novel ideas in teaching and learning methods, but also cutting-edge research, which helps continuously improve the interdisciplinarity of curriculum. At the same time, they have an opportunity to find potential outstanding undergraduate students who are interested in research, and attract them into their research groups.

Apart from internal supports at multiple levels, external stakeholders such as the industry has also been involved. Activities from the patterns of the industry consist giving lectures, joint-designed courses, offering internships, and hosting forums. For example, one foundation course of the "*Internet* +" program is "Industry Lecture Series", which was held biweekly by managers or employees in key business sectors from various industries. Feedbacks from students indicated that although systematic knowledge learning or skills training is not provided in this lecture, students benefit a lot from recognizing industrial trends, and finding their interests.

Discussion and Conclusion

The two Emerging Engineering programs established in the context of the "New Engineering" major policy in China provided new insights into the Vision-Teaching-Support framework in curriculum design and interdisciplinary engineering education (Van den Akker, 2003; Van den Beemt et al., 2020).

Findings in this study show that Emerging Engineering programs emphasized general engineering, interdisciplinary innovation, and future-oriented competencies, which are high-level outcomes comparing with the accreditation standards. Therefore, it is of great significance to prepare students with future-oriented competency. These competencies closely relate to curriculum design. We also identify two different curricular structures supporting the achievement of the "vision" of the curriculum. As a result, student-centred structures which integrate curricular content from diverse deferments constitute core of curriculum design. Furthermore, the formation of the deeply interdisciplinary curriculum requires joint efforts from the university, academic departments, faculty/staff and students, as well as industrial partners.

As we and related studies have suggested, interdisciplinary engineering education calls for broader-reaching learning outcomes (Klein, 2013), integrative involvement (Gresnigh et al., 2014), and systematic coordination. Also, teaching and learning strategies or pedagogies are required to be enrolled in (Khan & Law, 2015). In this study, we find that interdisciplinarity might also serve as an "interdependent variable" to facilitate students' learning, for example, students embrace challenge-based learning when then are motivated by interdisciplinary

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coursework. Yet how challenge-based learning, project-based learning, and other teaching and learning methods can be promoted by interdisciplinary curriculum design still remains an ill-defined question. This gap brings us back to the conceptual framework, more aspects across the three dimensions are required to be identified to support future curriculum design in interdisciplinary engineering education. Therefore, our future work includes incorporating pedagogies, assessment, and other aspects in the overall study of interdisciplinary curriculum design. Also, we imagine enhancing interdisciplinary curriculum design via including more experiences and practices, not only in China but also globally to amplify our samples and datasets, and finally contribute to institutionalizing interdisciplinary engineering education at both educational and practical levels.

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Faculty perspectives on Future Engineering Education

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ABSTRACT

New societal challenges have emerged, and the Sustainable Development Goals present a concise summary of the engineering grand challenges (National Academy of Engineering, 2007). Further, the global society face challenges such as digitalization, future sustainable development and industry 4.0 engineering education is expected to respond by educating engineers with the relevant knowledge and competences useful in dealing with these complex problems both in terms of technology, climate and society (Kolmos, 2021). Engineers need to see themselves as global citizens embracing the human challenges, and engineering institutions need to prepare graduates to be able to work on solutions to these complex problems. Future engineers need to understand the impact of new technologies both on an individual level as well as at a systemic and societal level. Not least to understand how technologies can contribute to solutions for future complex societal problems.

The question is how engineering education will respond? What are the strategies for developing the academic disciplines and the future engineering competence profiles, and which changes emerge in curriculum when adapting to future emerging technologies and complex problem solving? Five Nordic Universities have participated in this study (Denmark, Finland, Iceland, Norway and Sweden). From each university four professors have been interviewed. The professors represent four different engineering disciplines: mechanical engineering, civil engineering, biotechnology and energy engineering. These disciplines are common engineering disciplines, offered at the selected universities.

All engineering education in the Nordic countries follow the Bologna structure with three year Bachelor and two year Master education. The aim of this study is to study and compare how different faculties anticipate and predict future changes within their discipline.

The findings indicate that there are differences among the four disciplines. The engineering programs with a more core science component such as energy and bio technology anticipate less differences in the future curriculum compared to mechanical and civil engineering. All disciplines anticipate that emerging technologies such as big data and AI will influence the curriculum, and especially production/mechanical and civil engineering also point out new learning objectives like systems understanding.

Having in mind that engineering education is a broad field the aim of this study is not to highlight a single coherent outcome but to highlight approaches and understandings for how to prepare future engineering education from an engineering faculty perspective.

KEYWORDS
Nordic STEM, Engineering education, future complex problems

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Introduction

New societal challenges like climate change, biodiversity, and the Sustainable Development Goals (SDGs) have emerged. Engineering institutions need to prepare graduates to be able to work on understandings and solutions to these goals. An engineer might think that their work is only relevant to clean water, energy, industry, smart cities and responsible production. However, technology underpins the entire society and technology should contribute to improving all the SDGs as well as poverty, hunger, health, equality, work and economic growth, climate action, life on land and in water, peace, and partnerships. Engineers need to see themselves as global citizens and embrace the human challenges.

The new emerging technologies will change human interactions, including the way engineering education is organised. There will be an expected increase in the use of the emerging technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and robotics, and these will saturate all corners of society from the daily life of citizens to industrial production and global collaboration. Future engineers need to understand the impact of these new technologies for the individual as well as at a systemic and societal level, not least to understand how the technologies can contribute to a solution to one or more of the SDGs.

As the global society face challenges such as the SDGs, engineering education is expected to respond by educating engineers with the relevant knowledge and competences to come up with adequate solutions. There is no doubt that engineering and science will be essential in solving these issues and in redirecting the global society for a sustainable world.

We need to educate engineers who are able to deal with these complex problems both in terms of technology, climate and society (Kolmos, 2021). The question is how faculty in engineering education respond?

Regardless of wether we are approaching the future from the fourth industrial revolution or from a sustainability angel, there will be a need for interdisciplinary collaboration. Industry 4.0 is embracing all digital technologies and thus bring drastic changes to both industry and society. The application of new technologies such as the Internet of Things (IoT), Artificial Intelligence (AI) and robotics, advanced materials, additive manufacturing, multidimensional printing, bio and neuro technologies, virtual and augmented realities and many more are just some of the new technologies which characterise the fourth industrial revolution (Lorenz, Rüßmann, Strack, Lueth, & Bolle, 2015). The Boston Consulting group emphasize that the interaction among the single technologies is necessary for an efficient and automated production and if engineering education should be exemplary and match the needs of companies, there would be a need for interdisciplinary collaboration across a number of programs and disciplines. At the university level, this will involve collaboration among computer science, robotics, automation, production, management, electronics and not to forget materials as necessary elements in the education of engineers.

In Japan the concept of Industry 4.0 has been brought into a new concept of Society 5.0 to indicate that the emerging technologies are not only about industrial efficiency, but indeed also about how the digital technologies are connected to people and systems which are all connected in cyberspace and by the application of AI (Nahavandi, 2019; Onday, 2019).

The development of new technologies as well as the ability of using existing technology is of vital importance when addressing the Sustainable Development Goals such as poverty, hunger, health, water and energy. To achieve this desired development engineering education needs to respond to these challenges and educate graduates who can handle these challenges. A need for a more holistic, system-based and interdisciplinary approach to engineering knowledge and engineering learning appears significant. Obviously, there is a need for more attention to understand and integrate interdisciplinarity to be able to analyse and develop sustainable solutions to these complex problems, and for students to learn methods for how to deal with complex, real-world problems such as the sustainability problems.

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Faculty approaches

A limited amount of research exist on faculty approaches to future engineering education. Few studies have been conducted on how faculty perceive employability or so-called work-related learning aiming to prepare students for the engineering profession. A Swedish study indicates that academic faculty are relatively positive towards including employability issues in the curriculum. Especially faculty members with prior work experiences valued employability and the study also finds that faculty members consider preparations for the engineering profession an essential part of engineering education (Magnell, Geschwind, Gumaelius, & Kolmos, 2014).

A US study reports considerable differences in how three different stakeholder groups regard employability: the graduates, the faculty educating them and the human resource managers who are recruiting the graduates (Rosenberg, Heimler, & Morote, 2012). The three stakeholder groups gave a rather diverse view on the skills needed for the job, the skills learned in education and the additional need for training. The academic knowledge together with critical thinking got the highest priorities for the faculty.

Another study also clearly indicates that faculty across academic departments do have very different perceptions across the different engineering branches of how to integrate employability into engineering going from *add-on strategies to integration by pedagogies to a value and competence perspective* (Magnell & Kolmos, 2017). This reminds us that engineering embraces many different scientific profiles from life sciences like biotechnology, to physics based engineering like energy to construction and industry based engineering branches like civil engineering and production.

Few studies have been conducted on faculty perceptions on the integration of sustainability. A Swedish study on academic staff perceptions show a large variation in perceptions of sustainability from waste separation to a complex understanding and integration of sustainability challenges (Sammalisto, Sundström, & Holm, 2015). The study also indicates that if sustainability should become an institutionalized part of the curriculum, the role of the top management is crucial in the acceptance and implementation process.

In another study, Shepard and Furnari (2013) identified different views among faculty members varying from, on the one hand, strong arguments for integrating sustainability issues in the curriculum to, on the other hand, an emphasis on academic freedom and the right to choose what and how to teach.

The few studies on faculty perceptions are more focused on looking back, or on looking at the current situation, than looking ahead. Students' perceptions and learning is much more researched, even if the formal and the taught curriculum is constructed by faculty who will normally be at the university for lifetime. So, the faculty perceptions are incredibly important for the future of engineering education.

For this study, the overarching aim is to find out how engineering education responds to contemporary challenges such as the need for the development of a Sustainable society and the transformation into a digital society and which changes can be anticipated for the next coming 10-year period?

Methodology

The study is based in the Nordic context, which is interesting given that this constitutes a relatively homogeneous group of countries that partly share culture and geographical environment. At the same time, these countries have completely separate political systems, which means that universities and education have nevertheless developed quite independently of one another. The study focuses on perspective provided by the university faculty. Professors from five Nordic universities, each representing one Nordic country, Denmark, Finland, Iceland, Norway and Sweden are included as participants. The professors represent four different engineering disciplines; mechanical engineering, civil engineering, biotechnology and energy engineering. These disciplines can be seen as common engineering disciplines and were offered at all selected universities.

Anticipation of the future and levels of implementation

Imagining the future can be difficult. The anticipation of the future is usually based on our existing knowledge of the presence and our expectations for the future which may be regarded as emerging trends – new areas that will grow. Lustig (2017) has formulated three horizons which can be applied as indicators for finding/analysing emerging trends (Lustig, 2017). The First Horizon is the current dominating trend of today – what are we doing. The second horizon represents the short- to medium-term development for the future. The third horizon is about what is emerging and will be tomorrow's trend, where the pockets of the future will be visible. Here it is difficult to find a real pattern - or just to imagine what the emerging trends can be. It might be difficult to distinguish between horizons. The second horizon overlaps and link the current practice and the new elements of the third horizon and is a transition space. In order to be able to draw attention to the third horizon in the interviews, respondents were asked to both reflect upon how the present engineering education practice meets the challenges of today and how they imagine this to change in the long-term future, 10 years ahead. However, even when several of the institutions were undergoing changes, this proved to be challenging. It is difficult to imagine future trends and the interviews cover both what the respondents actually anticipate of the future, and the present challenges.

Context of the study

The universities offer engineering education of a similar structure, as all countries have adapted the Bologna agreement, in which 29 European countries agreed upon a system where students complete a 3–4-year bachelor's degree which may then be followed up by a 1-2 years master's degree (Case 2017). The learning outcomes are similar but not identical, as the Bologna model aims for students should be able to transfer between universities and countries throughout their studies. Most students do not enter the job market after their bachelor's degree but rather finalize their master's degree before entering the job market.

The universities vary in size, and in what educational model they have adapted. Three of the five universities describe themselves as a university that offers students an educational model that is special to their engineering education, but no more special than that the model works within the Bologna model.

Settings

Four professors at each of the five partner universities were selected to participate in a semi-structured interview. Out of the 20 interviewees, the majority hold a position as full professors and the others associate professors representing the following four engineering disciplines. 1. Biotechnology engineering 2. Mechanical (or industrial economy or production) engineering 3. Energy engineering 4. Civil engineering. They were chosen as either having a managing position in education at the university or a strong research position. The engineering disciplines were chosen because they constitute common engineering disciplines that have existed for a relatively long time. They also represent different types of engineering disciplines, where production, energy and civil engineering are seen as disciplines originating from the needs of industry, while biotechnology, chemistry and mechanics are more closely related to the traditional academic subjects. These disciplines were also available at all the participating universities, albeit under slightly different names and descriptions. As the effect of digitization was one of the challenges that the study intended to investigate, it was chosen not to include computer engineering as one of the disciplines to be investigated.

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Interviews

Most interviews were conducted by two persons from the project team: one main interviewer and one representative from the university of interest. On average, each interview lasted about one hour. Before the interview took place, the informants were provided with the interview protocol, including the questions and short texts presenting the three contemporary grand challenges the informants were asked to specifically reflect upon, sustainable development, digitalization of society and future employability. In this study, only sustainable development and digitalization is considered. They were also asked to give their personal perceptions of how the development of their research field was affected by the implementation of knowledge linked to the grand challenges.

The following questions formed the basis of the interviews.

1. How do you think the challenges affect the development of your discipline?
2. How do you think the challenges will affect the educational programme(s) you are involved in?
3. What do you expect the situation to be 10 years from now?
4. How will students learn engineering in the future?
5. Are there other challenges ahead that we have not mentioned?

The interviews were transcribed verbatim and were analysed with the help of the NVivo software. Due to the aim of this research an iteration between data-driven and concept-driven coding have been used. In the preliminary phase of the coding data was the driver of the coding, giving a possibility to detect and elaborate on important topics and elements from the interviews. Three coders have been coding the interviews, securing a wide perspective on findings from the interviews. Based on the three coding, six thematic concepts were highlighted. Data was then yet again coded, branching the interviews into these 6 thematic concepts, “Digitalization in education”, Sustainability”, “Industry 4.0”, “Employability”, “Interdisciplinarity” and “The future Engineer”. For this paper, focus has been on elaborating on the role and education of the future engineer and in particular on the themes sustainability, Industry 4.0. In doing so, it has been possible to create an overview of how the different interviewees envision the future of engineering education, creating a matrix of methods, approaches and competences for the future. As the interviews have been conducted with different universities and people from different programs, the aim of this research has not been to compare or find a common way of viewing the future of the engineer. Instead, the aim has been to highlight differences and similarities across different disciplines and countries providing understandings and approaches for how the broad field of engineering will be developed in the future.

Findings

The themes Sustainability and Industry 4.0 can be considered drivers for change, whereas the theme “Future engineering competences” is considered to represent the faculties’ present and future response to challenges such as sustainable development and opportunities such as Industry 4.0. There is consensus in the interviews that the need for Sustainable development and Industry 4.0 is and will change society. However, different opinions are expressed, concerning the change on teaching and future curricula. In the following two tables, an overview is presented.

Table 1: Findings according to country and discipline

Name of university	Interview 1	Interview 2	Interview 3	Interview 4
Aalborg University • Sustainability • Industry 4.0	Civil • Boundary condition – demand. Sustainable context. • New tools 3D Modelling, 3D printing	Bio • No big change (no push) • Big data – from lab to data analysis. Personalized medicine.	Energy • Agenda- Everything more sustainable • Big data, Energy "handling"	Production • Moral obligation. In our genes. • Analyse data (lack of it skills) Big and small. Transform from operation to monitoring, controlling. AI.
Aalto University • Sustainability • Industry 4.0	Mechanics • Academic advisor, student centred education. Focus on what the want to focus on. • More computations. A lot of data from tests	Bio • No demand. Not related to the core. New materials. Separate life. Teacher cooperation • Robotics, more programming, 3D..	Construction • Big issue. Using natural resources. Sustainable materials. Life-cycle-analysis. • Material technology, life-long-learning	Mechanical • Defined by law that companies make profit. No push for sustainability. Needs to be – no options – more panic • Both optimistic and pessimistic. Don't know how far it will go. Disappointing experiences.
KTH (Royal institute of Technology) • Sustainability • Industry 4.0	Production • Broad topic. Life cycle. Systems engineering. Track things – Big data, AI – cyber sec. More cross disciplinarity – no siloes • Getting competent people. Eco-syst.	Bio (technology) • A new sort of cross disciplinary program with clear focus on climate change or environment. Delayed response in well respected disciplines Math, physics. New education related to sustainability. • Life-long-learning	Civil • Environmental impact in building. – heating, life cycle, moisture, • More programming, Information models. Tools 3D objects.	Energy • More generalists less specialists. More holistic view on systems – needed in managed sustainability. They need to have good understanding for natural sciences. But also social sciences. • New materials. Education is not keeping up with speed in industry and society.
Reykjavik University • Sustainability • Industry 4.0	Civil • No push. Cheap warmth – less isolation. Getting more rain. Hydro power and geothermal. Few electrical cars – because of distance. • 3D modelling, AI, Strict building regulations last for 50 years.	Mechanical • No push. Ethics of engineers is important. Sustainability aspect in study • Collaboration – user is always human. Automatizing of things	Bio medical • No push. Just more and more need for education about sustainability. No interest a little bit of the track for biomedical engineering. Can be some project, can be a theme or something in different courses. • Big data, e-health	Production • No push. The sustainability has become much more acceptable than it was when I was in school. Life-cycle-analysis • AI, Data (huge amount), controlling data
University of Stavanger • Sustainability • Industry 4.0	Civil • Not change much. Need basis theoretic and that will be the same. New materials. Focus needs to change in education • BIM, 3D printing	Mechanical • New materials, new methods of creating energy. • 3D printing, programming	Bio • Cope with them both in a theoretical and practical aspect. New ethics. • More is robotized (pipetting). More programming	Mechanics • No push. Will change when shaping the curriculum according to society. Discussing how can digitalization in education contribute to sustainability. • Digitalized manufacturing Robotised. 3D printing.

Table 2: Findings according to discipline and issues

Study Programme	Sustainability	Industry 4.0	Future Competences (how to achieve the challenges)
Bio	• No big change (no push) • No demand. Not related to the core. New materials. Separate life. Teacher cooperation • A new sort of cross disciplinary program with clear focus on climate change or environment. Delayed response in well respected disciplines Math, physics. New education related to sustainability. • No push. Just more and more need for education about sustainability. No interest a little bit of the track for biomedical engineering. Can be some project, can be a theme or something in different courses. • Cope with them both in a theoretical and practical aspect. New ethics.	• Big data – from lab to data analysis. Personalized medicine. • Robotics, more programming, 3D.. • Life-long-learning • Big data, e-health • More is robotized (pipetting). More programming	• No major changes to what they are doing now (courses, implementation of sustainability etc.) • More international collaboration • Life long learning • Knowledge of how to cope with complex problems • Strong disciplinary skills (the transdisciplinarity can be there but the disciplinary skills comes first) • More T shaped engineers in the future • Multi-disciplinary, multi-cultural projects
Civil	• Boundary condition – demand. Sustainable context. • Big issue. Using natural resources. Sustainable materials. Life-cycle-analysis. • Environmental impact in building. – heating, life cycle, moisture, • No push. Cheap warmth – less isolation. Getting more rain. Hydro power and geothermal. Few electrical cars – because of distance. • Not change much. Need basis theoretic and that will be the same. New materials. Focus needs to change in education	• New tools 3D Modelling, 3D printing • Material technology, life-long-learning • More programming, Information models. Tools 3D objects. • 3D modelling, AI, Strict building regulations last for 50 years. • BIM, 3D printing	• Holistic academic engineers (understand the detail in combination with the whole system) • Each engineer will have to know the context → not durable with just a synthesizer at the end. • System thinking + fundamental core skills • Workmanship (planning processes, systematical thinking) • Life long learning (stop imagining we can teach everything)
Energy	• Agenda- Everything more sustainable • More holistic view on systems – needed in managed sustainability. They need to have good understanding for natural sciences. But also social sciences.	• Big data, Energy "handling" • New materials. Education is not keeping up with speed in industry and society. • Balance between new things – too many thing – shallow – a combination.	• Use of linkedin/internet for networking • System thinking skills • Critical thinking skills • Solving problems in new ways • More generalists less specialists.
Production	• Moral obligation. In our genes. • Academic advisor,student centred education. Focus on what the want to focus on. • Broad topic. Life cycle. Systems engineering. Track things – Big data, AI – cyber sec. More cross disciplinarity – no siloes • No push. The sustainability has become much more acceptable than it was when I was in school. Life-cycle-analysis	• Analyse data (lack of it skills) Big and small. Transform from operation to monitoring, controlling. AI. • More computations. A lot of data from tests • Getting competent people. Eco-syst. • AI, Data (huge amount), controlling data	• Being able to handle data • Move away from the narrow specialist (have the deep dive but still keep the context broad to keep the generalism) • The T or ∏ shaped engineers • We need to have both the engineers with the deep dive and the system thinkers. • More interdisciplinary team work • Combine fundamental skills with contextual knowledge
Mechanical	• Defined by law that companies make profit. No push for sustainability. Needs to be – no options – more panic • No push. Ethics of engineers is important. Sustainability aspect in study • No push. Will change when shaping the curriculum according to society. Discussing how can digitalization in education contribute to sustainability. • New materials, new methods of creating energy.	• Collaboration – user is always human. Automatizing of things • Digitalized manufacturing Robotised. 3D printing. • Programming skills • 3D printing, programming	• Technical skills • The disciplines themselves are likely to change • System thinking is lacking • Always a need for very specialized engineers • Life long learning

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Sustainability

In terms of sustainability, clear differences are seen among the countries. The push for sustainability seems to be dependent on what country the informant represents rather than what discipline they represent.

A country such as Iceland seems to be less inclined to push for including sustainable development in education than some of the other countries. This fact is seen across all the disciplines. Iceland geographical conditions, with relatively long distances between places, have resulted in low numbers of electrical cars and the geological conditions in Iceland offer opportunities for using inexpensive energy such as hydropower and geothermal heating, compared to the other Nordic countries. As a result, for example indoor heating is very cheap, thus influencing civil engineering to a degree where less isolation is needed. Nevertheless, ethics of engineers is considered important for mechanical engineering education, and there is a responsibility to include sustainable aspects in the study programmes. More and more education in sustainability is needed and sustainability has been more accepted as a part of education during the last years.

Similar to Iceland, Norway seems to push very little for sustainability in the disciplines; however, the study indicates that there is a need for this to change, and as for mechanical engineering, it will change when the curriculum is shaped according to what society expects. Still, focus is on basic engineering knowledge, such as how mechanical systems work. For civil and energy engineering in Norway, new materials will be introduced and new methods for creating energy will emerge, however, the basic theoretic are expected to stay the same.

In Finland, there is no general push for sustainability either, but in mechanical engineering there are considerations that students should be able to choose courses to create an education based on their interests. For civil engineering in Finland, Sweden and Denmark there is a push for sustainability. In Finland it is considered a big issue, involving use of natural resources, sustainable materials and Life-cycle-analysis. In Sweden there is an environmental impact in building – heating, life cycle, moisture etc. and in Denmark it is mentioned as a boundary condition - a demand where the end user and funding agencies want a context that is sustainable. Opposite to this, civil engineering in Norway sees no push or change regarding sustainability. Students must learn the basic theoretic and this will stay the same regardless of external influences.

In terms of production there is a certain push in Sweden and Denmark. In Denmark, it is regarded a moral obligation, something that should be in their genes. But it is complex and they often have discussions about not knowing the consequences of the decisions made on sustainability. However, Danish students should not be leaving university without knowing they have an obligation and also have some opportunities. In Sweden, sustainability is considered a broad topic, involving important areas such as life cycle, systems engineering, the ability to track things (Big data, AI – cyber security) etc. and a need for more cross disciplinarity without siloes.

Looking at biotechnology and sustainability in particular, many similarities are found across the countries. Sustainability is not considered the core of the discipline, hence there is no push and less expectation for changes. In Finland, for example, no one is asking for more environmental microbiology, they want to have things that are more related to what they feel is the core. In general, all countries, focus more on “white” biotechnology rather than green biotechnology. Sustainability is considered an enormous area with many aspects to take into account. From Norway it is noted that even if there are potentials of solving problems, sustainable research comes with ethical limitations. For example - GMO – genetic modifications may be used to a higher degree for achieving sustainable solutions, however not all countries allow handling with GMOs.

Within the field of Energy, two professors from Sweden and Denmark have participated in this study. In Sweden, sustainability creates a focus on educating engineers who are able to have

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a holistic view on the systems working with. Fundamental knowledge of natural systems must be aligned with insight and knowledge from social science. In Denmark, the agenda is to make things more sustainable. The technology solutions for doing so are implemented. There are no new technologies that can really radically change the thinking, but there needs to be more effort put into opening the eyes for the students. Energy engineering in Sweden mentions more generalists less specialists and a more holistic view on systems is needed in managed sustainability. The students need to have a good understanding for natural sciences, but also for social sciences.

Industry 4.0

Compared to the challenges of sustainability, the challenges or opportunities concerning Industry 4.0 seem more similar among the countries. Big Data, AI, robots are all concepts that are connected with Industry 4.0. However, the ability to access Big Data affects the engineering disciplines differently. Personal medicine, e-health, biodata, energy management, test data and production data, etc. are some of the areas the informants mention as future areas. The development of 3D printing and 3D modelling is mentioned as important in several disciplines, especially civil engineering sees a great potential when it comes to BIM (Building Information Modelling).

Along with the appearance of new technologies and new tools, new routines and methods will follow, which will eventually influence the disciplines. In Denmark, this change is already present within biotechnology. More work is robotized, such as pipetting, and there is an ongoing transformation from students' lab work to data analysis. The use of Big Data has been part of biotechnology in Sweden and Norway for a long time. In production, the manufacturing process has been digitalized and a transformation from monitoring to controlling data becomes very crucial. For civil engineering and construction new materials emerge. Moreover, Energy engineering in Sweden describes new materials and the problem that education is not keeping up with speed in industry and society.

Future Engineering Competences

With an overview of focus points and challenges in relation to the themes sustainability and Industry 4.0, the professors identify a demand for changes in the curricula, embracing the demand for new engineering competences in the future. Here the significant differences are to be found among the disciplines more than among the countries. In general, difficulties concern the inclusion of new competences, as present curriculum is already filled with courses, project work and assignments spanning the full semester. Within biotechnology in particular, it seems crucial to keep the basic elements of physics and mathematics in the curricula, providing students with fundamental knowledge through existing courses. Biotechnology stresses the necessity of a strong disciplinary foundation and sees it as a part that cannot be neglected or reduced. Highlighting a necessity to come up with new tools and methods for how to expand and keep the professional edge. For the mechanical programs, it is stressed that the disciplines themselves are likely to change, but technical skills are mentioned as essential. Society will always need very specialized engineers who can nurture the basic foundation of the subjects, securing engineers to be able to handle and unfold the basic elements of the systems working in.

More of the disciplines regard holistic engineers, with strong system thinking skills, as essential for the future. In the future, more interdisciplinary teamwork will be required, and the ability to combine fundamental skills with contextual knowledge will be essential. Engineers will have to understand the details in combination with the context, giving the engineers a more holistic understanding of the problem with which they are working. Interviewees within the field of Civil Engineering in Denmark state the importance of holistic engineers who are able to combine their fundamental core skills with contextual system thinking. The future engineer must be able to bind the bits and pieces together in a broader context. The field of production also emphasizes the importance of a contextual understanding as an essential competence when

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entering the industry afterwards. It is concerned with providing students with deep disciplinary knowledge though still keeping the generalism at a level where the students are able to connect and interact with other disciplines. Creating a matrix combining vertical deep fundamental knowledge with horizontal interactions and contextual understandings across disciplines.

Even though biotechnology states the importance of deep fundamental competences, biotechnology in Finland also sees a need for educating engineers to be more skilled in using tools and methods for the future complex problems we are facing today. People are concerned with the unresolved issues we are facing, and it is emphasize to the importance of teaching engineering students to cope with these complex societal challenges and to translate these abstract, wicked challenges into manageable problems. It is about moving away from focusing only on educating the "I-shaped" engineers but to also focusing on educating "T-shaped" engineers with connections, understanding, respect and better capabilities for co-working with experts from other fields.

Production states the importance of data handling in the future. Engineers must have a profile that moves away from the narrow focused specialist towards more T shaped profiles or ∏ shaped engineers. Working with Big data is considered important for almost every discipline. Engineers should have professional knowledge about data, having in mind how to handle and analyse data, work with new tools like 3D modelling and develop efficient programming skills. For some of the disciplines there is a gap between the need and the competences available at present. Production in Denmark mentions a lack of skills concerning data analysis, and production in Sweden mentions the challenge of getting competent employees in the future. The combination of an extreme technology push for new markets and of getting hold of the right competences creates a need for life-long learning. Mechanical engineering in Iceland talks about automatisation, robots and programs and the relation to the user that is always a human being and how is it going to react to these new things. Therefore, the social and psychological effects of the industrial revolution need to be considered as well. Production in Denmark does not distinguish between small or big data but highlights the importance of engineers with competences to analyse the state of the system and know how to work based on data. Another digital aspect highlighted as important in the future is the use of Linkedin and the internet in general. Energy from Denmark emphasizes the importance of teaching future engineering graduates to use the internet in a smart way, applying and building strong professional networks around the world. Both in terms of knowledge sharing, research and competence development.

Conclusion

There are differences among the educational policies in the Nordic countries which become visible in the policies for the integration of sustainability in engineering education. Engineering is not just engineering. Engineering disciplines differ in how they approach the future engineering education. Engineering disciplines range from disciplines focused on basic sciences such as chemistry, physics, energy – all closely related to natural phenomena – to engineering disciplines established to solve problems or to fulfil needs and demands from society and industry. The study shows differences in how engineering disciplines respond to the external factors of sustainability and industry 4.0. Due to both disciplinary differences and differences among the countries, there are differences in the approach to sustainability. Basic sciences such as biotechnology stresses the importance of keeping a focus on core, fundamental competences essential for engineers now as well as in the future. As opposed to this, civil engineering is stressing the need for more holistic engineers in the future, able to apply a system thinking approach to problem solving. In general, all disciplines appear to have difficulties adding more to present curricula; this seems to be a barrier, and the universities struggle to find the right balance between deep fundamental knowledge in combination with interdisciplinary system thinking. However, more of the respondents in this study highlight the importance of students being able to learn-to-learn, to be able to adapt and develop their competences in a lifelong learning process. Methods and curricula must enable engineering

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students to understand and cooperate across disciplines and by that tearing down the walls between disciplines. An engineering profile that resonates well with the T-shaped engineering profile, which focuses on understanding the details of the problem in combination with an overall understanding of the system working in.

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Predicting and Evaluating Engineering Problem Solving (PEEPS): Instrument Development

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ABSTRACT

CONTEXT

Judging the feasibility of solutions has become an increasingly important engineering skill as engineering problem solving has become more complex and technology-dependent. Engineering education must take care to foster engineering judgement in our students to produce robust problem solvers primed to critically evaluate and interpret output. Our work uses expertise development and dual-cognition processing theories (Dreyfus & Dreyfus, 1980; Smith, 2009; Simon, 1987) to frame such engineering judgement as engineering intuition or the ability to assess the outcome of an engineering solution and predict outcomes within an engineering scenario (Miskioğlu and Martin, 2019).

PURPOSE OR GOAL

Our overarching goal is to create classroom interventions that explicitly recognize and enhance the development of engineering intuition. Accomplishing this goal requires a means of measuring engineering intuition before and after such interventions. This paper discusses our process to develop the Predicting and Evaluating Engineering Problem Solving (PEEPS) tool for measuring engineering intuition.

APPROACH OR METHODOLOGY/METHODS

PEEPS is built directly on our prior qualitative work with practicing engineers, which revealed the construct of engineering intuition (Aaron et al., 2020). The emergent findings were combined with questions adapted from the Concept Assessment Tool for Statics (Steif & Dantzler, 2005) to create a preliminary survey assessing intuition. Additional items asked participants to assess their level of confidence in their answers. The survey was designed such that the statics problems could be switched out for other forms of engineering problems. Think-aloud sessions were used to check face validity and usability prior to full deployment in Spring 2021.

ACTUAL OR ANTICIPATED OUTCOMES

This study details the process used to create PEEPS. Modifications were made following 19 think aloud sessions. The initial deployment in Spring 2021 resulted in 88 completed responses with responses primarily coming from white, male, aerospace engineering students who had previously performed well in their statics courses.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This work showcases a new survey designed to assess the engineering intuition of engineering students. Next steps include expanding the work to a more diverse sample of engineering students, further validity checks of the instrument, and pairing the instrument with newly created educational interventions designed to better foster engineering intuition development in students.

KEYWORDS

engineering judgement, problem solving, survey development

Introduction

It is important for engineering students to develop requisite technical and professional skills in preparation for an engineering career. This skill includes an ability to navigate problems, or intuition, which is critical to engineering practice (Miskioğlu et al., 2021b). A better understanding of intuition is central to being able to design curricula that promotes intuition development.

Intuition is a key trait of the expert in most expertise development models (e.g., Benner, 1984; Dreyfus & Dreyfus 1980; Chi, 2006). The concept of intuition also emerges as one-side of many dual-cognitive models. For example in Kahneman's model of System 1 versus System 2, intuition lies within System 1 and relies on fast responses and "gut feelings" that arise through recognition of patterns and previous experience (Kahneman, 2013). Intuitive responses are fast and effortless and accompany the development of expertise (Dringenberg & Abell, 2018). Experience is a primary contributor to development and implementation of intuition (Kahneman, 2013; Dreyfus & Dreyfus, 1980). Intuition is often domain-specific like expertise. Research has suggested that engineering intuition results from experience with the specific methods and situations of engineering problems (Penner & Klahr, 1996; Miskioğlu et al., 2020).

Engineering intuition has not been widely studied in engineering but has emerged in the fields of nursing and management because of its perceived role in expertise development. Intuition has been shown to be prevalent in nursing with more frequent use among more experienced nurses (Leners, 1992). Business managers use their intuition to make faster decisions when information is missing (Simon, 1987; Burke & Miller, 1999). Studies performed in both nursing (Smith, 2009) and management (Simon, 1987) have claimed that expertise is developed primarily through experience and recognition. A clear definition of and way to measure intuition are missing in the existing literature despite the wide acknowledgement of intuition in expertise models and the literature on nursing and management.

We have studied the definition of engineering intuition in previous work. We define it as the ability to: (1) assess the feasibility of a solution or response, and (2) predict outcomes and/or options of a scenario (Aaron et al., 2020). Our emergent definition comes from interviews with practicing engineering professionals to better understand how they make decisions on the job as well as their own perception of intuition and its use in engineering (Miskioğlu et al., 2021a). Our current aim is to develop an instrument capable of measuring engineering intuition quantitatively. Here we discuss the steps undertaken to create the Predicting and Evaluating Engineering Problem Solving (PEEPS), a tool designed to measure engineering intuition. The final objective of PEEPS is to measure the effectiveness of classroom interventions to support the development of intuition.

Methodology

PEEPS was developed during Spring 2021 as part of a mixed methods study. The design of PEEPS was informed by emergent themes that arose through qualitative interviews of practicing engineers. Themes were used to design survey questions that were tested using a think-aloud approach prior to deploying PEEPS more widely.

Question Development

Our qualitative work revealed that intuition consists primarily of two abilities: (1) the ability to predict an outcome, and (2) the ability to judge the feasibility of a solution or outcome (Aaron et al., 2020). The instrument consists of two main questions that ask respondents to provide a prediction and a "sensibility check" (i.e., judging the outcome).

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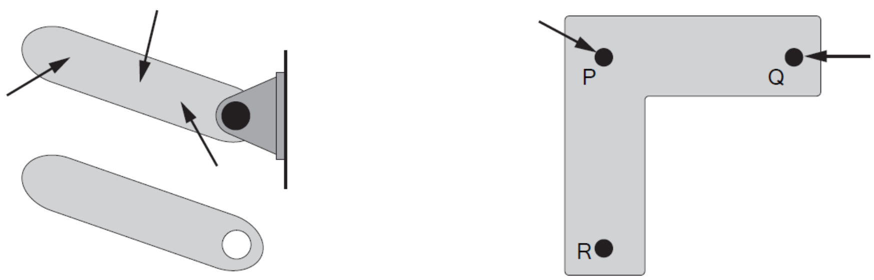
Our previous work has also shown that intuition and expertise are domain specific (Miskioğlu and Martin, 2019; Aaron et al., 2020; Patel & Groen, 1991; Seifert, Patalano, Hammond, Converse, 1997; Chi, 2006). For example, you might have intuition about how much stress a steel beam can sustain at room temperature but not at extremely low temperatures. Our survey structure recognizes this domain-specificity and serves as a template in which the technical question can be replaced to test intuition with respect to any engineering domain. Our initial work uses the domain of statics. Questions were obtained from the Concept Assessment Tool for Statics (CATS), which has been tested with adequate validity evidence (Steif & Dantzler, 2005; Steif & Hansen, 2006; Roman, Streveler, Steif, & DiBello, 2010). The two CATS problems we chose are shown in Figure 1.



Which one of the following additional loads, if given the right magnitude, could lead to equilibrium?

a. Sensibility check problem

Given the two non-zero forces in the image, which additional load, if given the right magnitude, could lead to equilibrium?

b. Prediction problem

Figure 1: Statics problems used for PEEPS

The CATS problems are context-free. A context was developed for each problem to better mimic a real-world engineering scenario. Stories, scenarios, or cases have been shown to support problem solving (Jonassen & Hernandez-Serrano, 2002; Mariappan, Shih, & Schrader, 2004; Segall, 2002). The prediction problem in Figure 1a became a partially opened hatch with the following setup.

> *You are building a bookshelf and are placing an L-bracket to keep a shelf in place. Given the two non-zero forces in the image, which additional load, if given the right magnitude, could lead to equilibrium?*

The sensibility check problem in Figure 1b became a support for a bookshelf initially with the following description.

> *Imagine that you are trying to open a hatch. You can only open the hatch partway, so the system is in static equilibrium. One side of the hatch has a pin which allows the part you are pushing to rotate freely without friction. Assume the weight of the system and your push through two hands results in the following 2D loads. Could the reaction of the pin be as shown?*

The modified CATS problems were reviewed by the research team and were also externally reviewed by a long-time statics instructor to ensure that the contexts we developed were appropriate.

The CATS problems described above represent the interchangeable domain-specific technical scenarios. The heart of the survey are the follow-up questions. For both problems we asked about the participant's confidence in their answer as our qualitative results demonstrated a link between confidence and use of intuition (Aaron et al., 2020). We also asked about their general process for arriving at the selected answer. The sensibility check question asked an additional three questions regarding the likelihood of taking additional steps to justify their answer if someone challenged them, the reasoning for their likelihood,

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and their first approach to justify their answer. The prediction question asked how likely they would be to go with just this prediction to their manager, the reasoning for the likelihood, and what would make them more likely to go to their manager. The survey ended with demographic questions to support testing differences between groups.

Face-validity Data Collection

Face-validity data was collected through a series of approximately 30 minute think-aloud sessions (Ericsson & Simon, 1993) with 19 undergraduate student participants between February and March of 2021. All participants were recruited from a single US institution after having completed statics. The intial pool consisted of 100 students. We ultimately pivoted to convenience sampling due to low yield from initial recruitment. PEEPS was initially created in Microsoft Forms for simplicity and was tested in Microsoft Forms by seven students. Microsoft Forms did not have the desired functionality, so the survey was moved to Qualtrics for the remaining think-aloud sessions.

Think-alouds were conducted iteratively in cycles that allowed us to update and retest the PEEPS. During the think-alouds, students verbalized their thoughts as they progressed through the survey. We conducted brief interviews following each think-aloud to gather additional data on the user experience with the survey navigation, survey length, question order, and question clarity. Think-alouds concluded when the survey no longer needed modifications.

Deployment

We deployed the survey in April 2021 recruiting participants via email. The survey was sent to engineering students who were currently enrolled or had taken a statics class. Emails were sent by the authors, faculty at other universities who taught statics, and others within the broader engineering education community. We targeted instructors in our professional networks as well as those at US-based institutions whose instructors for statics and dynamics classes were publicly listed. We also advertised the survey through the Educational Research and Methods division of the American Society of Engineering Education. Most of the instructors that replied directly were from US institutions. Student university affiliation was not collected, so the reach of the survey beyond the US is unknown. Responses were collected until mid-May. A total of 172 responses were collected, of which 88 were complete (two of these 88 answered some but not all of the demographics questions) and used for our dataset.

Preliminary Results

The results presented here demonstrate the survey evolution through think-aloud sessions as well as early results from the first deployment of the finalized survey.

Think-Aloud Results

The sample (see Table 1) roughly mirrors the demographics found in a recent survey on engineering universities (Roy, 2019; ASEE, 2021). The prevalence of seniors with internships and good grades suggests that this sample was relatively experienced with the types of questions being asked in the first deployment as the think aloud sessions were selected by convenience.
In response to the think-aloud sessions the survey was modified by: (1) adding an initial warm-up question, (2) changing the problem order, (3) re-wording the CATS scenario prompt, (4) modifying the illustrations, and (5) altering the follow-up question wording.

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Table 1: Think Aloud Participant Demographics (n=19)

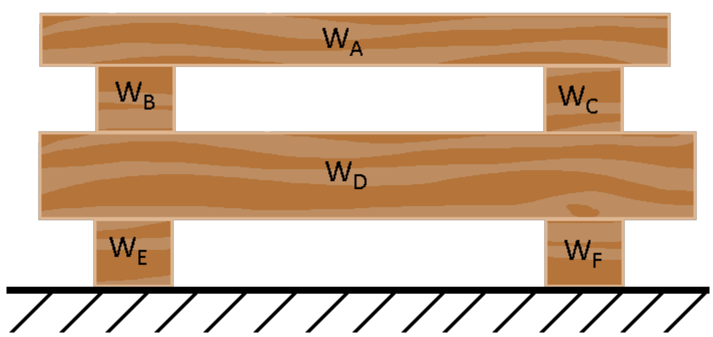
Gender	N	Year	N	Race/Ethnicity*	N	Internship	N	Statics Grade	N
Male	14	2nd Year	2	Asian	1	Yes	14	A	10
Female	4	3rd Year	2	Hispanic	3	No	5	B	9
Cisgender	1	4th Year	15	White	13			C	0
				Pacific Islander or Hawaiian Native	1			D	0
				Middle Eastern or North African	2			F	0
				American Indian Or Alaska Native	0				
				Black or African American	1				

* Multiple selections possible

(1) Adding an Initial "Warm-up" Question

Early think-aloud participants appeared to be startled by the question (responses were similar to "oh no") when they arrived at the first CATS problem. This response was alleviated by creating an easier problem (see Figure 2) at the beginning of the survey to reacclimate students with statics problems prior to assessing their responses. We once again added a context to the problem to help students situate the scenario.

Imagine that you are drying lumber by placing the drying pieces on top of smaller pieces of wood. The stack of wood is arranged symmetrically where $W_B = W_C$ and $W_E = W_F$.



Consider the free body diagram of W_B, W_C, and W_D. The contact force between two blocks is labeled so that N_{DE} is the force of block D on block E, and so forth. Which is the correct free body diagram?

Figure 2: Added initial statics problem

(2) Changing Problem Order

We switched the order of the two problems of interest (prediction and sensibility check) to align with increased perceived difficulty. Most students thought the prediction problem was more difficult, so this question was shifted to follow the sensibility check question.

(3) Re-Wording Sensibility Check Prompt

The prediction problem wording remained the same, but the sensibility check problem underwent a slight wording change with the final scenario sentence. Students were

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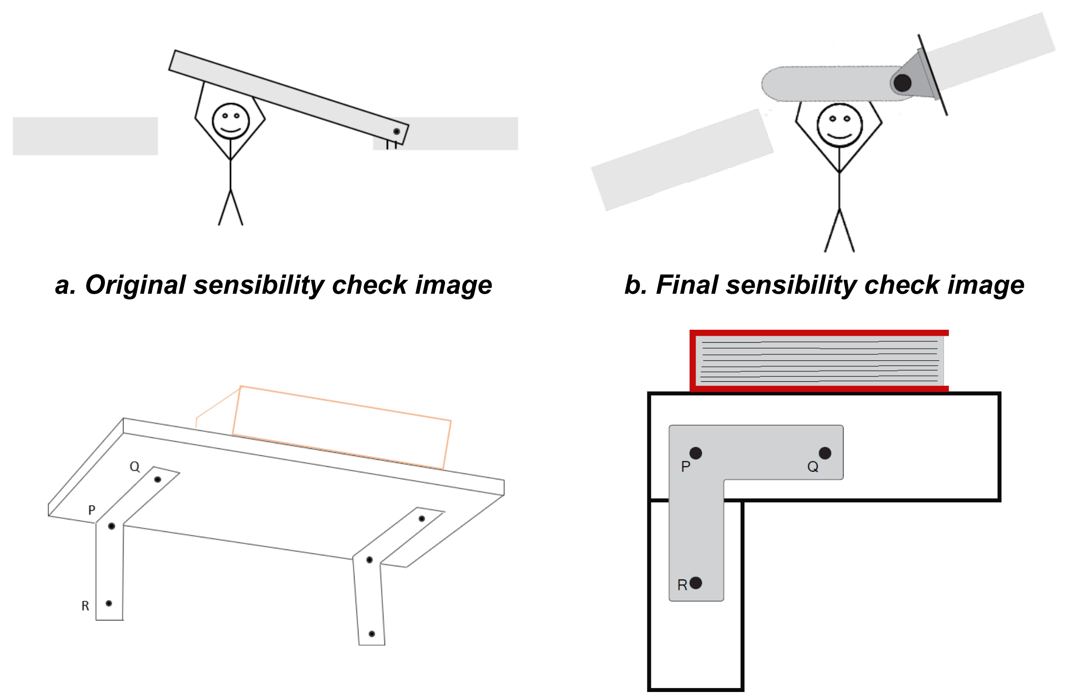
sometimes confused about the “push through two hands,” so we modified this language to “force through two hands” which was better received.

(4) Modifying Illustrations

We included figures within the survey to illustrate the context around the CATS questions. Figures (see Figure 3) were adjusted after feedback to better represent the forces in the CATS questions and clarify the images. For example, we rotated the “hatch” in the sensibility check problem (see Figures 3a and b) to better align the downward force seen in Figure 1a with gravity. The first version of the bookshelf prediction problem did not depict the L-bracket in Figure 3c as a flat object as shown in Figure 1b, so we modified how the L-bracket was attached to the bookshelf in the final version shown in Figure 3d. We also embedded the diagrams without forces from Figure 1 into the images in Figures 3b and 3d to better depict how the members related to the images in Figure 3.



a. Original sensibility check image ***b. Final sensibility check image***

a. Original prediction image ***b. Final prediction image***

Figure 3: Figure changes between first and final version of PEEPS

(5) Altering Follow-up Question Wording

The first two questions after the prompts remained the same (“How confident are you in your answer?” and “How did you choose your answer?”). The remaining questions were altered.

The original and final sensibility check questions are listed in Table 2. We realized that the first question listed in Table 2 assumed that students would justify their answer, so we modified that question to the likelihood that they would take additional steps to justify their answer. We also added in logic to skip the justification approach (final question in Table 2) if the students answered “definitely would not.” During the think-aloud sessions, some students were confused with the last (original) question on what “previous question” referred to, so we clarified the previous question in the final version and changed the order. We initially left the justification approach question as an open-ended question. Answers quickly converged to

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allow this question to be converted to a fixed-item, multiple choice question with an option to specify if not listed.

Table 2: Original and final questions for sensibility check question

Original Questions	Final Questions
If someone challenged you on your answer, how would you justify your answer? *[open-ended]*	In the event that someone challenged you on your answer, what is the likelihood that you would take additional steps to justify your answer? a. definitely would not *[if selected, skip final question]* b. maybe/not sure c. probably would d. definitely would
How likely are you to go through with the justification approach you chose in the previous question? a. definitely would not b. maybe/not sure c. probably would d. definitely would	Explain your reasoning for the rating you gave in the previous question (the likelihood of taking additional steps to justify your answer). *[open-ended]*
Explain your reasoning for the rating you gave in the previous question. *[open-ended]*	What would be your first approach to justify your answer? a. Perform calculations b. Check reference materials (static notes, textbooks, etc.) c. Physically demonstrate the system d. Not listed (please specify)

The original and final prediction questions are listed in Table 3. Students were reminded to reflect on the statics question at the beginning of the questions. The format was modified to mimic the flow of questions in the sensibility check prompt. We modified the open-ended

Table 3: Original and final questions for prediction question

Original Questions	Final Questions
If you were in a situation where your manager asked a similar question, how likely would you be to go to your manager with just this prediction? a. definitely would not b. maybe/not sure c. probably would d. definitely would	You've made a prediction about the loads on the bookshelf (your answer on the previous page). If you were in a situation where your manager asked a similar question, how likely would you be to go to your manager with just this prediction? a. definitely would not b. maybe/not sure c. probably would d. definitely would *[if selected, skip last question]*
How would you check your answer?	Explain your reasoning for the rating you gave in the previous question (the likelihood that you would go to your manger with just this prediction). *[open-ended]*
	What would make you more likely to go to your manager? a. First performing calculations b. First checking reference materials (static notes, textbooks, etc.)

	c. First physically demonstrating the system d. Not listed (please specify)

question to align with our primary interest in understanding the reasoning behind the choice rather than how the students would check their answer. We still wanted to know what additional work students would complete to feel more confident in going to their manager. A question was added to capture what would make students more likely to go to their manager with similar options to the last question in Table 2.

First Deployment Results

The first deployment following changes made from the think-aloud sessions resulted in 88 completed responses. The respondent demographics are shown in Tables 4 and 5. Respondents primarily identified as white and male, were mostly aerospace engineers, and over two-thirds had a parent with at least a 4-year degree. Respondents were primarily in their second-year (42%) followed by third-year students (28%). The average internship experience (n = 33) was 7.3 months for those with such experience.

The demographics of our initial survey are roughly representative of the race and sex profile of undergraduate enrolment in US universities (Roy, 2019). Aerospace engineers are overrepresented as the author’s university is primarily an aerospace-focused university. The number of students who self-reported receiving a B or better in statics indicates that our sample was relatively knowledgeable in the types of problems tested in this survey.

Table 4: First Deployment Participant Demographics (n=88)

Major*	N	Race/Ethnicity*	N	Parent’s Degree	N
Aero Engr.	45	American Indian	1	Doctorate	4
Mech Engr.	27	Asian	10	Masters	16
Civil Engr.	6	Black	3	4-year Degree	43
Other Engr.	3	Hispanic	7	2-year Degree	5
Physics	5	White	72	Some College	8
Math	2	Prefer Not to Answer	5	Professional Degree	1
Prefer Not to Answer	1			High School	7
				Less than High School	2
				Prefer Not to Answer	0

* Multiple selections possible

Table 5: First Deployment Participant Demographics Continued (n=88)

Year	N	Internship	N	Gender	N	Statics Grade	N
1st year	9	Yes	33	M	59	A	43
2nd year	37	No	52	F	24	B	25
3rd year	25	Prefer Not to Answer	3	Prefer Not to Answer	3	C	16
4th year	14					D	2
Prefer Not to Answer	3					F	1

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						Prefer Not to Answer	1

Early Results: Relationship between Answer Correctness and Confidence

Our initial analyses considered differences in confidence levels among respondents who correctly answered the sensibility check and prediction problems. The answers to confidence levels were re-coded as numbers (1 = not at all confident, 2 = maybe/not sure, 3 = pretty confident, 4 = completely confident). Both the prediction and sensibility check were found to not be normal using the Shapiro-Wilk normality test ($p < 0.001$ for both the sensibility and prediction problems), so the unpaired, two-samples Wilcoxon test (also known as Mann-Whitney test) was used to determine if the confidence levels of the students who answered correctly differed from those who answered incorrectly. The correlations between average confidence levels and correct/incorrect answer were significant for both the sensibility check problem ($p < 0.003$) and the prediction problem ($p < 0.002$). Respondents who answered incorrectly had lower average confidence for both the sensibility check problem ($p < 0.002$) and the prediction problem ($p < 0.001$) as demonstrated by the means of each group in Table 6. This result suggests that respondents were more confident when they got the correct answer. This alignment of confidence and accuracy may be a result of the overall high statics-performance of the participant population. The majority of the respondents self-reported having received a letter grade of A or B in their most recent statics course making it possible that this sample was better able to predict their outcome. That is, their high competence in the subject area may have given respondents a more accurate ability to evaluate their performance (Kruger & Dunning, 1999). The alignment between confidence and accuracy also suggests high metacognitive sensitivity of the respondents (Flemming & Lau, 2014). Further analysis and additional data collection to diversify the sample is ongoing.

Table 6: Summary Statistics of Confidence Levels by Correct or Incorrect Response (n=88)

Answer Response	Confidence - Sensibility Check			Confidence - Prediction		
	N	Mean	SD	N	Mean	SD
Incorrect	31	2.52	0.677	55	2.55	0.789
Correct	57	3	0.756	33	3.15	0.795

Conclusions and Future Work

This work details the creation and design choices behind PEEPS, a new survey designed to assess engineering intuition. A series of think-aloud sessions were used to modify the survey before initial deployment in Spring 2021. The initial deployment resulted in 88 completed responses primarily by high-performing, white aerospace engineers. Preliminary analysis suggests that when answering the prediction and sensibility check problems correctly, respondents were more confident in their answer.

Next steps for this project include validity checks of the instrument, further analysis of the results, and expanding deployment during the 2021-2022 academic year to obtain a more diverse student sample. The eventual goal with this survey is to be able to measure educational interventions that are designed to better foster engineering intuition development in students.

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Constructing a comprehensive and adaptive survey for cultural analysis of engineering departments

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ABSTRACT

CONTEXT
Culture influences the dynamics and outcomes of organizations in profound ways, including individual-level outcomes (like the quality of work products) and collective impacts (such as reputation or influence). As such, understanding organizational culture is a crucial element of understanding performance; from an anthropological perspective, 'performance' is not an outcome of culture, it is a part of culture. A key challenge in understanding organizational culture, especially in complex academic organizations, is the lack of a flexible, scalable approach for data collection and analysis.

PURPOSE OR GOAL
In this study, we report on our development of a survey-based cultural characterization tool that leverages both lightweight data collection from stakeholders in the organization and public information about that organization. We also integrate perspectives from prior literature about faculty, students, and staff in academic departments. Taken together, the resulting survey covers key elements of culture and allows for scalable data collection across settings via customizations and embedded logic in the survey itself. The outcome of this work is a design process for a new and promising tool for scalable cultural characterization, and we have deployed this tool across two institutions.

APPROACH OR METHODOLOGY/METHODS
We leverage prior research, our own preliminary data collection, and our experience with this approach in a different setting to develop a cultural characterization survey suitable for delivery to multiple engineering department stakeholders (faculty, staff, and students). We start with a modest number of interviews, stratified by these three groups and achieving saturation of responses, to understand their views on their organization, its strengths and weaknesses, and their perceptions of how it 'works'. We merge this information with public data (for instance, departmental vision or mission statements, which convey a sense of priorities or values) as well as prior literature about higher education culture. We also draw upon our experience in another setting as well as pilot testing data, and the result is a carefully-constructed set of dichotomous items that are offered to department stakeholders in survey form using an electronic survey platform. We also collect background and demographic information in the survey. The resulting data are analyzed using Cultural Consensus Theory (CCT) to extract meaningful information about the departmental culture from the perspectives of the stakeholder groups.

ACTUAL OR ANTICIPATED OUTCOMES
The resulting survey consists of two parts, each with sub-components. The two top level survey parts contain: (i) items common to all respondents in all settings (i.e. all institutions in this study), and (ii) a set of institution-specific items. Within those sections, the framing of the items is calibrated for the stakeholder groups so that items make sense to them within the context of their experience. The survey has been administered, and the data are being analyzed and interpreted presently. We expect the results to capture the specific elements of local culture within these institutions, as well as differences in perspectives and experience among the three primary stakeholder groups.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
This study demonstrates a scalable approach to survey development for the purposes of cultural characterization, and its use across settings and with multiple stakeholder groups. This work enables a very nuanced view of culture within a department, and these results can be used within academic departments to enable discussion about change, priorities, performance, and the work environment.

KEYWORDS
Cultural characterization, anthropology, survey development

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Introduction

Motivation

Academic culture is a complex manifestation of an organization's history, development, people, facilities, and practices. Understanding academic culture can afford insights into how an institution operates and why it achieves specific outcomes. Both the day-to-day operation and the adoption of new innovations are affected by culture (Baba & Pawlowski, 2001; Merton et al., 2009), and from an anthropological perspective organizational performance is an integral part of, not an outcome of, organizational culture. The engineering education research community has begun to apply cultural perspectives to the analysis of our education enterprise (Besterfield-Sacre et al., 2014; Borrego et al., 2010, 2013). Academic institutions do not possess a single culture, but instead are composed of multiple subcultures. Even within stakeholder groups (faculty, staff, or students) multiple subcultures emerge that further complicate the cultural milieu within an institution.

A significant challenge in taking a cultural perspective on engineering education is that there are no standard, widely-agreed-upon approaches to characterizing culture within an academic organization. Within specific disciplines, certain methods might prevail: anthropologists might use ethnographic approaches, while business analysts are beginning to apply natural language processing (NLP) to mined evidence from sources like Slack channels (Pandey & Pandey, 2019). While often powerful, these approaches are also quite time-intensive, challenging to scale, and may involve specialized tools such as NLP that are not always accessible to researchers interested in culture.

In previous work (Berger et al., 2021), our team of engineering education researchers and anthropologists described a process for understanding faculty culture within a single academic department. In brief, we used data from a wide range of sources to construct a final group of 40 cultural statements. These participants, who all held faculty roles within an academic department, indicated their agreement or disagreement with each cultural statement using a dichotomous scale via an electronic survey; they also provided background characteristics (race, gender) that were not otherwise obtainable by our research team. We used Cultural Consensus Theory (CCT) to analyse the data, eventually uncovering two subcultures within this faculty group, and these subcultures were characterized by their sense of empowerment and disposition to change. We discovered no systematic relationships among any of the background variables (race, gender, years of service, research metrics, etc.) and membership in the subcultures. Survey-based cultural characterisation using CCT proved to be both useful and scalable.

In this paper, we extend our prior work by describing our design process for a multi-institution, multi-constituent survey. We are currently engaged in a large, funded project that spans five institutions with different histories, research/teaching priorities, and formal structures; we therefore hypothesize that they have measurably different cultures that affect adoption and adaptation of the innovation. Our goal with this paper is to share our experiences with survey construction, so that others might adopt this process in their own culture-oriented work. The larger project focuses on propagation of an educational innovation to new settings, and we expect alignment with local culture (example: expectations about faculty-student relationships) to be important influencers of successful adoption.

Background

Research contexts

The larger project of which this study is a part focuses on adoption and adaptation of a specific educational innovation with five institutions, all located in the central and eastern United States. The institutions are briefly described in Table 1, and each has its own history, traditions, and norms that have evolved over time in response to a wide range of criteria.

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While these institutions share certain features (e.g., they all offer Bachelor degrees in engineering, they are all predominantly White institutions [PWIs]), we anticipate that their cultures are quite different and therefore that their implementations of the innovation will be different. Here, the term 'institution' refers to a research site, and the term 'adopter' to refers to an individual faculty member who has adopted the educational innovation.

Table 1: Institutions enrolled in this adoption and adaptation study. Carnegie classification is a framework for describing characteristics of US higher education institutions (Indiana University Center for Postsecondary Research, 2018)**.**

Institution	Description
A (5 adopters)	Comprehensive school in a rural setting with national (US) recruitment for Bachelor engineering programs. *UG enrolment*: 5,000 (40% in engineering). *Carnegie classification*: private, not-for-profit; Master's Colleges and Universities.
B (3 adopters)	Comprehensive school in an urban setting with national (US) recruitment for Bachelor engineering programs; historical religious mission. *UG enrolment*: 9,200 (13% in engineering). *Carnegie classification*: private, not-for-profit; Doctoral Research Universities: High Research Activity.
C (1 adopter)	Comprehensive school in a rural setting with regional recruitment for Bachelor engineering programs; strong religious mission; young engineering program (5 years). *UG enrolment*: 3,700 (6% in engineering). *Carnegie classification*: private, not-for-profit; Doctoral/professional Universities.
D (7 adopters)	Comprehensive school in a rural setting with international recruitment for Bachelor engineering programs. *UG enrolment*: 35,000 (28% in engineering). *Carnegie classification*: public; Doctoral Universities: Very High Research Activity.
E (2 adopters)	Comprehensive school in an urban setting with international recruitment for Bachelor engineering programs and a strong STEM emphasis. *UG enrolment*: 17,000 (60% in engineering). *Carnegie classification*: public; Doctoral Universities: Very High Research Activity.

In addition to the institutional differences, each of the adopters is a member of an academic department that varies in characteristics such as faculty size, career stage, and work history; number of Bachelor students and their backgrounds; financial health; physical infrastructure; and many other dimensions.

CCT Approach

CCT's history dates back to the 1980s, with origins in the medical and anthropology communities (W H Batchelder & Anders, 2012; William H Batchelder & Romney, 1988; Romney et al., 1986). In brief, CCT attempts to identify consensus views held by groups of individuals based upon their responses to specific items, which can be presented either via an interview or survey format. A common implementation of CCT uses dichotomous responses to cultural statements. CCT is a specific type of cluster analysis in which the clusters are groups of individuals who share certain viewpoints on the cultural statements presented to them. The mathematical details of CCT have been well described elsewhere (Batchelder et al., 2018), but here we emphasize the three key assumptions that must be satisfied in order for CCT to be a valid approach (Romney et al., 1986):

- participants experience a common culture, which means they have sufficient knowledge of the culture through personal experience to respond to each statement and that there is a 'common' response for each statement,

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- participants' responses are independent of each other but related to the 'common' response, and
- statement difficulty (described below) is consistent with certain requirements about heterogeneity.

Statement 'difficulty' is a CCT term-of-art that captures the idea that participants should have an experiential basis on which to respond (that is, they do not have to 'guess'), and that there is likely to be a difference of opinion across respondents about the statement. As a practical matter, statements that clearly have only one correct response would result in a monoculture (no subcultures) because all participants would agree on that response. Factual statements such as "This Bachelor program requires 120 credits for graduation." fall into this category of factual statements that do not shed light on the existence of subcultures.

Survey Development Approach

The survey development approach unfolds in phases and leverages our prior experiences (Berger et al., 2021). As detailed in the next three subsections, these three developmental phases provide a sound foundation on which to build the CCT survey and interpret its results. We use the term 'culture' to represent all the things people "have, think, and do" (Ferraro & Briody, 2017) within their environment. Each institution will have a culture within which we expect to find 'subcultures', or sub-group holding views or beliefs at variance from those of the larger culture or from other sub-groups. Subcultural alignment represents a set of views or 'ways of doing' that will likely affect adoption/adaptation decisions of our faculty partners.

Phase 1 – Cultural Exploration

In order to develop a CCT survey with the best potential to reveal extant subcultures, researchers must first become acquainted with the culture they intend to probe using the survey. This cultural exploration phase requires the researchers to balance two competing priorities: (i) to gain a reasonably thorough, if general, understanding of the culture including specific points of differentiation among respondent opinions (potentially differentiated by stakeholder group), and (ii) the resources required to gain this understanding. The goal is for researchers to be able to build dichotomous CCT statements that have the potential to uncover subcultures, and our approach rested upon several key actions and strategies.

We strongly advocate for a site visit to the location of the cultural characterization, because the first strategy (in-person **observation**) provides key details to researchers about *facilities and physical layout, relationships, and hierarchies*. In our site visit work, we request facilities tours, including classrooms, laboratories, student and faculty lounge areas, and so forth. The layout, access, usage, and frequency of pass-through all provide clues to the ways in which constituents work together and collaborate. In our work, we have visited academic departments in which the strength of student-staff relationships was very apparent as indicated by the frequent discussions, presence in shared spaces, and generally collegial interactions. In other cases (especially large-enrolment programs), the student-staff distance becomes obvious because of the relative lack of substantive interactions and the transactional nature of the discourse. In general, site visits allow the research team to pose CCT survey items about relationships, collaboration, and the role of the physical plant in creating a welcoming and productive environment.

We also recommend a set of **interviews** using purposive and snowball sampling stratified by the three departmental stakeholder groups; in our case, this included *faculty, departmental staff, and students*. We started with faculty allies with whom we had prior relationships, and they helped us establish a strong rapport with other faculty and staff members in the department. In our case, our faculty allies became primary sources of information because of their excitement about the project and their willingness to discuss their experience in the department at length. These faculty also have a relationship with the research team and trust us to faithfully interpret and represent their department in a fair and honest way. Other interview participants may or may not immediately trust the research team, so we attempt to establish rapport with each interviewee via transparent communication before the interview. Our experience has been positive in this regard, and most constituents seem quite willing to discuss their department and its operations. The semi-structured interview protocol may be informed by on-site observations, and our protocol generally targets common features of academic cultures (Godfrey & Parker, 2010; Merton et al., 2009) and leverages our prior work (Berger et al., 2021) such as: resources (funding, space, time), relationships (collaboration, student-staff relations), leadership (trust, effectiveness, decision making), change (educational/pedagogical), scale (enrolment, staff), day-to-day life (work-life balance, priorities). When considered as a whole, the interview data generally reveal specific issues on which respondents hold differing views.

We also recommend **documentary evidence** as collected from university and departmental *websites*, *hard-copy literature* used for publicity, and other *public information*. These materials reveal how the university and department express their mission and vision. Public sources also provide factual information about enrolment, staffing, degree completion, drop-out rate, and so forth, all of which give a picture of departmental operation and may help contextualize information learned via interviews. Websites and publicity items may also convey a sense of the department's identity: do the communications typically highlight faculty, or students? Do they emphasize research projects driven by faculty and research sponsors, or student projects focused on independent, hands-on learning? Do they describe curricular features (and innovations thereof), or experiential learning such as study abroad? This public information conveys a sense of what the department thinks its identity is and helps the research team triangulate to understand the department in more depth.

Our preferred execution of this plan involves a site visit team of 3-4 researchers being present within the department for 2-3 days to focus on the **observation** and **interview** portions of the cultural exploration (the third portion focused on **documentary evidence** does not need to be completed while on site). We acknowledge the resource requirements for this approach, and we have been fortunate to be supported by a grant from a US funding agency for this work. The interviews can be completed by phone/teleconference, although our experience has been that rapport-building with interviewees is more effective in person. Obviously in-person observation of the departmental environment can only be done by visiting the department in person. We recognize the resource requirement as a limitation of this work that will prevent many others from duplicating our approach. We also acknowledge the consequences of COVID, and we were unable to perform an in-person site visit at one of the institutions (institution B from Table 1) due to travel restrictions. In this case, we relied on faculty allies at the institution, Zoom-based interviews, and documentary evidence.

Phase 2 – Statement Formation and Down-Select

From the evidence collected in Phase 1, our research team then assembles a large collection of candidate dichotomous items for potential inclusion on the CCT survey. We first review the data to form a set of categories that appear to be "on the minds" of department constituents, especially those for which the data show differences of opinion. In our experience, scale, change, relationships, leadership, resources, and workload are common dimensions of disagreement

We then construct candidate items according to several important criteria derived from the literature or from our prior experience (Berger et al., 2021). CCT items should:

- use a mixture of forward and reverse formulations. (Example: "This department embraces opportunities for change…", or "This department does not embrace opportunities for change…"). (Romney et al., 1986)
- express a cultural feature that is likely to reveal disagreement among respondents. (Example: "In this department, the student academic workload is so high that it is difficult for students to participate in extracurricular activities.") (Romney et al., 1986)

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- make it very unlikely that an individual respondent would indicate agreement ("yes") or disagreement ("no") to a large majority of the statements. (Rationale: such a response pattern ("all yes") can be interpreted as an attention check and be used to discount certain respondents from the dataset.)
- use language calibrated for each constituent in the respondent group. (Example: an item targeting workload might include different details for faculty (teaching and research) than for staff (administrative and other duties).)

Our experience is that an initial, very large number of items (>100) can be generated quickly to capture the main themes observed across the Phase 1 data. Phase 2 involves:

1. Calibrating language. Each CCT item should be composed using language that is unlikely to be misunderstood by respondents, is calibrated to their environment, and is streamlined for easy reading (for instance, we recommend using active voice and colloquial language, and avoiding idiomatic expressions).
2. Evaluating strength of evidence. The group of CCT items should represent the most likely distinguishing features of the culture, and as such each CCT item should be carefully evaluated against the evidence collected in Phase 1. Items that are based upon weak evidence may not be suitable for inclusion in the final survey.
3. Down-selecting for final inclusion. Because the CCT items are short (a single sentence), and the answers dichotomous), our research team has deployed CCT surveys with as many as 60 items. To be sure, the completion rate decreases as the survey length increases, but our experience with surveys of this length has been reasonably positive, with response rates above 60% on a 40-item faculty survey (Berger et al., 2021) and nearly 20% on a 60-item student survey (unpublished). Response rate also depends upon recruitment efforts and incentives for respondents.

Phase 3 – Implementation and Delivery

The practicalities of survey delivery are important because they substantially enable data analysis in a number of ways. First, our team has delivered surveys electronically, using the survey landing page to present respondents with the details of informed consent (and the option to opt out of participation), and the CCT items themselves broken into sections of approximately 20 items per survey page.

The electronic implementation of the survey also provides an opportunity to collect data that is not available from other sources, which may include gender and race/ethnicity information. Research teams generally do not have access to faculty and staff personnel files, so it is useful to ask for information about job history (years of service in the department, etc.). These questions reveal respondents' level of exposure to the department's culture and may be important in interpreting their subcultural membership. It may also be useful to ask questions about other workload, which for faculty could be roles in professional societies, conference organizing duties, roles on editorial boards, and other non-trivial time commitments. For staff, this could include items about university-level service or other workload not readily apparent from their job title alone. For students, these questions might focus on other time commitments (a job, or extracurricular activities) or their future career path (industry, government, academia). Our research team certainly recommends augmenting the CCT items with these other demographic and background questions.

For faculty at our own institution, we have also used other public sources of information to augment our dataset with professional information such as number of publications, h-index, external research funding, and teaching responsibilities (such as number of students or number of credit hours taught; see description of matching mechanism below).

After pilot survey testing with a small group of respondents, we draft a final version of the survey that is estimated to take respondents 10-12 minutes to complete. Depending upon the population and available funding, we have offered a monetary incentive for completion of the survey, and this incentive has been reviewed and approved by our institution's human

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subject protection office. When deploying within our home institution, we generate custom email invitations and survey links for each individual, with a personalized greeting to the email invitation. For deployments outside our institution, we use an anonymous link sent to email alias lists via our partners at the other sites. Obviously in the case of an anonymous link, we cannot connect a respondent's data to other public data sources (such as, for faculty, citations and h-index), so the demographic information on the survey itself becomes even more important for our interpretation of the results.

Discussion and Lessons Learned

Our research team has engaged in this process with constituents in academic departments at three institutions so far, with one more under way and one planned for a site visit in Fall 2021. We have significant experience building CCT surveys to characterize culture, and we have learned several important lessons about survey deployment and results interpretation.

Experiences with Cross-Institution Delivery

As part of our on-going research, we recently delivered a CCT survey to three constituent groups (faculty, staff, students) at two partner institutions. To enable cross-institution comparison, we built a single instance of the electronic CCT survey with built-in logic to present certain items to respondents based upon their institution and role. First, we built a master set of CCT items that are presented to all constituents, regardless of role or institution. These items were built according to the three phases described above, with the added steps of synthesis across the two institutions to identify items relevant to both settings. Then, we considered items that would be most relevant to only one institution, with further consideration of the strength of evidence from each institution and appropriateness for each constituent group. We then constructed the survey according to the design principles above, integrating survey logic to ensure each respondent was presented items relevant to their experience. The survey was distributed via anonymous links, and after respondents provided their consent on the first page of the survey, they were asked to indicate their institution and role. Using this information, the survey flow directed respondents to the relevant CCT items.

Survey delivery using an anonymous link holds several consequences as well. First, because of human subjects protection policies and practices, it is time-prohibitive to obtain identified information from another university's data systems for students, and it is virtually impossible to obtain HR-related records for faculty and staff. In addition, the scale of data collection may make it quite labour intensive to obtain the kind of public faculty information we were able to efficiently collect for the modest number of faculty respondents at our own institution. *As such, identified data collection at any institution other than our own was beyond the scope of what we could reasonably achieve given our resources and time allotted to the project*. The implications are important, starting with recruiting participants. Using an anonymous link, we could not personalize the email invitation with an individual's name, and the invitation itself had to be sent by a local ally on the other campuses because they have access to email lists that our research team does not have access to. We suspect response rates were affected as well; the human subjects research approval was secured through our institution, which means respondents were aware that the survey was being delivered by a member of their community (our research team's ally on the campus) *on behalf of an external research team*. Invitees were likely less motivated to spend their time responding to the survey in the service of researchers at another institution. Finally, as a practical matter, we could not effectively follow up with potential respondents, and we had to rely on our local contacts at each institution to send follow-up reminders to the email lists and encourage individuals to respond. We suspect this lack of personalization, while a consequence of our resource and time situation, negatively affected the response rate via selection bias of respondents.

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Experiences with Data Analysis

CCT is a powerful method for detecting subculture sentiment within a broader population, and survey-based CCT can be executed at a large scale. However, data analysis requires careful consideration of subsetting decisions along with CCT analysis itself. The survey created in this research affords two main categories of analysis that provide significant flexibility in exploring the data: (i) subsetting, then CCT (the 'subsetting' approach), and (ii) CCT with descriptives (the 'descriptive' approach). In the subsetting approach, we explore hypotheses about the ways in which specific constituent groups respond to the same set of items. For instance, if we use the subset of student respondents, CCT explores questions about the extent to which students share views about specific issues like student-faculty relationships or peer-to-peer collaboration. On the other hand, we could do a similar subsetting procedure by institution, by role (faculty or staff), or in many other ways all of which have implications for interpretation and constraints related to (sub-)sample size.

In the descriptive approach, we use the entire dataset in the CCT analysis, identify the number of subcultures present in the respondent population, and then examine the descriptive characteristics of those subcultures. For instance, if one of the subcultures is populated primary by staff respondents or by respondents from a particular institution, then we can draw some conclusions about that constituent group.

The sample size and representativeness issues are significant, and the strength of inference possible depends upon the subset sample sizes and the size of the populations in the descriptive analysis. In either case, the CCT data are compared against data from other sources (collected in Phase 1 and/or via member checking) to substantiate any inferences and build trustworthiness of the data and our interpretations. The optimal response rate depends upon the number of subcultures present and the extent to which the sample spans those subcultures. In our prior work with faculty (Berger et al., 2021), a sample *size* of 54 (a response *rate* over 60%) was sufficient to confidently identify two subcultures, and we further established trustworthiness via comparison with other data collected and member checking.

Conclusions

This paper explains the development, deployment, and data analysis associated with large-scale, survey-based data collection for cultural characterisation in academic organizations. We describe a systematic approach that seeks to balance the intensity/cost of preliminary data collection and survey development against the results of the CCT analysis. Our experience with CCT thus far demonstrates the insights available to researchers using this survey-based approach to cultural characterisation. Our continuing work focuses on critically evaluating the subsetting and descriptive approaches to CCT data analysis to obtain the most complete picture of academic culture.

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Process Mining Model to visualize and analyze the Learning Process

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CONTEXT

In online learning environments, the teacher provides students with a learning path to follow in order to acquire the expected competencies and skills. However, students' profiles are different as they can learn according to different learning paces or media content. Therefore, the actual learning path followed by each learner may vary from the initial path provided in the learning management system (LMS). This paper proposes an analysis of the learning paths followed by the students in order to identify and promote the most adapted learning processes in order to improve competencies and skills acquisition.

PURPOSE OR GOAL

The learning traces left by students in their learning environment could be exploited in order to better understand and guide learning processes. Unfortunately, with large-scale education, the analysis of different learning paths can be a complex task to be manually carried out by teachers. For this reason, our objective is to propose an approach to model, visualize, analyze and recommend the most efficient learning process in order to improve students' education experience and results.

APPROACH OR METHODOLOGY/METHODS

The approach adopted is based on the learning traces left by the students following their interactions with the Learning Management System (LMS). After collecting, processing, and storing these learning traces, Process Mining technologies are used to analyze the data through an exploration of the learning process, as well as the students' learning paths.

ACTUAL OR ANTICIPATED OUTCOMES

The first results obtained have made it possible to visualize the learning process, as well as the learning paths followed by each learner. They also provide analysis indicators for understanding and optimizing the learning process and the students' paths in digital learning environments. These results allow the stakeholders (training managers, teachers, and students) to improve the way they teach and learn.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This approach made it possible to comprehensively understand the learning processes and the learning paths of each learner, to visualize their differences, as well as their advantages and disadvantages. The analysis of the learning processes promoted a correlation study between the behavior of the learner (i.e. the number of connections between the sections of a course followed) during the learning process and their mark obtained on the final exam. The correlation coefficient of the evaluated courses was of the order of 0.49 and 0.53 respectively. Moreover, in order to improve the predictive model, it's necessary to implement advanced analysis: diagnosis, predictive and prescriptive based on the descriptive elements (Process visualization). This allows teachers to have an integrated tool for analyzing learning traces through a monitoring, diagnostic, alert, and early intervention system in order to better promote the success of students.

KEYWORDS

Learning Analytics, Learning Process, Process Mining, Learning Paths, Online Education

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Introduction

Nowadays, online learning is largely present in educational institutions around the world. In online learning environments, teachers provide students with a learning path to follow in order to acquire the competencies and skills related to the courses. However, students present different profiles and they learn according to different learning paces and can interact differently face to heterogeneous media content. Therefore, the final learning path followed by each learner may vary from the initial path provided in the learning management system (LMS). The learning traces left by students in their learning environment could be exploited by teachers for an improvement of the learning, but unfortunately, with large-scale education, the analysis of different learning paths can be a complex task to be carried out manually by teachers. In the Learning Analytics domain, several solutions applying different methods to improve learning processes have been developed to visualize data about students and their performance or to generate recommendations using prediction models to improve the decision-making process. Other solutions have also been proposed in order to manage adaptive feedback and support collaborative argumentation in F2F (*face to face*) contexts. In contrast, studies oriented to better understanding how exactly the learning process occurs have not been extensively carried out. Nevertheless, an integrated approach aimed at analyzing students' behavior patterns, could offer interesting benefits by combining both process mining and learning analytics techniques. In this paper, a Process Mining Model is proposed to visualize and analyze the learning process, as well as the learning paths followed by the students in order to globally improve students' results. This will consist of the generation of a step-by-step modeling process to guide the implementation of learning analytics techniques based on process mining: starting with the collection of data (definition of sources), the storage of data (Learning Record Store), treatment of data (necessary transformations to be able to implement the process mining), analysis of data (application of process mining) and finally, data visualization (the respective analyses "process discovery"). The paper is organized as follows: Section II describes the Background. Section III summarizes Related Works. Section IV presents the proposal for the process mining model. Finally, section V concludes the paper.

Background

In the context of learning environments, every interaction made by the stakeholders (students, educators, institutions), leaves important traces of information that can be recorded, obtaining large sets of educational data or *Big Data*. The term *Big Data* is referred to as datasets whose size is beyond the ability of a typical database software tool to capture, store, manage and analyze (Manyika et al., 2011). The capability to extract value from such datasets is the work of Learning Analytics, defined as the application of analytics to enhance or improve student success, as well as the use of data, statistical analysis, and explanatory and predictive models to gain insight and act on complex issues (Arroway et al., 2016).

Learning Analytics is still in its infancy; however, its short life has produced numerous conceptualizations (Munguia et al., 2020). It has also helped with the development and implementation of tools that allow institutions to monitor and understand their students and the barriers to student learning. To provide a better understanding for educators of how their content is being used and how effective it is in favor of enabling its continual enhancement. Also enabling students to take control of their learning to give them better information on how they are progressing and what they need to do to meet their educational goals (Leitner et al., 2017).

Students within an LMS follow a learning path, defined as the implementation of a curriculum design; it consists of a set of learning activities that help users achieve particular learning goals (Nabizadeh et al., 2020). However, all the students due to their different profiles, backgrounds, and levels of knowledge, have particular behaviors, and accordingly, the resulting learning path can differ across students. All the data generated through these interactions can be stored implementing xAPI (*Experience API)* which is a technical

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specification that aims to facilitate the documentation and communication of learning experiences (Advanced Distributed Learning (ADL) Initiative, 2013)

All the stored data can be analyzed, bringing benefits not only in terms of learning research but also in terms of didactics and actual teaching practice (Juhaňák et al., 2019). To accomplish this it is possible to apply process mining techniques, defined as the creation of a consistent and explicit process model given an event log and the use of tools to diagnose issues observing dynamic behavior (van der Aalst, 2016). Process mining is an emerging discipline providing comprehensive sets of tools to provide fact-based insights and to support process improvements, this new discipline builds on process model-driven approaches and data mining. The goal of process mining is to use event data to extract process-related information, to automatically discover a process model by observing events recorded by some enterprise system. This field has had important developments and their main goals are focused on offering ways to automate some tasks integrated into a human task and to control the information flow. (Aalst, 2011).

Related Works

One of the approaches was developed by Gutiérrez et al., 2020, which includes the implementation of LADA, a Learning Analytics dashboard to help advisers in the decision-making process, thanks to the delivery of predictions in terms of percentage of students academic risk based on an Adaptive Multilevel Clustering technique using data from the past such as previous academic records, and data from the present like the specific course selected by the student. The success component uses these estimations translating the percentage of risk in the likelihood of student success towards an individual course or a group of selected courses.

Additionally, (Han et al., 2020) developed a dashboard system for both students and instructors to support “collaborative argumentation”. The student dashboard delivered benefits such as monitoring current learning status, receive adaptive assessing from the teachers and support for FCA (face-to-face collaborative argumentation), and allow the possibility to ask for help from the teacher. The teachers’ dashboard benefits were related to monitoring the general performance of the class and identifying groups that needed help, which allowed teachers to improve decision-making regarding selection and preparation of the support to give to students based on their respective needs.

Furthermore, Aljohani et al., 2019 presented a “course-adapted student learning analytics framework” that had four different levels. Instructor level, data level, data analytics level, and presentation level (data visualization). The instructor level, included some configurations steps, being the first to specify the tools from the LMS to apply into the course; the second was to specify the data of interest, based on the chosen LMS tools; and finally in order to communicate with students could be implemented emailing process or posting in the announcement area of the LMS. As for the data level, this aimed to extract and retrieve the data from LMS that relates to the LMS tools being used by students for the course, to be later analyzed in the data analytics level employing several techniques. Regarding data visualization, the AMBA tool was developed which is a web-based application; teachers and students had access to the tool; as for the teachers they were able to configure the tool, and as for the students, the tool provided three types of feedback in the order of statistical, textual and visual.

Additionally, Juhaňák et al., 2019 carried out a study, centered on student behavior in LMS (in this case, the widely used open-source system Moodle), specifically on student interactions while engaging in specific quiz-based learning activities. The analysis of student interactions uses process mining methods, allowing for mapping and modeling the process of completing quizzes by students.

The following Table 1 summarizes the approaches of the sources consulted, in the different steps identified to implement Learning Analytics.

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Table 1: Learning Analytics Implementation Comparison

Features	Sources				
	(Gutiérrez et al., 2020).	(Han et al., 2020)	(Aljohani et al., 2019)	(Juhaňák et al., 2019)	Proposal
Data Collection	YES	YES	YES	YES	YES
Data Storage	YES	YES	YES	YES	YES
Data Treatment	NO	YES	YES	YES	YES
Data Analysis	Multilevel Clustering	Statistical Analysis	Unclear	Process Mining	Process Mining
Data Visualization	YES	YES	YES	NO	YES

Process Mining Model

Model Overview

The main goal of this model is to generate a generic approach. A step-by-step guide that helps institutions acknowledge all the concepts related to the implementation of a Process Mining model to visualize and analyze the learning process that takes place on an LMS (see Figure 1).

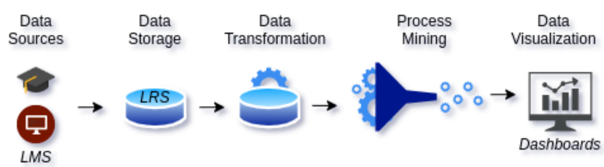

Figure 1: Process Mining Model to visualize and analyze the learning process.

Data Sources

In order to visualize the learning process, it is necessary to extract all the relevant information referring to how these processes occur, and the places where such activities happen are systems like OLE *Online Learning Environment* or LMS *Learning Management Systems*. In those systems each click, view, answer, success, error, time consumed, resource downloaded, viewed, listened or score obtained, has an important meaning, and all of those interactions build some digital footprint, also called Learning Records which are the one's vitals to collect.

Data Collection

To collect, extract and store the interaction data, it is necessary to follow a standard approach like the one proposed byTinCanAPI or xAPI (Experience API) which is a technical specification that aims to facilitate the documentation and communication of learning experiences. In general, when an activity needs to be recorded, the application sends secure statements in the form of *noun, verb, object* or *I did this* to a Learning Record Store (LRS) which is a server that is responsible for receiving, storing, and providing access to Learning Records. In general (Advanced Distributed Learning (ADL) Initiative, 2013) explains that its necessary to collect the following:

- **Actor**: is an individual or group representation tracked using Statements performing an Action within an Activity. Is the "I" in "I did this".
- **Verb**: Is the action being done by the Actor within the Activity within a Statement. A Verb represents the "did" in "I did this".

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- **Activity**: a type of Object making up the "this" in "I did this"; it is something with which an Actor interacted. It can be a unit of instruction, experience, or performance that is to be tracked in a meaningful combination with a Verb.

Data Treatment

The process mining analysis starts with an 'Event Log' and inside this structure, a process is described as follows, a process consists of *cases,* a case consists of *events* such that each event relates to precisely one case and each *sequence* of activities executed for a case is a *trace*. Each line in the event log presents one event. Events within a case are *ordered.* Events can have *attributes (e.g.,* activity, time, cost, resource, etc) (Aalst, 2011). The event log structure can be summarized as follows:

- **Case ID**: indicates at which case or instance belongs an event or activity.
- **Activity**: Action captured by the event.
- **Timestamp**: Indicate the time when the event took place.

Concerning the proposed model, the first field to build the "Case ID", should include information that allows a unique identification of the actor (student), like the student ID. The second field is the activity field, this can be obtained using the "activity" of the previously stored learning experiences. Regarding the timestamp field, the easiest approach is to duplicate the timestamp information of each learning record into the respective event log. Table 2 displays an example of a construction of an event log from trace data of a course called "Advanced Databases" followed by twenty-one students (some interactions of two students are displayed). Additionally, it is possible to record other information considered important, which subsequently will function as filters in the analysis phase, the "verb" of the learning experiences previously-stored the could be used. Another interesting filter could be the grades associated with the student, however, this isn't necessary to add it in the events logs, on the contrary, this information could be stored in a separate file with a simple structure that contains the "Case ID", and the respective grade; Table 3 describes an example of this (20.0 scale). At the analysis phase, it will be possible to filter by grades, adding the grades table to the analysis and connecting the events logs to the grades table using the "Case ID" as a foreign key.

Table 2: Event log construction example from trace data

case_id	activity	timestamp	status
55138	Data Integration Introduction	12/01/21 08:23	viewed
55138	Data Integration Introduction	12/01/21 08:23	completed
67108	Data Integration Introduction	12/01/21 08:32	viewed
...	...	...	...
67108	Lab 1 - Data Integration	12/01/21 09:07	viewed

Table 3: Grades file

case_id	final_grade
67256	17,539
67108	15,091
55138	13,746
...	...
67239	6,672

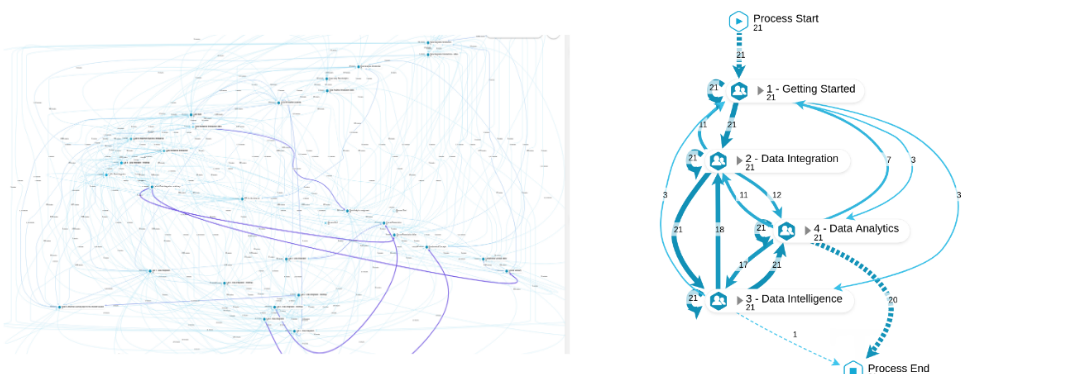
Data Analysis

Once the data have been transformed to the necessary structure 'event log', one of the most suitable algorithms to implement in this step is the *"discovery"* type. This technique takes an event log and produces a model without using any a-priori information (Aalst, 2011). It is important to point out that the actual implementation of this algorithm is not specified by this model, thus it can vary from one implementation to another. However, it is strongly recommended to use an online existing solution that already implements process mining, for example, the Celonis platform (*Process Mining and Execution Management Software*, n.d.) to speed up the process. However, regardless of the final implementation once applied to the discovery algorithm, the discovery model should be "representative" for the behavior seen in the event log (Aalst, 2011).

To summarize some benefits of applying process mining to educational event logs (from trace data), hereafter these are going to be described focused on the three main stakeholders of a learning process (educators, training managers, and students).

Benefits for educators

- **Visualize globally the learning process:** with this kind of analysis, it is possible to visualize globally all the interactions made in the learning process by all students (Figure 3a). At first, this visualization is too complex to be analyzed, however, it is possible to group the activities by sections (several activities can be part of the same section or learning outcome), with this approach it is possible to globally visualize all the interactions of the students grouped as needed (Figure 3b). Case frequency is also displayed, which applied to the current context represents the number of students that follow a specific path. In (Figure 3b), it is possible to visualize that twenty-one students started the process and went to perform the activities of the first section “1 — Getting started”. After that the twenty-one students went to the second section “2 — Data Integration”, being in this section eleven students went back to the first section “1 — Getting started”. In summary, it gets visually described all the sequence of resource usage by students, it is possible to see not only the straight link between resources but also all the turns, reuses and go-backs, performed in the way.

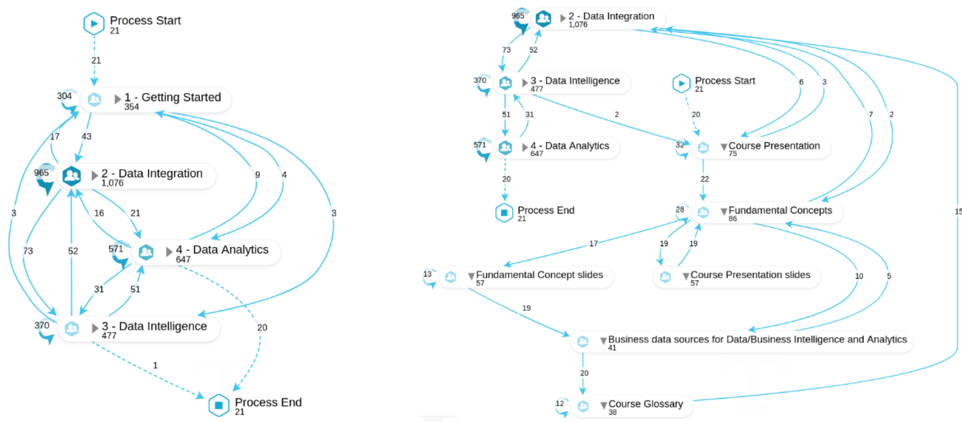


a) Global visualization learning path not grouped　　b) Global visualization learning path grouped by sections.

Figure 3: Learning process. Case Frequency - Process explorer Celonis platform.

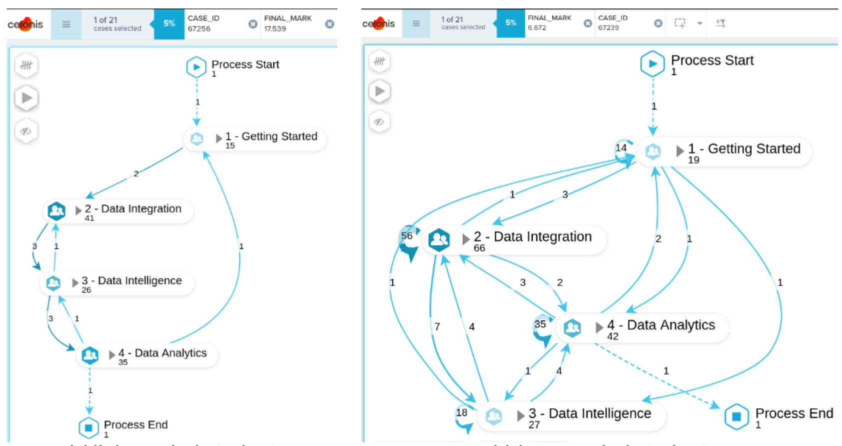
- **Visualize frequency of resource usage**: the activity frequency can also be displayed (Figure 4a), which translates to the number of times an activity was performed. This can be helpful at the time of evaluating the resources usage and value. Several assumptions can be performed based on the number of times a resource is being used; depending on the context this could lead to improvement of the quality of resources if they are considered as difficult for students. As previously stated the visualization can be generally grouped by sections (Figure 4a), or detailed sections expanded (Figure 4b).

- **Visualize the learning process of an individual student or group of students:** it is possible to filter the cases (students), to visualize the individual performance or even subgroup performance. The filter can also be performed by grades to help identify the paths taken by students that led to higher or lower grades. Also, could help to identify patterns in behavior to be able in the future to predict if a student could be at risk of obtaining a bad grade or even dropping out. Another important benefit is the possibility to visualize students having problems with specific subjects. For example, Figure 5a and Figure 5b, represent the learning path taken by two different students who obtained a grade of 17.539 over 20 and 6.672 over 20 respectively. The big disparity between these two students' grades can be visualized also in the path taken. In Figure 5a it is possible to see a more organized path, with fewer connections between sub-learning paths of the course. On the contrary, Figure 5b, represents a learning path more disorganized, with several connections between sub-learning paths of the course.



a) Global visualization - Learning path grouped by sections. b) Detail visualization per sections of a the learning path

Figure 4: Learning process. Activity frequency - Process explorer Celonis platform.



a) High graded student b) Low graded student

Figure 5: Individual Learning process grouped by sections. Case frequency - Process explorer Celonis platform.

Benefits for training managers

- **Predictions of students' performance:** In order to predict student's performance, it was necessary to apply a more detailed study of the individual cases. In general, two courses were analyzed, called "Advanced databases" and "Cloud Computing II" respectively. For each of the courses a generic path was constructed, in Figure 6a we see an example of this generic path for the course "Advanced databases". With this, it is possible to visualize the weights between sections of a learning path. We hypothesize that the connections between sections directly related should weigh 'one', while the connections between sections not directly related should weigh the sum of the previous weights. For example the weight of the connections of the sections "1 - Getting Started" and "2 - Data Integration" has a value of 'one', however, the connection between the sections "1 - Getting Started" and "3 - Data Intelligence" or vice-versa has a value of 'two' which is the sum of the two previous steps. This is proposed with the idea of carrying out a linear regression model taking as an independent variable the sum of weight per connections of students' individual paths and as the dependent variable the final grade. As a result, it is possible to predict the grades of the students based on their interactions on the learning management system, analyzing their learning paths and identifying patterns. This study was performed with two courses and Table 4 represents the results obtained and the

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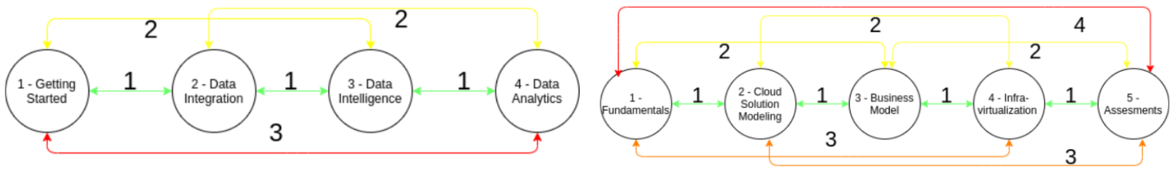
corresponding correlation coefficient, in both cases the coefficient represents an average value, in consequence further testing with more courses data need to be analyzed in order to improve the predictive model, based on each particular course.



a) Generic path. Course Advanced Databases

b) Generic path. Course Cloud Computing II

Figure 6: Generic path with weights between sections.

Table 4: Linear regression on the number of connections of students' individuals' paths

Course	Final grades predictive model	Correlation coefficient
Advanced Databases	-0.13 * connections + 15.84	0.4951
Cloud Computing II	-0.08 * connections + 19.99	0.5373

Benefits for students

- **Learning path recommendations for a course:** recommendations for the learning path are related to the one that obtained the higher grades. Based on the previous academic course, recommendations can be made to students following the same course. In Figure 7 it is possible to visualize a learning path of students that obtained grades between 18 – 20 on a scale of 20.

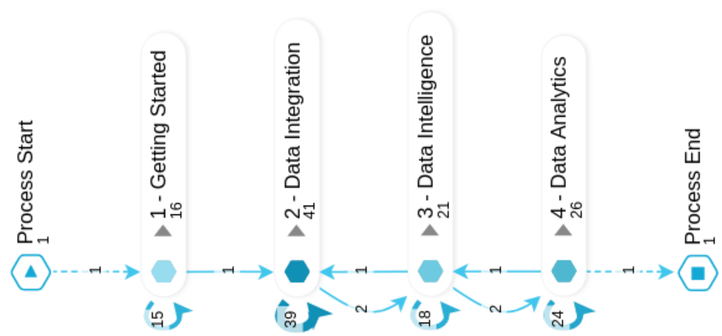


Figure 7: Path with high grades. Case frequency - Process explorer Celonis platform.

Limitations

This research was performed during the academic year of 2020-2021 and the data available for the courses analyzed was limited to only this period. In order to improve the results of the recommendations and predictions, it's necessary to analyze more data from the same courses but in another academic period.

Conclusions and Future work

This paper proposed the design of a Process Mining model to visualize and analyze the Learning Processes of students. The analysis is performed by collecting learning experiences from students in regular LMSs, store them on a common LRS using the xAPI standard and apply some transformations to build event logs. Those event logs are then analyzed using process mining and their results are exposed visually recreating the learning processes in their given contexts. This approach allows the possibility to explore all the different ways that students take to learn similar subjects (different learning paths); be able to visualize globally, individually, or by subgroups the learning process of each one of them, and remark their differences, advantages, or disadvantages. The frequency of resource usage can also be visualized and each teacher can draw their own conclusions that help them evaluate the quality of their resources. Consequently, teachers and educational institutions can have access to the visualization of all this information allowing them to self-reflect on their practices and have an overview of the current situation that could help them to make the best decisions that would help improve as much as possible the learning environment processes. The analysis of the learning processes promoted a correlation study between the behavior of the learner (number of connections between the sections of a course followed) during the learning process and their mark obtained on the final exam. The correlation coefficient of the two courses studied was of the order of 0.49 and 0.53 respectively, representing an average value. In consequence, to improve the predictive model, it's necessary to implement advanced analysis: diagnosis, predictive and prescriptive based on the descriptive elements (Process visualization). This allows teachers to have a complete tool for analyzing learning traces through a monitoring, diagnostic, alert, and early intervention system to better promote the success of students.

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Developing an Instrument to Measure the International Engineering Educator Certification Program Participants' Learning Experiences

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ABSTRACT

This paper focuses on the design and development of an educational survey instrument that will effectively measure the participants' self-rating of competence and professional confidence acquired through a given faculty development program. To develop the instrument, a nine-months long engineering faculty development program - IUCEE International Engineering Educator Certification Program (IIEECP) was chosen, and the developed instrument was implemented on Indian IIEECP certified faculty. The IIEECP program is a specially designed certification program designed to improve the pedagogical acumen and professional confidence of Indian engineering educators. For this study a total of 193 participants were recruited and effort was made to capture as diverse a population as possible. The sample included 59 percent women and 41 percent men teaching different engineering disciplines in different types of engineering institutions in India. The survey instrument is designed in three part that include i) demographic analysis, ii) a 39-item questionnaire related to the achievement of specified learning outcomes of the IIEECP program, and iii) a set of six qualitative questions designed to help participants rate their enhanced competencies and professional confidence. An exploratory factor analysis (EFA) was conducted to examine the factor structure of the survey instrument under consideration. The EFA revealed six distinct factors each corresponding the six different modules. The Cronbach's alpha for the six factors ranged between 0.82 and 0.87, indicating high internal consistency between the items. The study serves as an effective measurement tool for faculty, engineering institutions as well as the IIEECP expert team. For the faculty, it provides a practical tool for self-reflection; for the institutions it allows to develop criteria for faculty readiness and identify their training needs. For the IIEECP team it provides invaluable feedback to further refine and reinforce the program. The designed instrument demonstrates how the efficacy of faculty development programs can be measured through participants rating of acquired competencies and confidence. One of the limitations of this work is that the evidence for content validity was not collected. The instrument will benefit from evidence collected from the expert team teaching and evaluating each module of IIEECP. Investigating the influence of participants' demographic variables on participants' performance and professional confidence is another direction for future work.

Keywords: effective teaching, exploratory factor analysis, faculty development, international certification program, survey instrument

Introduction

India is known to be the global hub of engineering education with over 1.5 million engineers graduating every year. Today, India has over 3,500 engineering institutions that can be classified in different tiers. Except for the graduates coming from elite, top ranking engineering institutions like the Indian Institutes of Technology (IITs) or the National Institutes of Technology (NITs), the un-employability rate amongst Indian engineering graduates is alarming. Citing the latest report by All India Survey on Higher Education (AISHE, 2019-2020) issued by the Ministry of Education, India, one commercial magazine claims that nearly 80% of engineering graduates are unemployable [1]. The information is confirmed in another article

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"80% of Indian engineers not fit for jobs - says survey" by a reputed business magazine (Business Today, March 25, 2019).

A well-recognized reason for this unhappy situation is the lack of pedagogy-savvy faculty and the use of outdated teaching practices leading to poor preparation of students for a demanding workplace. Over time a lot of national and international resources have been spent in faculty development mainly in the form of short 5-10 days workshops. In 2007, a group of American engineering educators of Indian origin came together to form a volunteer organization for improving engineering education in India. The organization initially named as Indo-*US* Collaboration for Engineering Education (IUCEE) was soon renamed as the Indo-*Universal* Collaboration for Engineering Education when other educators from Singapore and Australia joined the organization. The IUCEE also started its activities with a series of conventional one-week long faculty training programs. Over 2008 -2010, more than 2500 faculty from all over the country were trained. However, it became clear that in order to bring in sustainable change in the competency and confidence levels of the faculty, a more formally structured training program needs to be designed which would include theory and a substantial practicum component.

Faculty development programs (FDPs) for university faculty focused on improving teaching skills began in the early 1970s internationally and since then there have been numerous FDPs conducted nationally and internationally [2]. The duration of the faculty development programs is usually in the form of a day, three-days, five-days, two-weeks, etc. Different research studies on the effectiveness of FDPs present minimal assessment of the activities of simplistic measures mostly relying on participant feedback or satisfaction surveys [3]. A few exceptions exist, for example, researchers assessed the outcomes of the FDP after the completion of the program by collecting data from observing faculty members teaching and analyzing them [4]. Six faculty members teaching in the clinic and/or in the classroom were observed and interviews were conducted to collect data. In a study, by Hoffmann-Longtin et al., [5], focused on understanding the trends on assessment on FDPs, summarized that there is need to shift the focus on assessing the impact and outcomes of FDPs and the data collection methods for evaluating the effectiveness of the FDPs must be critically designed. With this as a brief background and motivation, in this study the authors present a survey instrument designed following the outcomes of a nine-month long certification program which aimed at assessing the participants self-assessment of their competency in their confidence on performing different tasks learned in the certification program.

Per se, a single assessment tool cannot be used to assess different programs as the needs and defined goals/outcomes of different programs vary. However, the approach presented in the paper can be used to design survey instruments to measure participants personal perceptions related to the different outcomes of the faculty development program.

Design Framework for IIEECP

In 2014, the IUCEE invited a reputed education technologist (Dr. Veena Kumar, retired Professor and Head, education Technology, Indian Institute of Technology, Delhi, India) to design a comprehensive certification program - the IUCEE International Engineering Educator Certification Program (IIEECP), inspired by a similar certification program offered by IGIP (translates in English as the *International Society for Engineering Pedagogy*), Austria. IGIP is a renowned European engineering society with over 40-year tradition of making valuable contribution to engineering pedagogy and faculty development. IGIP has certified over 1500 faculty in 52 countries (Wikipedia).

As the IIEECP program was fully customized to meet Indian education, socio-economic, cultural ground realities, it was quite different from the certification program offered by IGIP. However, both programs covered similar theoretical, ethical, and practical issues, and both led to a valuable certification in engineering pedagogy. The IIEECP was formally launched in January 2015 with the financial support of Microsoft India. In 2016, IGIP recognized the IIEECP for joint certification. The underlying philosophy of IIEECP is to focus on developing both

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professional skills and personal growth (Figure 1). The most challenging of all was to bring in a new mindset that distinguished a good academician from a good teacher, and conceptually recognizing that teaching was a skill that needed to be learnt with time and effort.

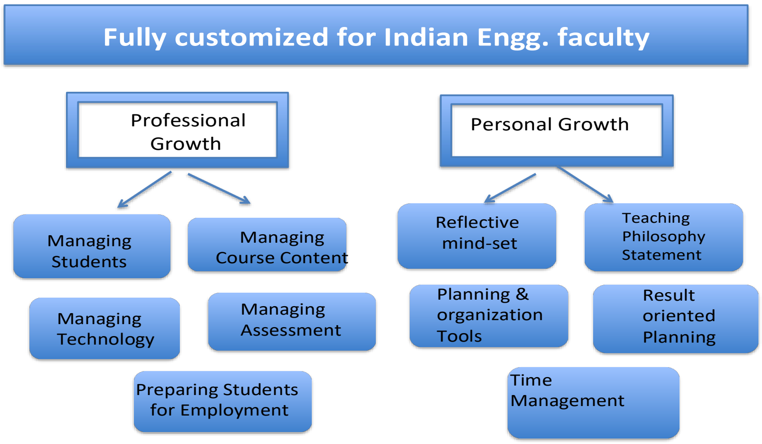

Figure 1: Underlying philosophy of IIEECP

IIEECP Program Format

The program was designed to be delivered in three phases:

1. Phase I, three days face–to-face workshop to discuss key theoretical concepts.
2. Phase II one semester long practicum program, delivered in blended mode. The participants are expected to be teaching a regular course during this phase where all strategies learned will be implemented and evaluated through student feedback. Weekly assignments and thought-provoking discussions form an integral part of this phase. Each assignment includes a brief reflective report on the strategy practiced.
3. Phase III involves submission of a teaching portfolio and a capstone presentation to reflect upon and assess ones' own learning and developing a personal plan for teaching.

Program Content

The program input is packaged in six modules, each module addressing an important component of the higher-education pedagogy. The specific learning outcomes of each module that form the bases of the instrument are listed below.

Module 1 - The Teaching- Learning Process

At the completion of this module, the participants will be able to:

- Summarize major theories of learning propagated by educationists such as Skinner, Piaget, Vygotsky, Maslow, and Gardner.
- Identify academic & employment needs of Millennial and generation Z learners
- List the three domains and levels of Bloom's Cognitive Taxonomy
- Summarize Theories of Motivation.
- Design lectures using the Keller's ARCS Theory of Motivation
- Incorporate Joseph Lowman's 2-D Model of Effective Teaching in course delivery
  Compose a personal teaching philosophy statement including short and long-term goals for personal and professional development

Module 2 - Course Design & Delivery

At the completion of this module, the participants will be able to:

- Compose course learning outcomes using Bloom's taxonomy & aligning them to institution's program objectives.
- Sift and sequence content to plan independent study projects.
- Incorporating MOOCs and other open sources in your course.

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- Design an effective lecture incorporating active learning
- Design and implement a Flipped class.
- Planning an effective first day of a new course.

Module 3 - Creating a Dynamic Classroom
At the completion of this module, the participants will be able to:

- Identify and manage student differences in terms of background, preparation, learning styles, demographic differences, and linguistic competencies.
- Design and implement the 12 commonly used active-learning activities (summarizing, think pair & share, minute papers, verbal quizzes, TAPPS, etc.) within lecture time.
- Implement active learning activities in a large class.
- Manage disruptive student behaviour in class.

Module 4 - Collaborative Learning
At the completion of this module, the participants will be able to:

- List importance of collaborative learning in attaining graduate attributes.
- Design and implement project-based learning pedagogy.
- Plan different steps for preparing and implementing Collaborative activities.
  - selection of topic, creating teams, designing problems, creating assessment and rubrics for evaluating individual and group performance and collecting student feedback.

Module 5 - Harnessing the Power of Technology
At the completion of this module, the participants will be able to:

- Create a dedicated course website using free resources.
- Use simple freely available technology options like ‘polls everywhere’ and ‘mentimeters’ to enhance classroom instruction.
- Record video/audio materials to support classroom/online teaching.
- Use animations and simulations.
- Identify and use Virtual Labs effectively.

Module 6 – Effective Assessment
At the completion of this module, the participants will be able to:

- Distinguish the role of assessment ‘for learning’ and ‘of learning’.
- Write good questions and mapping them to Bloom’s taxonomy.
- Manage in-class questioning and verbal quizzes.
- Create assessment for group work.
- Create Holistic and analytical rubrics.
- Use the sandwich model for providing constructive feedback (written and verbal).

The following sections provides details of the methodology used: development of survey instrument, the number and profile of the sample, process of data collection, and exploratory factor analysis, results and conclusions arrived at.

Methods

Development of the Survey Instrument

The survey instrument for this study was developed in Spring 2021 by the authors. The instrument includes six scales each corresponding to each of the six modules. Survey items were framed based on specific learning outcomes of each module. The instrument is intended to capture the IIEECP certified faculty members personal assessment of enhancement in their competencies and confidence level as a result of attending the certification program. The survey instrument is designed in three part that include i) demographic analysis, ii) a 39-item questionnaire related to the achievement of specified learning outcomes of the IIEECP program, and iii) a set of six qualitative questions designed to help participants rate their enhanced competencies and professional confidence.

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The survey items were initially written by the first author and were reviewed by the second author. The survey items were revised based on the feedback from the second author. Table 1 provides the overview of the survey instrument which includes the six scales, description of each scale, number of items in each scale and sample items for each scale. The faculty respondents were asked to rate their confidence in accomplishing participants' tasks related to skills learned in each of the six modules on a five-point Likert scale with response options (1) strongly disagree (2) disagree (3) neither agree nor disagree (4) agree (5) strongly agree.

Table 1: Overview of Scales of the IIEECP Survey Instrument

Scale (# of Items)	Sample Items
The teaching-learning process (7)	• I can define major theories of learning required in teaching my courses. • I can design my lectures using the ARCS model of motivation.
Course design and delivery (7)	• I can design my course using backward design. • I can implement an independent study program which helps me to complete my course in time.
Creating a dynamic classroom (7)	• I can design activities for generating intellectual excitement. • I can manage students with disruptive behavior.
Harnessing the power of technology (6)	• I can deliver online classes effectively. • I can effectively use virtual labs in laboratory courses.
Collaborative learning (5)	• I can effectively implement collaborative activities. • I can create instruments for evaluating group performance in a collaborative activity.
Effective assessment (7)	• I can create effective rubrics for class assignments. • I can effectively deal with unethical practices during assessments

The evidence for content validity was gathered from the second author, as the second author is closely associated with the design and development of the certification program. In this study, no external experts were recruited to provide feedback on the clarity, relevance, and appropriateness of the survey items. The evidence for the face validity of the survey instrument was collected by asking two potential participants to provide feedback on the complete survey addressing issues related to wording, clarity, and phrasing of the survey items.

The Sample – Numbers & Profile

The target population for this study were Indian faculty members who had completed the IIEECP certification. The survey was distributed to around 900 certified faculty members across India. A total of 280 faculty members responded to the survey which resulted in a response rate of approximately 31%. Most of the respondents were from the 2019 & 2020 batches. First the certified faculty members email addresses were collected, and the potential participants were invited to complete the survey through email during Spring 2021.

As mentioned, a total of 280 responses were received. The participants responses included six blank responses, three participants responded to less than 50% of the questions, and 78 participants responses were same on all the questions (they strongly agreed or agreed or disagreed on all the questions in the survey). The final sample after cleaning the data included 193 responses.

Table 2 shows the respondents' profile and demographic information. The sample included 59 percent women and 41 percent men, 54 percent faculty from the autonomous institution, and 31 percent faculty from affiliated universities. Most faculty completed IIEECP in 2020 (36%) and in 2019 (29%). About a third of the faculty held assistant professor positions (68%). The final sample after cleaning the data included 193 responses from ten different states, a pictorial representation of the participants respondents from different parts of India. Figure 2 shows the respondents' representation from different parts of India.

Table 2: Faculty Respondents Demographic Information

Category	Description	
	n	%
Gender		
Male	113	59
Female	80	41
University Setting		
Autonomous institution	104	54
Affiliated to university	59	31
Private university	30	16
Current Position		
Assistant professor	131	68
Associate professor	36	19
Professor	17	8
Others	9	5
Academic Department		
Electrical & electronics engineering	23	12
Computer science engineering	41	21
Mechanical engineering	23	12
Civil engineering	08	4
Electronics and communications engineering	45	23
Humanities	19	10
Others	34	18

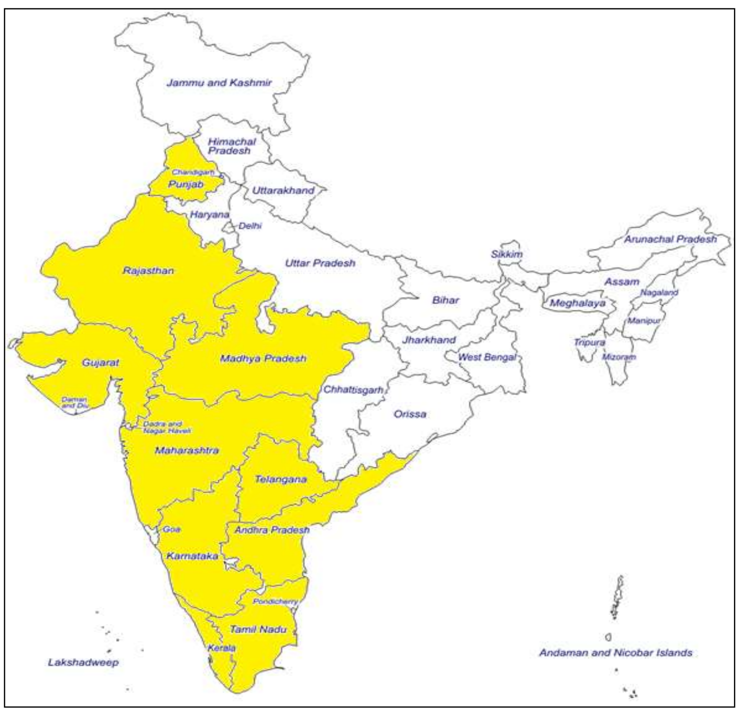

Figure 2: Faculty respondents' representation from different parts of India

Data Collection Procedure

The invitation to complete the survey was also sent through WhatsApp and Telegram networking apps. Two follow-up reminders were sent to the potential participants to complete the survey. The participants who completed the survey did not receive any remuneration. All responses were critically scanned for errors and completeness. Responses with missing information were removed to avoid the biases that it would bring in the analyses. Participants who did not respond to more than 50% of the questions on the survey were deleted, participants with same responses for all the questions were also removed from the data. The missing data on the survey items was handled using the group mean substitution method. To ensure significant correlation among the items with one another in each scale, inter-item correlations were examined. The suitability of the survey items for factor analysis was determined using the Bartlett's test for sphericity (*$p<0.05$*). To check the meaningful variance among the extracted factors from the survey items, Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) was used.

Exploratory Factor Analysis

To investigate the fundamental factor structure of the IIEECP survey instrument and the items that belong to each scale, exploratory factor analysis (EFA) was conducted. Principal axis factoring was used to extract the factors and Promax with Kaiser normalization method (kappa=4) was used as the rotation method. To determine the number of factors to be extracted from the data, Kaiser's criterion, parallel analysis, and scree plots were used [6]. Items that had low loadings on all factors (<0.4) or cross loadings on at least two factors (>0.3) were removed from the factor structure [6]. This process was repeated until there were no low- or cross-loading items remaining. With the finalized factor structure for the scales of the survey instrument, Cronbach's alpha (α>0.8 preferred) was used to calculate the internal consistency reliability for each scale of the instrument [7]. The final scores for each scale were calculated by averaging the scores of all items associated with that scale.

Results

The suitability of the IIEECP survey instrument was confirmed by the Bartlett's test of sphericity (*$p<0.001$*) and the Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) indicated that if factor analysis was conducted then the extracted factors would account for meaningful variance (KMO=0.946) [6]. Scree plots, parallel analysis, and Kaiser's criterion methods suggested extracting three, five, and six factors respectively from the data. The authors decided to develop the instrument with six factors as this matched the number of hypothesized factors. The inter-item correlations for each of the hypothesized scales were significantly correlated (*$p<0.01$*), thereby supporting a six-factor structure of the instrument.

Two items – "I can design my lectures using the ARCS model of motivation" (The teaching-learning process) and "I can map advantages of including collaborative activities with promoting graduate attributes" (Collaborative learning) – had factor loadings less than 0.4 on all the factors and were removed from the data. Eight items cross-loaded (loadings > 0.3) on two factors and were removed: "I have better clarity about my responsibilities as an engineering educator" (The teaching-learning process), "The quality of my lectures has improved substantially" (Course design and delivery), "I can successfully develop good rapport with my students" (Creating a dynamic classroom), "I can video record lectures and upload them on you tube" (Harnessing the power of technology), "I can create a course website using free resources like Canvas, Google Classroom, Edmodo, etc." (Harnessing the power of technology), "I can effectively use virtual labs in laboratory courses" (Harnessing the power of technology), "I can effectively implement collaborative activities with my students" (Collaborative learning), and "I can deal with unethical practices during assessments" (Effective assessment). One item cross-loaded on three factors and was removed: "I can design my course using backward design" (Course design and delivery). Five items were deleted as they had different focus than most of the items in that factor.

The final factor structure with the list of items in each factor and factor loadings is presented in Table 4. The items in each factor are sorted in decreasing order of the factor loadings. The factor loadings for the first factor range from 0.67 to 0.81, the second factor from 0.75 to 0.81, the third factor from 0.52 to 0.75, the fourth factor from 0.43 to 0.81, the fifth factor from 0.42 to 0.77, and the sixth factor from 0.55 to 0.90. The Cronbach's α (coefficients of internal consistency reliability) for the six factors ranged from 0.82 to 0.87. Table 3 shows the mean and standard deviations of the questions on the survey related to performance and professional confidence of IIEECP certified faculty members. Like the other survey items, the participants responded to these questions on a five-point Likert scale. The average values of

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the self-reported scores by the faculty respondents on all the six prompts presented in Table 3 are more than four (out of five). This indicates that most of the faculty members who completed the IIEECP has shown improved performance and professional confidence.

Table 4: Final factor loadings of the IIEECP survey instrument

#	Category	F1	F2	F3	F4	F5	F6
	The Teaching-Learning Process (Cronbach's α=0.85)						
1	I have been sensitized about my role in keeping my students engaged and motivated	0.81					
2	I can use major theories of learning in teaching my courses	0.77					
3	I can define major theories of learning required in teaching my courses	0.74					
4	I can compose my teaching philosophy statement	0.73					
5	I can identify my short and long-term professional goals	0.67					
	Course Design and Delivery (Cronbach's α=0.82)						
6	I can plan an independent study program which helps me to complete my course in time		0.81				
7	I can implement an independent study program which helps me to complete my course in time		0.80				
8	I can implement a flipped class		0.76				
9	I can plan a flipped class		0.75				
	Creating a Dynamic Classroom (Cronbach's α=0.85)						
10	I can successfully manage students with disruptive behavior			0.75			
11	I can predict students with disruptive behaviour			0.61			
12	I can plan my office hour effectively for individual and small group meetings			0.52			
	Harnessing the Power of Technology (Cronbach's α=0.87)						
13	I can effectively incorporate virtual labs in lectures				0.81		
14	I can effectively integrate MOOCs in my courses				0.51		
15	I can deliver online classes effectively				0.43		
	Collaborative Learning (Cronbach's α=0.85)						
16	I can create instruments for evaluating individual performance in a collaborative activity					0.77	
17	I can create instruments for evaluating group performance in a collaborative activity					0.74	
18	I can plan effective collaborative activities for my course					0.42	
	Effective Assessment (Cronbach's α=0.84)						
19	I can deal with plagiarism practices during assessments						0.90
20	I can create effective rubrics for class assignments						0.83
21	I can create effective rubrics for class projects						0.68
22	I can create good question papers for tests and exams						0.66
23	I can create good open-book tests/exams						0.55

Table 3: Descriptive Statistics of Performance and Professional Confidence

#	Prompts	Mean	SD
1	After using the strategies learnt in IIEECP, my student rating has improved	4.14	0.79
2	After being sensitized by IIEECP, my rapport with the students in class has improved	4.24	0.78
3	After being sensitized by IIEECP, my rapport with the students outside the class has improved	4.20	0.81
4	After completing IIEECP, my confidence to take on leadership role in the department has increased	4.28	0.77
5	After completing IIEECP, my professional confidence in interacting with the industry has increased	4.10	0.84
6	After completing IIEECP, my professional confidence in interacting with the engineering community has increased	4.23	0.78

Conclusions

In this paper, a survey instrument was designed to measure the competencies, skills and professional confidence acquired by Indian engineering faculty through the IIEECP. The instrument was designed on the basis of the specified outcomes for each of the six modules of the certification program. An exploratory factor analysis was conducted to determine the factor structure and it resulted in six factors aligned with the six modules of the certification program. The internal consistency reliability of the six factors was checked using the Cronbach's α.

The instrument was found to be effective in measuring the target skills and professional confidence. The study brings some valuable outcomes for engineering education in India. To begin with it provides a framework around which engineering institutions can develop their own criteria for faculty evaluation. It allows a better understanding of faculty training needs and how to address them. The instrument will serve as a practical tool for faculty to self-reflect and assess their own competencies as well as their learning needs. Finally, the survey instrument provides invaluable feedback to the IIEECP team to assess the strength and weaknesses of different modules, and to further reinforce the program.

One of the limitations of this work is that the evidence for content validity was not collected. Hence, in a future version, the instrument can be further improved by collecting evidence from the expert team teaching and evaluating each module. Investigating the influence of participants' demographic variables on all the six modules is another direction for future work. A follow-up qualitative study is planned to investigate the beliefs and perceptions of the certified faculty members to understand changes in their personal and professional growth after completing the certification.

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A Critique of Quantitative Methodologies to yield Critical Quantitative Methods in Engineering Education Research (EER)

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ABSTRACT

CONTEXT
A critical examination of quantitative research methods has been ongoing. Feminist and critical theorists have long problematized quantitative methods for their alleged 'view from nowhere' that offer neutral insights to the questions of inquiry (Haraway, 1988; Nagel, 1989). However, scholars have shown that these seemingly reproducible research methods have negative implications because they do not always consider the researcher assumptions or decisions that go into their design (Zuberi & Bonilla-Silva, 2008; Walter & Andersen, 2016).

PURPOSE

We position this paper as a bridge between the quantitative methods that are prized for their ability to offer scalability, order, and comparison with the critical methods that emphasize power relations and describe the historical and institutional context. We seek to examine the assumptions and decisions embedded within quantitative research methods by drawing on the analytics of power and knowledge.

APPROACH

We conducted a qualitative content analysis of a purposeful sample of recent engineering education research articles. Our review consists of recently published quantitative research articles from the Journal of Engineering Education (JEE), Australian Journal of Engineering Education (AJEE), conference papers from ASEE, as well as articles from Race Ethnicity and Education. This is not an exhaustive review of researcher decision-making in quantitative research but allows us to examine the primary modes of decision-making through a lens of power and knowledge relations.

ACTUAL OUTCOMES

This review results in a synthesis of the considerations that engineering education researchers make when conducting quantitative research. Our focus is not necessarily on reporting standards for specific methods like cluster analysis or regression. Instead, the anticipated outcome is a set of themes regarding how engineering education research can integrate criticality into the quantitative perspective. We, like others in engineering education, are cautious of research methods that lack transparency. These approaches reduce heterogeneous populations of engineering students and faculty to seemingly insular characteristics for the purpose of offering generalizable claims. Through this work we do not seek to promote qualitative research methods over quantitative methods but work to recontextualize researcher decisions through an examination of power in the production of knowledge.

CONCLUSIONS

Ultimately, research is a human endeavour and as such is entwined with complexities of power and knowledge relations. Through an analysis of decision-making in the quantitative research design process, we develop a practice of critical examination as researchers to make inferences about populations who are different from ourselves.

KEYWORDS

Research methods, Power/knowledge, Decision-making, Quantitative research

Introduction

Quantitative research has the power to find commonalities across different contexts. Reproducible quantitative methods hold the capacity to generate insights at scale and discern patterns across seemingly disparate localities, promoting generalization as their purpose. As such, many policy decisions are spurned from large-n quantitative studies (Gillborn, Warmington, & Demack, 2018). Although reproducibility and repeatability are prioritized as the pillars of most quantitative research, these ideals assume that the researcher and their implicit and explicit decisions are without consequence to the inferences drawn from the results. Past and present research teach us about the harmful consequences these seemingly repeatable and reproducible insights have had on minoritized populations (Zuberi & Bonilla-Silva, 2008; Walter & Andersen, 2016).

We do not aim to critique the quantitative methods from a technical standpoint in this article. Instead, we examine a subset of the countless researcher decisions that are often taken for granted in quantitative research. These decisions are not always explicit; some decisions are implicit assumptions, whereas others follow accepted disciplinary standards. However, although the decisions are accepted and normalized, we offer this critique on methodological practices in engineering education research to reassess and recontextualize researcher decisions.

Before we examine researcher decisions in present day quantitative research, we must acknowledge its historical formation. To historicize quantitative methods and quantification is to interrogate the cultural historical context of present research practices, which provide us with a deeper understanding of the power relations embedded in knowledge produced by quantitative methods (Foucault, 1977).

Quantitative Methodologies

Quantitative methodologies abstract information across various local contexts to standardize insights broadly. These methodologies allow the "messiness of local context [to] be removed, ordered, scaled, compared, and rearranged as required by researchers" (Walter & Andersen, 2016). This universality is a common assumption of quantitative techniques. Notably, in the university setting, "mathematics [...] has long been almost synonymous with rigor and universality" (Porter, 1995, p. VIII). The implications that quantitative methodologies have more power in the production of knowledge is especially important as they have been used in policy and administrative interventions. Foucault and others have argued that quantification and statistics have been "an agency for acting on people, exercising power over them" (Walter & Andersen, 2016; Porter, 1995, p. 78).

While "numbers turn people into objects to be manipulated," quantification provides communication lines across disciplinary and even national boundaries (Porter, 1995, p. 78). Similar to economic exchange, in which money can be converted across borders, "numbers are the medium through which dissimilar desires, needs, and expectations are somehow made commensurable" (Porter, 1995, p. 86). The seeming ability for these insights to efficiently travel and scale across knowledge and cultural boundaries was not unrelated to the increased effort through the 1960s and 1970s to incorporate quantitative measures in public decision-making (Porter, 1995; Gillborn et al., 2018).

Engineering Education Research

A critical discussion of research methodologies in engineering education is not new. Engineering education researchers have published some critical examinations of quantitative methods in engineering education (Douglas, Rynearson, Purzer, & Strobel, 2016; Godwin, 2020; Holly, 2020). Alison Godwin, in her recent editorial in *Studies in Engineering Education*

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provides an antiracist critique of quantitative research methods, specifically addressing notions of neutrality and objectivity in quantitative research. She notes that as researchers, “we leave our research fingerprints all over our work” (2020, p. 79). Moreover, Godwin et al. (2021) promote a distinction between person-centered analyses and variable-centered analyses.

Person-centered analyses can be identified by how individuals are treated during analytical procedures. A person-centered analysis treats the individual as a whole, one indivisible unit, to preserve variation. Thus, the response to an outlier in a person-centered analysis is not to remove it; instead, extreme values are put in conversation with other individuals’ responses as holistic comparisons. Moreover, person-centered analyses can incorporate data-driven methods. These methods take an inductive approach by focusing on relationships as given in the data as opposed to theoretically-driven frameworks. Person-centered approaches can use data-driven approaches to find hidden groups or structures to evaluate the patterns found in the data; however, not all data-driven approaches are person centered. In a broader categorization, variable-centered analyses - i.e., methods that prioritize predefined categories by mapping patterns among the chosen variables to them. Some data-driven approaches are designed to assign individuals to predetermined categories, but others can help researchers find subgroups that preserve variation within the individual.

We use this paper to build on and expand this work by Godwin (2020) and her coauthors (2021). We draw insights from neighboring disciplines who have implemented critical quantitative methods. In 2018, a special issue in *Race, Ethnicity, and Education* was published on QuantCrit, which integrates critical race theory (Garcia, López, & Vélez, 2018) and quantitative research methods. Moreover, *Indigenous Statistics* describes the incommensurability of indigenous ways of knowing with some statistical methods that have been imposed on indigenous communities (Walter & Andersen, 2016). By centering everyday experience in its sociopolitical context, these two examples of critical quantitative methods produce insights by addressing power/knowledge relations of traditional quantitative research.

Quantitative Methods and Social Justice

Statistical-based research, similar to power and knowledge, is not neutral or value-free (Gillborn, Warmington, & Demack, 2018). Statistics commonly used in quantitative methods are steeped in a history spanning decades of eugenics through the works of scientists such as Galson, Pearson, and Fisher (Clayton, 2020) and other inferences justifying the othering and subjugation of Black, Indigenous, disabled, and countless peoples seen by society as inferior on a scale of whiteness. The long-lasting impacts of the power imposed by researchers for knowledge production that supported the aims of white supremacy is present in all facets of inequity within the United States. The knowledge associated with statistical reasoning and applied through quantitative methods provides power to the beholder of said methods. As a foundation of quantitative methods, the use of statistical tests, treatments, and deduction automatically places a degree of power for those conducting said analyses. Other inherent characteristics within quantitative research is the notion of validity and reliability, however these signifiers often are limited to the validity and reliability of tests rather than measurement reliability related to the data alone (Fan, 2013). Within the context of social justice, the distillation of data and inferences made have been counter to the liberatory nature of justice work. Within engineering education, this countering has resulted in an overall lens within quantitative work that does not for instance take into consideration the “agency and asset based” (Holly, 2020; p.629) experiences of Black people. However, there exists paths forward that acknowledge, apply, and take deference to cultural sensitivity in steps of quantitative research from data collection and stakeholder involvement to recruitment of participants (Awad, Patall, Rackley, & Reilly 2016).

Methods

We performed a qualitative content review of purposefully chosen, recent STEM education literature to identify and examine researcher decisions and justifications in their quantitative methodologies. Our review focused primarily on the archives of the *Journal of Engineering Education*, ASEE conference publications, *Race Ethnicity and Education*, and the *Australian Journal of Engineering Education*.

> RQ1 - What are the assumptions or decisions that researchers disclose in quantitative research publications?
>
> RQ2 - How do quantitative researchers justify their decision-making processes in their research processes?

This paper is not exhaustive in its review of quantitative researcher decisions in the STEM or specifically engineering education literature, and we hope to present a more systematic review in our following work. This preliminary review served to identify a preliminary list of different types of researcher decisions and justifications. The decisions around data collection include those around response rates and representativeness in sampling. The decisions regarding data analysis concern reliability, specifically measures of internal consistency as well as assumptions and enactments of normality in the datasets.

Notably, we do not focus explicitly on researcher decisions that are outside of the research design, analysis, and results sections, which can be a limitation to the work. We do acknowledge that researcher decisions are not limited to these sections. The examinations of these features of quantitative research are not exhaustive of all researcher decisions, but provide a starting point from which to conduct a more comprehensive review of quantitative engineering education research.

Examining Researcher Decisions

In this preliminary review of the research, we examined empirical engineering education research articles with a quantitative focus to understand what decisions and justifications to those decisions researchers pointed to in their work.

Decisions in Collecting Data

The quantitative studies examined in this article fall into two categories for data collection, either they cited a validated survey instrument as their primary tool for data collection or they used data from an existing data set like the High School Longitudinal Study (HSLS). The authors who used a validated instrument included citations from research that previously published scales. Here, we highlight the decisions of representation and categorizations of participants.

Representative samples and categorizations

For the studies in which the authors administered surveys, they provided the response rates and consequent representativeness of their samples. Johnson and Wislar (2012) explain that 60% is often used as a threshold for response rate but caution no scientifically credible rationale that substantiates this threshold - or any others presented in the literature. Nonetheless, the limits of these response rates often impact minoritized students the most.

In one paper, the authors cited a 15% response rate from the student body. Because of this lower response rate their study had a “small number of minoritized respondents,” to which they were “unable to disaggregate the data by race” (Jensen & Cross, 2021, p. 378). These authors do note that this small number limited their ability to perform meaningful statistical analysis. This type of awareness is not universal, as another paper discusses their demographic data collection as categorizing students as White and “underrepresented minority race other than White” (Jackson, Mentzer & Kramer-Bottiglio, 2021, p. 149) -

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although, they did collect the finer demographic characteristics initially. This solution to binning data such that the groupings conform to conventional statistical practices has its own pitfalls. Shafer et al. (2021) show how regrouping students in such a fashion can mask disparities by subgroups within the aggregate category. The issue here is Simpson's Paradox; a trend can disappear or even reverse depending on how data are binned.

In a second journal article, the authors stated that "Unfortunately, the data collected do not contain demographic information for the students; thus, our analysis focuses on the population as a whole" (Chen, West, & Zilles, 2019, p. 578). These authors described their method for estimating "the demographic composition of the students in the data" which was to "[report] the demographic information of undergraduates who graduated with degrees in each discipline" (Chen et al., 2019, p. 578). While this method for estimation may have captured accurate demographic data, there is the concern that when they excluded various categories of data, they were excluding students from one demographic or gender. Even though the estimation was accepted, at least by the peer reviewers, the potential disparate impact of who was included and excluded cannot be identified. Thus, we caution assumptions around student representation in samples, especially when students are unable to describe who they are regarding data that represent them.

Even for studies that do collect data regarding minoritized status of students, the question of representativeness is critical. A recent ASEE publication notes that they used "chi-squared analyses [...] to determine the significance of the discrepancies in representation rates of marginalized students" (Bowen, Johnson, & Powell, 2021, p. 6). The authors calculated whether the minoritized students were participating in the study at different levels of representation than the students who are traditionally served by engineering departments. Additionally, this paper noted that their sample "must actually exhibit *better* representation rates or quantitative outcomes than non-marginalized populations to a statistically significant degree" (Bowen et al., 2021, p. 6). These authors note this decision as striving for equity rather than equality.

Finally, in an article from the journal, *Race Ethnicity and Education,* the author discusses their decision in sample restriction to Black and White women "as a racial comparison." The author goes on to say "this comparison is made not to normalize Whiteness, but as a way to indirectly understand how power drives policy decisions" (Campbell, 2020, p. 6). The differences in how authors discuss race and gender variables (and in other studies: disability status or sexuality) reveal some assumptions or accepted normalizations of what they represent. In quantifying each variable, we reduce the social relationships that make up the categorization. Additionally, this quantification stabilizes concepts that are not necessarily stable. For race:

> *'It' is not a thing, a reified object that can be measured as if it were a simple biological entity. Race is a construction, a set of fully social relationships.'" (Apple 2001, p. 204 emphasis kept).*

Further, the use of race in this fashion is what Zuberi (2008) calls a "form of racial reasoning" (p. 131). While seemingly stable categorizations are useful in helping insights travel, methodological transparency and awareness to the limits of such categorical reification is necessary to ensure that insights do not perpetuate harm onto vulnerable populations (Gillborn et al., 2018).

Decisions in Analyzing Data

In the sections pertaining to data analysis, including but not limited to sections titled data analysis, we observe several commonalities in the authors' decisions and justifications for their analyses. One of these decisions is to emphasize that various statistics match those found in previous literature. Notably, data analysis occurs throughout multiple sections of a research article. From scholars who discuss data cleaning as analysis (D'Ignazio & Klein,

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2020) to writing results and discussion as a form of analysis, the process of data analysis is not bound to the section titled analysis. Here, we discuss the decisions of determining internal consistency, normality, and the treatment of outliers.

Internal Consistency

Internal consistency has to do with how well a set of items measuring a certain construct produces similar scores when administered. This concept has been applied in several different ways, such as average inter-item correlation, closeness to unidimensionality, and internal consistency reliability (Tang et al., 2014). In engineering education, internal consistency often manifests through Cronbach's alpha. Several studies point to the similarity of internal consistency coefficients between their study and previous studies. In one study, the authors "measured Cronbach's alpha scores for the [X] subscales comparable to previous studies using the short form (Henry & Crawford, 2005; Osman et al., 2012)" (Jensen & Cross, 2021, p. 377). Similarly, authors note the Cronbach alpha score for a different subscale to be "consistent with previous work (0.905 compared with 0.84 and 0.89) (Jones et al., 2010)" (Jensen & Cross, 2021, p. 377). In a different example of internal consistency, authors used "ωh, which relaxes assumptions about the structure of measurement scales and is more appropriate than coefficient α in most cases (Zinbarg et al., 2005)" (Jackson et al., 2021, p. 152). These practices around reliability coefficients are often required in these research practices. Jensen and Cross provide transparency and robustness as they report the measures of internal consistency for each subscale dataset. Additionally, they compare these internal consistency values to several previous studies with similar values to justify the consistency of their data. In Jackson et al., authors note that they use the omega coefficient, ωh, to evaluate consistency instead of Cronbach's alpha, which they explain is an improved practice. They cite Zinbarg et al. to justify this decision.

Internal consistency is not the aim of Cronbach's alpha, however. As Sijtsma (2009) notes, Cronbach (1951) originally wrote that alpha provides a lower bound to the "true reliability" (p. 299) and does not say much of anything about the internal consistency of the items. Moreover, alpha is not a property of the itemset themselves; instead, it is the property of the itemset within the context of a specific population (Miller, 1995; Thompson & Vacha-Haase, 2000). Thus, comparing alphas to previous literature without considering the differing contexts can be misleading. These decisions and their justifications are commonly accepted practices in quantitative research nonetheless (Dunn et al., 2014).

The practice of testing for reliability has been one that goes further back than Cronbach in 1952. However, as we think about non-homogenous populations, we ask if there is a disparate impact with who the error variance explains and if this practice measuring internal consistency should remain homogenizing. A .70 coefficient for internal consistency at minimum is generally accepted (Tavakol & Dennick, 2011). This 0.70 implies that 70% of the variance in the scores is reliable variance and 30% is error variance. We question whether there are overrepresented demographics of students in the error variance. Through internal consistency calculations, do researchers unknowingly elevate the dominant student population's scores? Additionally, as the common practice of evaluating a consistency coefficient is to cite previous scholarship that may or may not have adequate demographic and gender representation, what does that say around whose survey answers produce dominant knowledge in the education research?

Normality and Outliers

The next feature of quantitative research is the way that authors evaluate normality in their data. Notably, not all quantitative research articles work under the assumption of a normal distribution in their data, but many do with statistical tests to support an assumption of normality. However, to fit into a normal distribution, authors have discussed various methods for excluding data that fall outside of the necessary parameters. Godwin et al. (2021) note that the treatment of outliers is a decision that can affect minoritized individuals most severely. Because a subset of the data does not conform to the appropriate distribution,

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students outside of the bell curve's main body are not included in the analysis - erasing their contribution to the study.

Two concepts are commonly used to assess the normality of a variable, skewness and kurtosis. Skewness is a measure of asymmetry, examining the extent to which side of the distribution has a longer tail than the other. Kurtosis measures the tailedness of the variable's distribution, which corresponds to how flat or peaked the distribution is. The cutoffs for these variable distribution properties vary. In one example, the authors "excluded asynchronous exams whose score distribution's kurtosis was more than 10" (Chen et al., 2019, p. 578). For variables with at least approximately normal properties, outliers are still threats to the performance of classical statistical tests. These authors note that their filter "eliminates asynchronous exams that have large deviations from the mean, which could have unstable effects on the regression coefficients" (Chen et al., 2019, p. 578). These types of justifications are worrisome as we question who is excluded when the data are forcefit to statistical normality.

In addition, this article notes another group of records they excluded as those that "Were outside the corresponding exam periods." They provide a footnote that states "in exceptional circumstances such as long-term illness, students take an asynchronous exam outside the normal exam period" (Chen et al., 2019, p. 588). Long-term illness or chronic illness are recognized by the American with Disabilities Act (ADA) as a disability. For the authors to note that these students were excluded because of their disability is jarring and reinforces the ableism all too common in the university setting (Brown & Leigh, 2020) as well as the ableism in research that upholds notions of normality but from a statistical perspective and from a societal perspective (Wong, 2020; Hendren, 2019). As Godwin et al. (2021) would contend, this approach embraces a variable-centered approach to analysis.

Person-centered approaches embrace heterogeneity in their data and seek to preserve the variation in individual responses within the measures. In a different paper, the authors collect demographic and gender information that they use to disaggregate their data. Notably, these authors note that the research focus is to understand "differential experiences of students based on their characteristics and contexts instead of trying to normalise engagement 'for "average" students' (Polmear, Chau, & Simmons, 2020, p. 66). In their analysis, they conduct the "Levene's test [...] to examine homogeneity of error variances assumption" (Polmear et al., 2020, p.68). Additionally, they note that a "Histogram, Q-Q normal probability plot, skewness, and kurtosis were constructed and computed to examine if data met the normality assumption (Hair et al. 2019)" (Polmear et al., 2020, p.68). Specifically, because these authors do these analyses with a disaggregated data set regarding race and gender, they can preserve different student experiences rather than reporting findings that homogenize student experiences.

Positionality

The last decision we want to highlight is the existence of researcher positionality in articles. While positionality is rare in quantitative research broadly, in engineering education research it has yet to be introduced. In a previous systematic literature review of the Journal of Engineering Education, European Journal of Engineering Education, and International Journal of Engineering Education from 2008 to 2020, we did not find positionality discussed in a single quantitative research article (Hampton, Reeping, & Ozkan, 2021). While this decision can also be an aspect of the peer review process and the journal's priorities, we note its absence in EER because positionality has appeared in other STEM education research articles.

In an article by Young and Cunningham in the journal, *Investigations of Mathematics Learning*, the authors "note [that] our positionalities, as Black female researchers who were once young high schoolers, provide us experiential knowledge that guided our analytical

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understanding of the Black female learners in this study" (Young & Cunningham, 2021, p. 38). These authors provide their positionality at the end of the article.

We note that our positionalities, as qualitative, quantitative, visual, and mixed method researchers in engineering and medical education fields, have provided a broad range of research experiences each with countless opportunities to make and justify methodological decisions. Our positionalities as Black and White researchers, male and female researchers, straight and gay researchers, have led us to identify different assumptions with each other and in published articles. However, each author resides in the United States, and we acknowledge our US-centric scope in this review of the research.

Research is a series of decisions made by researchers with different positions in society. Generally, academic research has been produced by a non-representative demographic of the Global North. As we continue to rely on established norms and past research, we find it necessary to critique the tools that have been handed down to us. While quantitative research has opened up a vast array of possible insights, which is scaled further with introduction of machine learning research methods that further reify dominant narratives without critical contextualization. Lastly, in this paper we focus on examining researcher decisions in quantitative research in the field of engineering education, but many of these issues also exist in qualitative research as well (Holly, 2020).

Conclusion

In this work, we aimed to critically examine methodological decisions and subsequent justifications provided by quantitative researchers in engineering education research articles. To accomplish this aim, we reviewed engineering education literature to identify these patterns to provide examples of critical quantitative research methods for future quantitative researchers.

While research in the space of problematizing researcher decisions is not new, we situate this work within the engineering education research discipline to shed light on the power dynamics that exist in researcher-subject relations. Research is the culmination of a number of related human decisions, often justified by expertise, past research, standards, among other disciplinary practices. These decisions and their justifications have histories that require attention as seek to disrupt inequities that can stem from knowledge production that serves the dominant groups in power. In engineering education research, researchers seek out truths with respect to student learning, faculty learning, professional practice, institutional systems, among countless other aspects of the engineering environment. These countless decisions and their justifications are entangled in various histories that are important to acknowledge in the way we as researchers carry out education research.

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Assessing a Measurement Model of Self-regulated learning in an Online Collaborative Learning Environment

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ABSTRACT

CONTEXT

The ability of students to regulate their learning process is essential to the success of their education. This metacognitive ability is also called self-regulation of learning (SRL). The importance of SRL in education has been becoming a motivating factor for many researchers to develop the measurement model for students' SRL behaviour. One of the SRL measurement models in online learning is Online Self-regulated Learning Questionnaire (OSLQ), developed by Bernard et al.(2008). Several studies have tested, adapted and translated the OSLQ in different contexts. However, none of these studies assessed the OSLQ in online-collaborative learning environments, especially in Indonesia.

PURPOSE

The current study aims to assess the OSLQ measurement model's fitness in an Indonesian online collaborative learning environment. The result of this study will provide additional evidence to the validity of OSLQ as an instrument for measuring SRL in online learning, particularly for online collaborative learning.

METHODS

We collected questionnaire (Online Self-regulated Learning questionnaire) data from 277 students. We perform confirmatory factor analyses (CFA) through R studio software to assess the model's fitness to the data. As the indicators for the good of fitness of the model, we used several indices, like CFI, LTI, RMSEA, SRMR and Chisq/df ratio.

OUTCOMES

Based on the result of CFA, we obtained the value for each index as follow, Chisq/df = 1.66 , CFI = 0.926, TLI= 0.914, RMSEA = 0.055, and SRMR = 0.065. All the indicators showed that the OSLQ model has the goodness of fit to the data.

CONCLUSIONS

Based on these findings, we can conclude that the OSLQ can be used d as a measurement model for online collaborative learning.

KEYWORDS

Self-regulated Learning, Online Collaborative learning, Confirmatory Factor Analysis, Self-regulated learning Measurement, OSLQ

Introduction

In the mid of the covid-19 pandemic, many educational institutions moved their learning activities entirely online. This situation has made online learning the primary mode of instruction for many universities whose face-to-face instruction is impossible due to Covid-19 restrictions. In practice, the usage of online learning varies depending on the course characteristics. Some courses use synchronous lecturing mode using video conference platform, while others combine it with online-collaborated learning activities.

The ability of students to regulate their learning is required to succeed in their education (Bergin et al., 2005; Long & Aleven, 2017; Zimmerman, 2000). This metacognitive ability is also known as Self-regulated Learning (SRL) (Zimmerman, 1989). Several studies have shown that self-regulated learning strongly correlates with students' academic performance (Lucieer et al., 2016; Zimmerman, 1990). Theoretically, SRL is a metacognitive capability to regulate internal aspects like emotion, motivation and cognition to achieve the learning objective (Zimmerman, 1989). SRL is increasingly important in online learning, especially in the unit that combines its instruction with a project or collaborative learning activities(Barnard et al., 2009).

Because of the significance of SRL, many scholars have developed several approaches to assess students' self-regulated learning by considering the context of the learning process. According to Araka et al. (2020), in their review of trends in self-regulated learning in online education, the self-report questionnaire is the most common method for measuring students' self-regulation. This type of measurement also identified that most of the studies used MSLQ. Compared to MSLQ, all the items in the OSLQ have been contextualised to an online or blended learning environment. Barnard et al. (2008) argued that it was not appropriate to measure SRL using an instrument that was not intended in online learning.

In OSLQ, Barnard et al. (2008)measured the students SRL based on six subscales. These subscales are associated with six SRL strategies. The six scales consist of goal setting, environment structuring, task strategies, time management, help-seeking, and self-evaluation. Each SRL strategy has four to six items that will capture the student perceptions when practising each strategy (the description of each item can be seen in Appendix A).

Several studies have tested, adapted and translated the OSLQ in different contexts. A survey by Martinez-Lopez et al. (2017) adopted OSLQ to measure students SRL in a Russian MOOC (Massive Open Online Course). They reported that SRL skill was moderate, with a high goal setting and environment structuring level, but low in help-seeking. Similar to Martines-Lopez et al. (2020)., the study by Zalli et al. (2020) also adopted OSLQ in the Malaysian context and concluded that OSLQ is suitable to measure SRL in the MOOC environment. The latest study by Mutiara & Rifameutia (2021) adopted and translated OSLQ for the Indonesian context and reported that the Indonesian version only fitted for 22 of 24 items of OSLQ.

While these studies have extended the validity of OSLQ, none of them tests the instrument in the online collaborative learning environment. The purpose of the current study is to examine whether the OSLQ model can be used to measure SRL in the context of Indonesian online collaborative learning by assessing its goodness of fit. The result of this study will provide additional evidence to the validity of OSLQ as an instrument for measuring self-regulated learning in online learning, particularly for online collaborative learning.

Methods

Participants

The participants in this study were university students who enrolled in an online information system course at a private university in Indonesia. All of the students were in their second year. Among 500 students, 277 (55.4%) agreed to participate in the study. From these

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participants, 60.2 % (n = 167) were males and 39.8 % (n= 110) were females. Their age range was 18 to 27 years (*M* = 20.24; *SD* = 0.99).

Measures

The Online Self-Regulated Learning Questionnaire (OSLQ) by Barnard et al. (2008) was adapted and translated to build the measurement model of SRL for online collaborative learning in Indonesia. This questionnaire consists of 24 Likert- statements with five scales (ranging from 1 = *strongly disagree* to 5 = *strongly agree*). Barnard et al. (2008) grouped these items into six dimensions, each representing a latent factor in self-regulated learning. These six factors are i) goal setting, ii) environment structuring, iii) task strategies, iv) time management, v) help-seeking, and vi) self-evaluation. The information about the number of observed variables for each dimension can be seen in Table 1.

Table 1 SRL Factor Structure based on Barnard's model

Dimensions/ Factors of SRL	**Associated items (Appendix A)**	**Items per factor**
Goal Setting (GS)	GSQ1, GSQ2, GSQ3, GSQ4, GSQ5	5
Environment Structuring (ES)	ESQ6, ESQ7, ESQ8, ESQ9	4
Task Strategies (TS)	TSQ10, TSQ11, TSQ12, TSQ13	4
Time Management (TM)	TMQ14, TMQ15, TMQ16	3
Help-seeking (HS)	HSQ17, HSQ18, HSQ19, HSQ20	4
Self-evaluation (SE)	SEQ21, SEQ22, SEQ23, SEQ24	4
	Total items	**24**

Procedure

All of the students were enrolled in an online course named Project Management for Information System. This unit course was delivered online for 16 weeks through video conference once a week. In addition to the online lecturing, the students were also required to participate in the weekly online quiz. Students participated in individual learning activities and project-based learning. In week four, the students were asked to form a group that consisted of five to six students. In groups, students developed project management plans. Each group created their plan using a Wiki page provided in the learning management system.

The students completed the research questionnaire in the last week of the semester, consistent with the project ethics approval. The questionnaire was administrated through the survey feature in the learning management system. Before completing the questionnaire, the students indicated consent and only students who consented continued to the questionnaire page. Among 500 students, 277 students agreed to participate in the study.

Analysis

The factor structure of OSLQ as a measurement model in the online collaborative learning context in Indonesia was assessed using Confirmatory Factor Analysis (CFA) through R Studio Software (with Lavaan (Rosseel, 2012), Psych, QuantPsyc and MVN packages).

Before conducting the CFA, several assumptions were checked. There were no missing values as identified using R studio. Mahalanobis distance (D^2) values greater than chi-square were excluded as outliers (Brown, 2006; Harrington, 2009). Fifty-eight participants were labelled as outliers and removed from the sample. The remaining 219 responses were analysed. The statistical description of these data can be seen in Table 2.

Table 2 Description of Sample Data (N = 219)

Items	***M***	***SD***	***median***	***min***	***max***	***range***	***skew***	***kurtosis***
Goal Setting (GS)								
GSQ1	3.89	0.62	4	2	5	3	-0.05	-0.12
GSQ2	3.9	0.67	4	2	5	3	-0.16	-0.14
GSQ3	3.82	0.7	4	2	5	3	-0.06	-0.38
GSQ4	3.94	0.63	4	2	5	3	-0.29	0.43
GSQ5	3.75	0.79	4	2	5	3	-0.29	-0.3
Environment Structuring (ES)								
ESQ6	4.13	0.69	4	2	5	3	-0.34	-0.27
ESQ7	3.97	0.72	4	2	5	3	-0.25	-0.33
ESQ8	4.03	0.68	4	2	5	3	-0.21	-0.28
ESQ9	3.88	0.68	4	2	5	3	-0.29	0.11
Task Strategies								
TSQ10	3.55	0.77	4	1	5	4	0.04	-0.1
TSQ11	3.48	0.8	4	1	5	4	-0.28	-0.26
TSQ12	3.27	0.72	3	2	5	3	0.36	0.04
TSQ13	3.47	0.74	3	2	5	3	0.2	-0.31
Time Management (TM)								
TMQ14	3.64	0.7	4	2	5	3	-0.02	-0.28
TMQ15	3.66	0.65	4	2	5	3	-0.12	-0.15
TMQ16	3.62	0.7	4	2	5	3	-0.23	-0.12
Help Seeking (HS)								
HSQ17	3.98	0.64	4	3	5	2	0.01	-0.53
HSQ18	3.96	0.62	4	2	5	3	-0.09	-0.03
HSQ19	3.48	0.97	4	1	5	4	-0.34	-0.41
HSQ20	3.69	0.65	4	2	5	3	0.09	-0.38
Self Evaluating (SE)								
SEQ21	3.55	0.69	4	2	5	3	0.04	-0.27
SEQ22	3.79	0.63	4	2	5	3	-0.12	-0.05
SEQ23	3.74	0.7	4	2	5	3	-0.26	-0.01
SEQ24	3.89	0.65	4	2	5	3	0.01	-0.41

Note: Items are described in Appendix A

According to Bandalos (2014), the sample size (n > 200) is adequate for CFA analysis. Multivariate normality was assessed based on the value of Mardia skewness and Mardia kurtosis, as shown in Table 3. The data departed from the multivariate normal distribution. Some researchers (Brown, 2006; Gold et al., 2003; Kline, 2016; Yuan et al., 2005) argue that non-normality can be handled by using robust maximum likelihood as the estimator. Therefore, this study used robust maximum-likelihood (MLR) from the Lavaan R package.

Table 3 Result for Multivariate Normality Test (*N* = 219)

Test	***Statistic***	***p-value***
Mardia Skewness	5562.03	< 0.05
Mardia Kurtosis	41.066	< 0.05

Results

Assessment of model fit

This study used several CFA indices to measure the goodness of fit of the OSLQ as a measurement model. These indices consist of Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root means Square Error of Approximation (RMSEA) and Standardised Root Mean Square Residual (SRMR). Since this study uses robust maximum likelihood as the estimator, the indicators' value also refers to their robust value.

The threshold for each index varies to indicate model fit. The CFI requires a value greater than 0.9, TLI should be more than 0.9, SRMR less than 0.08 and RMSEA less than 0.06 (Brown, 2006; Kline, 2016).

Table 4 Goodness of fit based on the CFA

Indicator	***Chisq/df***	***SRMR***	***RMSEA***	***CFI***	***TLI***
Threshold for good fit	**<3**	**<= 0.08**	**<= 0.06**	**>= 0.9 (or close**	**>= 0.9 (or close)**
Indicator value	1.66	0.065	0.055	0.926	0.914

Based on the result of CFA (shown in Table 4), we obtained the value for the indices as follows, χ^2 /*df* = 1.66, CFI = 0.926, TLI= 0.914, RMSEA = 0.055, and SRMR = 0.065. All the indicators showed that the OSLQ model has the goodness of fit to our data. The path diagram of the CFA model, as shown in Figure 1, represents the relationship among the latent variables and the relationship between each latent variable to correspond observed variable. The relationship among the latent variables is explained by the covariance score ranging from 0.40 to 0,93. In comparison, the relationship between latent and observed variables is described by the standardised factor loading score. According to CFA results, all the observed variables have factor loading bigger than 0.40 (ranging from 0.43 to 0.84), representing an acceptable score (Tabachnick & Fidell, 2014). The standardised factor loadings for each observed variable can be seen in Table 5.

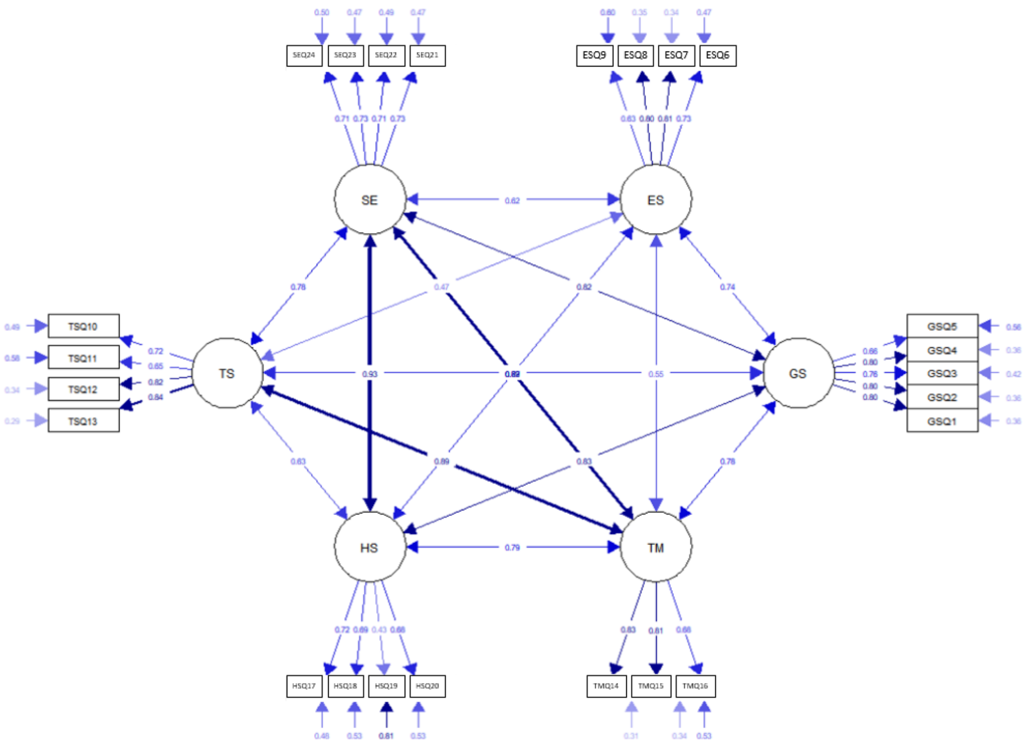

Figure 1 Measurement Model of OSLQ in Indonesian Online Collaborative Learning (*N* = 219)

Table 5 Factor loading for OSLQ Model in Indonesian Online Collaborative Learning

Latent Factor	Indicator	*Estimate*	*Std. Err*	*Z-value*	*p-value*	*Std. all*
GS	GSQ1	0.49	0.035	14.04	< 0.05	0.80
	GSQ2	0.54	0.035	15.34	< 0.05	0.80
	GSQ3	0.53	0.032	16.52	< 0.05	0.76
	GSQ4	0.50	0.040	12.65	< 0.05	0.80
	GSQ5	0.52	0.047	11.20	< 0.05	0.66
ES	ESQ6	0.50	0.044	11.33	< 0.05	0.73
	ESQ7	0.59	0.042	14.10	< 0.05	0.81
	ESQ8	0.54	0.045	11.95	< 0.05	0.80
	ESQ9	0.43	0.052	8.30	< 0.05	0.63
TS	TSQ10	0.55	0.048	11.50	< 0.05	0.72
	TSQ11	0.52	0.054	9.73	< 0.05	0.65
	TSQ12	0.59	0.052	11.29	< 0.05	0.82
	TSQ13	0.62	0.040	15.60	< 0.05	0.84
TM	TMQ14	0.58	0.037	15.48	< 0.05	0.83
	TMQ15	0.53	0.041	12.87	< 0.05	0.81
	TMQ16	0.47	0.046	10.33	< 0.05	0.68
HS	HSQ17	0.46	0.042	10.77	< 0.05	0.72

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Latent Factor	Indicator	*Estimate*	*Std. Err*	*Z-value*	*p-value*	*Std. all*
	HSQ18	0.42	0.044	9.51	< 0.05	0.69
	HSQ19	0.42	0.066	6.33	< 0.05	0.43
	HSQ20	0.44	0.045	9.88	< 0.05	0.68
SE	SEQ21	0.50	0.045	11.29	< 0.05	0.73
	SEQ22	0.45	0.040	11.15	< 0.05	0.71
	SEQ23	0.51	0.037	13.52	< 0.05	0.73
	SEQ24	0.46	0.042	10.94	< 0.05	0.71

Discussion

This study aimed to assess the validity of the structure of OSLQ as a measurement model of students' self-regulated learning in Indonesia in an online collaborative learning course. The adoption of OSLQ by several studies was based on the assumption that the socio and technical context influence the students' Self-regulated learning strategies. Most of these studies showed that OSLQ is reliable and valid as a measurement model of self-regulated learning in online learning. However, there are still limited studies that assess the validity of this model in the context of online collaborative learning environments, particularly in Indonesia. Thus the current study conducted a Confirmatory Factor Analysis (CFA). It used data from students who enrolled in an online collaborative course in an Indonesian private university. Among 500 students, 277 students agreed to participate in the study. After removing the outlier, there were 219 participants included in this study.

Based on CFA's model-fit indices (CFI, TLI, RMSEA, and SRMR), the OSLQ model had an acceptable fit to the data. This finding informed the validity of OSLQ as an instrument for measuring SRL in online learning with intensive collaborative activities. Additionally, this result also reported the validity and reliability of all 24 of the OLSQ items. This result is different from the study by Mutiara & Rifameutia (2021) that is only valid for 22 items of OSLQ.

The result of this study can be used as justification to use OSLQ as an instrument to measure student perception of SRL in the context of an online complex collaborative learning environment. It should be noted that the primary concern of this study is to assess the OSLQ as a measurement for individual SRL in a collaborative learning environment. The result is limited to information systems. Extending this model for measuring collective or socially-shared of regulation is one of the agenda for further investigation.

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Appendix A

The questionnaire item or OSLQ (Barnard, 2008)

Goal Setting
Item GSQ1: I set standards for my assignments in online courses.
Item GSQ2: I set short-term (daily or weekly) goals as well as long-term goals (monthly or for the semester).
Item GSQ3: I keep a high standard for my learning in my online courses.
Item GSQ4: I set goals to help me manage study time for my online courses.
Item GSQ5: I don't compromise the quality of my work because it is online.
Environment Structuring
Item ESQ6: I choose the location where I study to avoid too much distraction.
Item ESQ7: I find a comfortable place to study.
Item ESQ8: I know where I can study most efficiently for online courses.
Item ESQ9: I choose a time with few distractions for studying for my online courses.
Task Strategies
Item TSQ10: I try to take more thorough notes for my online courses because notes are even more important for learning online than in a regular classroom.
Item TSQ11: I read aloud instructional materials posted online to fight against distractions.
Item TSQ12: I prepare my questions before joining in discussion forum.
Item TSQ13: I work extra problems in my online courses in addition to the assigned ones to master the course content.
Time Management
Item TMQ14: I allocate extra studying time for my online courses because I know it is time-demanding.
Item TMQ15: I try to schedule the same time every day or every week to study for my online courses, and I observe the schedule.
Item TMQ16: Although we don't have to attend daily classes, I still try to distribute my studying time evenly across days.
Help-Seeking
Item HSQ17: I find someone who is knowledgeable in course content so that I can consult with him or her when I need help.
Item HSQ18: I share my problems with my classmates online, so we know what we are struggling with and how to solve our problems.
Item HSQ19: If needed, I try to meet my classmates face-to-face.
Item HSQ20: I am persistent in getting help from the instructor through e-mail.
Self-Evaluation
Item SEQ21: I summarise my learning in online courses to examine my understanding of what I have learned.
Item SEQ22: I ask myself a lot of questions about the course material when studying for an online course.
Item SEQ23: I communicate with my classmates to find out how I am doing in my online classes.
Item SEQ24: I communicate with my classmates to find out what I am learning that is different from what they are learning

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Refining an Entrepreneurial Mindset Master Concept Map through Multi-Institutional Collaboration

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ABSTRACT

CONTEXT

Over the past decade, there has been a substantial increase in the demand for the integration of entrepreneurial mindset (EM) into training of undergraduate engineering students. Although the engineering education field recognizes the importance of training related to this mindset, the assessment of EM development has lagged behind its implementation. Concept maps (cmaps) offer potential for direct EM assessment as they can provide a snapshot of students' conceptual understanding at a specific time point. A cmap uses nodes (concepts) and links (connections between concepts) as visual representation of an individual's perception of a topic.

PURPOSE OR GOAL

This study supports a larger project and focuses on applying a master/criterion EM cmap as a benchmark for scoring engineering students' cmaps. The research questions we will address are: What differences exist between students' cmap representation of EM concepts and the categories of a master EM cmap? How do student cmaps completed in different contexts compare in regard to their EM concept integration?

APPROACH OR METHODOLOGY/METHODS

This research study involved collecting EM-related cmaps from five distinct classes at different institutions representing a variety of institutional types and contexts, although only data from three institutions was analysed as part of this study. All cmaps were de-identified prior to analysis. A total of 65 cmaps were included in this analysis. Starting with a previously developed draft master EM cmap, we used the categories (or branches) from that cmap for categorically scoring students' cmaps. As part of the analysis process, training and calibration was completed for the two main researchers to ensure that the scoring process was reproducible. After which, cmaps were scored separately by both main researchers and inter-rater reliability was monitored for their scores.

ACTUAL OR ANTICIPATED OUTCOMES

This preliminary work benefits the engineering education community by demonstrating a reliable scoring approach that can be applied to evaluate cmaps generated for complex topics such as EM. This study provides insight into the challenges associated with using a master cmap approach to assess cmaps generated from multiple institutional contexts and different assignment prompts. Results are guiding changes to the draft master EM cmap to clarify categories and ultimately streamline the qualitative scoring process.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Through this study, we demonstrated how a master EM cmap can be used in the scoring of EM focused cmaps generated through multiple implementation methods. The results help us to address gaps in the literature on EM and operationalize a "definition" of EM that can be applied for direct assessment of the construct. After additional scoring, we will offer best practices that will assist faculty members with assessing EM development in their courses.

KEYWORDS

Concept maps (cmaps), entrepreneurial mindset (EM), undergraduate students

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Introduction

Entrepreneurship (or intrapreneurship) has become an important aspect to integrate within the engineering curriculum due to its focus on the development of collaborative skills, technical and analytical skills, and personal attributes like flexibility, resiliency, creativity, empathy and opportunity recognition (Byers et al., 2013; Sheppard et al., 2009). Entrepreneurial-minded engineers are expected to demonstrate both traditional technical expertise and organizational level leadership to meet the needs of changing markets (Kriewall & Mekemson, 2010). Accordingly, Entrepreneurial Mindset (EM) has been integrated into various engineering educational settings through projects, courses, and degree programs (Huang-Saad, Morton, & Libarkin, 2018). It has become accepted that EM is vital to instill in students as more industries seek well rounded individuals with an abundance of technical and professional skills (Byers et. al 2013; Dabbagh & Menasce, 2006). Further, engineering program accreditors such as ABET and Engineers Australia require assessment of student competencies that align with EM dimensions, particularly related to applying engineering knowledge through design processes and developing professional skills (Bosman & Ferhaber, 2018).

Although there has been a considerable increase in entrepreneurially-minded learning (EML) within engineering (Huang-Saad, Morton, & Libarkin, 2018), measurement of EM development has proven difficult (Zappe et. al, 2013). The use of tools such as surveys and rubrics for assessment have been successful, though the results of the studies have often been inconsistent with each other, making it difficult to draw any definitive conclusions about EM development (Huang-Saad, Morton, & Libarkin, 2018).

One direct assessment method that has been applied widely in educational research, yet not used very often within EM research, is the use of concept maps (cmaps) (Watson et. al, 2016). Cmaps involve creating an organized, graphical depiction of knowledge surrounding a specific topic and have been shown to be useful for assessment and training of students' understanding in various areas (Turns, Atman, & Adams, 2000; Watson et. al, 2016). The purpose of this paper is to introduce a reliable approach to assess EM development using cmaps. To achieve this purpose, we seek to address the research questions: *(1) What differences exist between students' cmap representation of EM concepts and the categories of a master EM cmap? (2) How do student EM cmaps completed in different contexts compare in regard to their EM concept integration?* Our approach involves scoring cmaps from different institutional and course contexts and comparing results to a published master EM cmap. This paper describes both our findings related to the research questions and our efforts to refine the assessment method based on those findings.

History and Applications of Concept Maps

Assessment of conceptual knowledge in students has been a widely approached topic within all forms of education (Rittle-Johnson, 2006). Studies have sought possible ways to understand this knowledge, as it has become accepted that true conceptual knowledge requires organization and the ability to draw from prior knowledge to make connections between concepts (Rittle-Johnson, 2006; Watson et. al, 2016). In the 1980s, Novak & Gowin (1984) built upon these ideas to create a tool that could be used to assess students' true understanding of a topic. They referred to their tool as a "concept map", (cmap) in which various ideas relating to a certain theme (concepts) are connected using linking phrases (propositions) (Novak & Gowin, 1984; Novak & Canas, 2008). Over time, cmaps have been used across disciplines for a vast range of topics, leading to a variety of interpretations of the tool throughout curricular practice. The most common method for organization of cmaps uses multiple hierarchies that branch from the main topic (Watson et. al, 2016). Hierarchies that are tied together using a linking phrase, known as a "cross-link", show increased understanding of the topic (Novak & Canas, 2008).

Cmaps have been implemented to encourage learning at all educational levels and have been associated with positive outcomes such as increase in critical thinking skills and ability to retain knowledge (Walker & King, 2002; Watson et. al, 2016). At the university level, cmaps are used for classroom activities, homework assignments (Patel, 2018), curriculum development, and lecture material (Turns, Atman, & Adams, 2000). There are several methods for scoring cmaps that give educators options for assessing their students' learning. We will briefly describe the four most frequently used methods, which include both quantitative and qualitative approaches. Often, more than one scoring method will be used to capture the breadth, depth, and connectedness of students' conceptual understanding.

Traditional scoring. Introduced by Novak & Gowin (1984), traditional scoring is the most used approach, which analyses maps based on the number of concepts, hierarchy levels, and cross-links. These results are inserted into a formula to produce the final map score (Novak & Gowin, 1984; Novak & Canas, 2008).

Holistic scoring. Besterfield-Sacre et. al (2004) found that Traditional Scoring was somewhat restrictive and failed to encompass the full depth of students' knowledge, so they developed a more qualitative approach to scoring. This method involves assigning scores to an entire cmap based on Comprehensiveness, Organization, and Correctness, and then adding the three scores together.

Categorical scoring. This is a common mixed methods scoring approach which involves assigning concepts to certain categories decided by the scorer. The number of links between the various categories are then assessed and applied to a formula for complexity analysis to obtain the final map score (Watson et. al, 2016).

Expert map comparison scoring. This method uses an "expert" designed cmap to compare to the student maps and ultimately determine their level of conceptual understanding of a topic (Turns, Atman, & Adams, 2000). This method can provide insight into possible disconnects between student and expert understanding, and also serve as a basis for analysing future maps on the same topic (Bodnar, Jadeja, & Barrella, 2020).

Methods

Study Design

This study is part of a larger project involving five institutions in the United States that are developing cmap activities related to entrepreneurial mindset. We will present methods and results from three institutions, which are classified as a small, teaching-focused, liberal arts university (Bucknell University); a small, private, research university (University of New Haven); and a large, public, research-intensive university (The Ohio State University). Concept mapping assignments were integrated into existing engineering courses and varied across institutions based on the course topic and learning objectives, as shown in Table 1. Each assignment used a prompt related to EM in general (for lower-level courses) or EM in the context of the disciplinary course content (upper level courses). Student participants were first asked to complete a survey as part of the consent process. This survey gathered data regarding each participant's experiences with EM and cmaps, as well as demographic information such as gender, race, institution, and current curricular semester. For example, if students answered "Yes" to the question "Do you have any prior experience or knowledge of entrepreneurial mindset or entrepreneurship?", they would also be prompted with the question "Was this prior experience or knowledge of entrepreneurial mindset or entrepreneurship from: Coursework, Co-Curricular Activities, Work Experience, Other?"

Two out of the three institutions from which data was analysed, opted to assign "Construct-a-map" activities, while the other institution chose "Fill-in-a-map". "Construct- a-map" asks students to create a cmap from scratch based on a prompt. The "Fill-in-a-map" activity involved providing students with a central topic, a predetermined cmap structure, and list of 22 EM related terms. Of the 22 related terms, 5 were pre-filled in and 17 were listed

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alphabetically in a concept word bank. Appropriate human subjects' approval was obtained prior to data collection.

Table 1: Concept Mapping Assignments at Each Participating Institution

Institution	Course(s)	Cmap Type	Prompt	Sample Size
Bucknell University	Technical communications (upper level)	Construct-a-map	Value proposition for an engineering business proposal	13
Ohio State University	Engineering Fundamentals (first year)	Fill-in-a-map	Entrepreneurial Mindset	38
University of New Haven	Thermo Fluids Lab (senior)	Construct-a-map	Value created by their Thermo-Fluid projects	14

Notes: The sample size refers to the number of students who completed a cmap.

Concept Map Scoring

Categorical scoring was applied to cmaps based on categories generated from a published expert map (Bodnar et al., 2020). The categories from the EM master cmap were used to code each concept in each student-generated cmap. There were a total of seven main categories and five subcategories identified, as shown below in Figure 1. Each category included numerous terms.

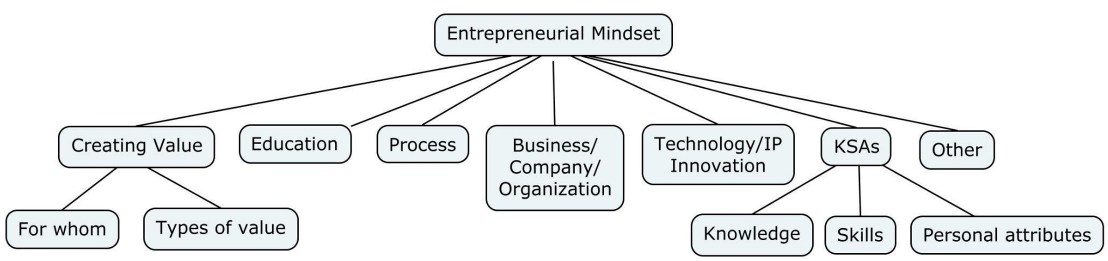

Figure 1: EM Categories for Coding

Cmaps were initially reviewed to correct spelling errors and identify prepositions that were meant to be concepts. Then, two researchers calibrated by categorically scoring one randomly selected cmap from each institution. Once the training was completed, the two researchers independently scored the remaining cmaps from one institution at a time. The researchers then met to reconcile any discrepancies, before proceeding to code maps from the next institution. In this manner, the researchers could learn from their coding process to help assist with better agreement on the subsequent institution's maps. An overall inter-rater reliability calculation using Cohen's Kappa alongside percent agreement (refer to Table 2) was used to check for coding inconsistency across the two researchers.

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Table 2: Reliability Analysis for Concept Map (Cmap) Scoring Process

Institution (Sample Size for Reliability Analysis)	Inter-rater Reliability (as measured by Cohen's Kappa)	Percent Agreement (%)
Ohio State University (n=37)	0.877	83.79
Bucknell University (12)	0.627	66.35
University of New Haven (13)	0.764	80.79

The results obtained for inter-rater reliability showed fair (0.4 to 0.75) to strong agreement above chance (>0.75) (Fleiss, 1986). Overall, percent agreement was seen as reasonable with values across two out of the three institutions above 75% and the final institution above 65%. It was also observed that the two measures employed for reliability analysis were in alignment with one another. The reliability measures are similar to those from other cmap categorical scoring studies (Barrella et. al, 2021; Cassol & Verrett, 2020). Both Bucknell and University of New Haven used similar cmap prompts, which allowed for the reconciliation discussion after scoring Bucknell maps to assist with improving overall agreement on University of New Haven maps. Disagreement tended to center on specific terms in each dataset or entire hierarchies that were categorized differently from the root concept. Other studies have described similar challenges with scoring judgments when the central topic is a complex, multidimensional construct (Watson et al., 2016; Svanstrom et al., 2018).

Results and Discussion

In the initial review of the categorical scoring across institutions (see Table 3), we observed that all the categories derived from the EM master map were used in student generated cmaps. We also found that there was very infrequent application of the category "other". This implies that the initial EM master map was comprehensive in terms of its ability to capture the concepts relevant to EM and that there were no significant gaps between student perception of entrepreneurial mindset and the categories of the master EM cmap.

To address the first research question "*(1) What differences exist between students' cmap representation of EM concepts and the categories of a master EM cmap*?", we compared the categorization of student cmaps across the three different institutions. Through this analysis, we found a range in the application of Entrepreneurial Mindset (EM) categories (refer to Table 3). We expected that the "Education" category would be used infrequently based on the assignment prompts and the student perspective as compared to the faculty perspective used to develop the initial EM master map. In fact, that category was not assigned to any of the Ohio State University cmaps and only to a few concepts in the Bucknell University and University of New Haven samples. The results may suggest "gaps" in student perceptions, such as business/company/organization functions for Ohio State University and University of New Haven students or engineering competencies/personal attributes (KSAs) for Bucknell University students. However, exploring our second research question suggests that student responses were sensitive to the assignment context and prompt such that the cmaps may not fully reflect students' perceptions of EM.

To address the second research question, "*How do student EM cmaps completed in different contexts compare in regard to their EM concept integration?*", we examined in more detail differences in the approaches taken to implement the cmaps at the three institutions and the selection of the assignment prompts. The variability in application of EM categories seems to be at least partially related to the initial prompt that was provided to students for constructing their cmap and the course context.

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Table 3: Use of Entrepreneurial Mindset Categories within Student Concept Maps

Category	Ohio State University	Bucknell University	University of New Haven
Creating Value	12.5%	20.2%	4.1%
Process	32.5%	22.2%	12.5%
Business/Company/ Organization	1.1%	15.2%	1.7%
Technology/ Intellectual Property	20.7%	36.4%	15.2%
Knowledge, Skills, & Attributes	32.7%	2.6%	65.3%
Education	0%	3.4%	1.2%
Other	0.6%	0%	0%

Ohio State University's cmaps had a broad focus on EM and due to the use of a Fill-in-a-Map structure, also provided students with concepts that covered a breadth of topics relevant to an EM. Despite providing students with the concepts to include in their map, we still observed that some students would interpret these concepts differently in their completion of the map. Examples included 3D printing, adapting, new ideas, time, and cost efficiency. For instance, adapting would sometimes be listed as a knowledge, skill, or attribute when referencing characteristics of the individual that was building their knowledge of an EM but in other occasions would fall under the category of technology/intellectual property when referencing innovation or new development. Another concept that was categorized differently across student maps was time. Students may have placed this under a type of resource where it would have been categorized as *Process*. In other situations, students would place time as a type of value that would be created by the technology. However, it was also quite common for students to randomly place time on the map, which led to difficulty in interpreting how to score this concept, leading it to fall under the "other" category.

The cmaps that were collected from both Bucknell University and University of New Haven were not explicitly focused upon the term "entrepreneurial mindset" but rather provided students with a prompt focused upon creating value through a student technical proposal (Bucknell) or lab project (New Haven). The students were also provided with less guidance in terms of map structure and concepts to be included through the application of the construct-a-map activity. In both cases, students were upper level and should have been exposed to EM in prior courses, which makes the less direct prompts appropriate for assessing students' understanding of EM. As such, we observed that these maps had a higher number of concepts that were relevant to either *Technology/intellectual property* or *Knowledge, skills, and attributes* than was observed in the Ohio State University cmaps. Understanding how to assign technical information and determining whether it pertained to new or existing technology was one of the main challenges we experienced throughout the scoring process of these two institutions' maps. For this reason, we proposed splitting apart Category 7 into the two sub-categories of traditional and novel technology to distinguish between these constructs moving forward. There is also the need in future implementations to encourage students to apply better linking words in their cmaps to aid with this classification.

For Bucknell University, students also completed a business model canvas as part of their technical proposal, which resulted in greater emphasis on the category

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Business/Company/Organization. In categorizing the concepts, we had difficulties distinguishing between process and business and/or business and creating value. It was determined at the end of our reconciliation process with this set of maps that a sub-category should be added to the *Business/Company/Organization* heading that has *Channels* (how do you pursue marketing, supply chain, etc.) to help capture concepts that were relevant to the business model canvas that did not exist in the initial expert cmap. This may also help address a challenge we faced with differentiating between the steps taken when creating a product from the work done once the product has been created (business related functions).

There were a few scoring disagreements that were common across maps from all three institutions. These disagreements included how to distinguish between process and technology/intellectual property, process and knowledge, skills, and attributes, and technology/intellectual property and knowledge, skills, and attributes. To assist with better application of these categories, we need to clarify the distinction between process and technology/intellectual property, making it clear where concepts such as product specifications should be located. A potential reasoning could be that *Process* is how we create the "thing" and then *Technology/intellectual property* is used as a category to define the "thing" and what it does. Throughout our scoring process we recognized just how important the linking words can be in interpretation of student cmaps, particularly when a concept could be placed under two different categories. For this reason, we recommend encouraging instructors to emphasize labelling links between concepts when students are completing cmap activities in classes.

Conclusion

Applying the codes from the EM master map worked well across different assignment types and prompts; all categories were used, and concepts were rarely assigned to the "other" category. Further, the coding revealed differences in student responses based on the assignment type, context, and prompt. Main challenges with the categorical scoring involved assigning specific terms that were not included in the original expert map dictionary or assigning the same term to different categories depending on the context in an individual student map. As a result of the initial round of categorical scoring, changes are being made to the codebook and coding process. Ultimately, the master EM cmap will be revised in order to better distinguish between categorical codes like business and process or existing technology/knowledge and new technology/innovation. The coding process is also being simplified to make scoring easier and account for predictable differences in interpretation such as critical thinking being viewed as a personal attribute and a skill, and thus belonging in the larger KSAs category. Final revisions to the coding process will be made after scoring cmaps from the other two institutions included in the larger study, which both used similarly straightforward prompts about EM and we expect will match well with the current categorical scoring process.

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Student reflection on engineering responsibility exemplified in a professional code of conduct

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ABSTRACT

CONTEXT

South African engineering graduates are required to demonstrate the acquisition of eleven graduate attributes set by the Engineering Council of South Africa (ECSA, 2020). One of these, graduate attribute 10, relates to Engineering Professionalism, where students are required to demonstrate "critical awareness of the need to act professionally and ethically and to exercise judgment and take responsibility within own limits of competence". Students are required to provide evidence of their understanding of engineering professionalism in terms of the ECSA Code of Conduct, which regulates the conduct of registered engineers in South Africa.

PURPOSE OR GOAL

This research investigates student understanding of their engineering responsibility as is evidenced in a formative assignment set as part of the fourth-year civil engineering course at the University of Cape Town. This recognises student learning around professional engineering responsibility to be a significant area of engineering education and research. The research thus aims to investigate student understanding of the professional code as exemplified in their comments analysing the ECSA Code of Conduct.

METHODOLOGY

This research will examine student assignments submitted as formative assessment of student understanding relating to ethics and professionalism relating to their professional code. This data was analysed by using the software NVivo, grouping comments in terms of different categories relating to:

- the specific item number of the code,
- reasons provided to justify the significance of the item in terms of personal, professional or public interest,
- areas which students flag as difficult to understand and
- areas where the students provide alternative formulations or suggest changes.

This data was consolidated to provide evidence of student learning relating to their professional responsibility in terms of a particular Code of Conduct.

ANTICIPATED OUTCOMES

This research is anticipated to provide insight as regards how students interpret the professional Code relating to personal priorities, professional considerations and/or responsibility to the public. The research also aims to demonstrate the value of the student voice in developing understanding of professional responsibility. This is seen to provide support for including student perspectives alongside expert and experienced perspectives engaging critically and constructively with how regulatory documents communicate to both inspire and regulate engineering professionals.

CONCLUSIONS

Providing evidence of student understanding relating to a specific code of conduct provides a new perspective on a key document for professional engineers in the context of South Africa.

KEYWORDS

Engineering professionalism, engineering responsibility, student reflection, professional code of conduct

Introduction

Student learning within engineering is the subject of a growing body of research (Fink, 2007; Case, 2013; Hattingh, Dison and Woolacott, 2019). Whereas learning in the sciences can be approached as the objective acquisition of facts and process, associated with this is the act of translating fact and detail into theory and meaning. Student reflection is a distinct area of student learning that requires students to intentionally activate both critical and consolidating functions to construct meaning and significance. Fink's analysis (2007) identifies significant learning to be the learning that persists beyond the specific context of the interaction and that impacts the identity and being-in-the-world of the individual.

This research positions student reflection as a valid and valuable lens through which to engage with student understanding relating to a professional code in a particular context: the Code of Conduct of the Engineering Council of South Africa (ECSA). Lave and Wenger's (1991) theory of "legitimate peripheral participation" may be applied to students' relationship to their profession and to their professional responsibilities. During their studies, students develop their professional understanding of their profession through proximal contact and interaction with the profession (Wenger, 1998). This interaction includes the engagement with disciplinary experts within the academic context; work experience (Martin, Maytham et al., 2005), experience on site (Gwynne-Evans, 2018) and as part of a community (Allie et al. 2009).

This research examines student submissions of an assignment that is part of the Professional Practice course in fourth year civil engineering programme at the University of Cape Town. The assignment requires formative critical engagement with the engineering professional code in the South African context. The 2021 civil engineering class at the University of Cape Town were divided into 20 groups of 6 students each. Groups were allocated to a specific project site where students set up and undertake a site visit. Students use what they learn in the context of the site visit, a desk study and through communication with the professional engineers to assemble a report pertaining to professional responsibilities and practice. Course assessment includes both individual and group assignments relating to a range of graduate attributes assessed at exit level.

Professional Codes of Conduct are constructed by experts in a specific geographic or disciplinary context and are complex, socially-embedded sensemaking processes (Statler and Oliver 2016). They are positioned to both inspire and to regulate behaviour of the professionals under their regulation (Harris, Pritchard et al., 2014). Codes of Conduct are thus positioned as living documents that respond to changes in context and/or technology, critique by stakeholders (Hilhorst, 2005) and the requirements of a discipline. Codes of ethics and professional responsibility require professional engineers to take responsibility for their actions and to apply their best professional judgment to their decision-making, no matter what other parties, including employers and clients, request or demand (Matsuura in Abass, 2020).

The ECSA Code of Conduct is one such document that has undergone changes in the 24 years since it was first published in 1997. At the onset of multi-party democracy in South Africa, legislative changes were effected in all areas of public and corporate life. These changes were implemented to bring legislation in line with the 1994 Constitution. Law-making over the past twenty-five years has been a response to this landmark shift in policy. There are thus clear traces of visible shifts of approach within policy and legislation.

This paper investigates the following research question: How does research into student reflection on their understanding of professional responsibility as represented in the ECSA Code of Conduct highlight areas of the professional Code that need to be clarified?

Methodology

The data for this research was accessed from fourth year civil engineering students' assignments. In the specific assignment, students were required to annotate the ECSA Code of Conduct in predetermined groups. This entailed students reflecting on the requirements of the Code, to initiate and respond to comments by group members on different items of the Code. The students were required to identify important areas of the Code that connected with their increasing understanding of their identity and responsibility as an engineering professional. This assignment was designed and set during the remote teaching and learning period initiated as a result of the curtailment of classes due to the onset of the COVID-19 pandemic. The original motivation for the assignment was to replace classroom discussion with a formal record of peer engagement and reflection. The student's engagement with the process showed an unexpectedly deep level of engagement and learning that prompted a formal research project the following year, requiring ethics clearance.

Reflection may be posited as a "professional practice and process that supports students to learn through experience" (Coulson and Harvey, 2013). Effective reflection for learning through experience requires a capacity for understanding one's own thinking and learning processes, critical self-awareness of values, beliefs and assumptions, and an openness to alternative, challenging perspectives. This process requires learners to take an active role in developing and applying their reflective skills, inferring a capacity for agency that may not be well developed in all learners. Coulson and Harvey identify a shared context and goal of learning as providing the initial scaffolding goal for learning-to-reflect. Developing a shared understanding and context for reflection provides the opportunity to practice the skill of reflection through giving and receiving feedback. The group assignment requiring the annotation of the Professional Code of Conduct provides that shared context for reflection. Here the group annotation requires students to critically and reflectively engage and respond to, one another's comments on the different sections of the Code of Conduct.

Although initially conceived of as a formative assessment, leading to the formal summative assessment, the record of comments provided a dataset that was available to be analysed. This was done using the software NVivo, grouping comments in terms of different categories relating to:

- the specific item number of the code
- the reasons provided to justify the significance of the area in terms of personal, professional or public interest
- areas which students flag as difficult to understand and
- areas where the students provide alternative formulations or suggest changes.

This data was consolidated to provide evidence of the way in which students' engagement with the formulation of the ECSA Code of Conduct demonstrates the students' ability to engage critically and reflectively with a document that forms part of the professional regulation of their profession. Here the Code communicates both as a vison document and as a regulatory document (Gwynne-Evans, Chetty and Junaid, 2021).

This assignment was deliberately placed early in the course as a way of connecting students with the formal code and as a way of encouraging a culture of teamwork and building understanding through critical engagement and interaction. Peer annotation of the ECSA Code of Conduct was seen to provide an opportunity to demonstrate critical engagement with text in a way that supplements the way students learn science-based subjects. The process was seen to enable and enhance students' ability to apply their critical gaze to a particular document in a way that would stimulate their awareness of critique as a process and develop their confidence and skill to articulate an argument. Both these capacities would further enhance the students' fulfilment of assignments requiring them to build an argument and to apply specific areas of the Code of Conduct to their experience of professional practice. In terms of the Nvivo dataset, this analysis will examine three topics that correlate to the sections with the majority of responses and that thus reflect and align with the focus of the students' attention.

The engineering student gaze is positioned as a legitimate perspective to engage critically with the Code from the periphery of the profession. This supplements the expert input on the formulation and revision of the document that takes place at intervals to fulfil the regulation requirements of ECSA (see the Engineering Professions Act (Act No. 46 of 2000).

The research applied for and received ethics approval to undertake the study and to publish student responses with their consent. Students had been approached at the beginning and again at the end of the course for permission to quote from their assignments. All quotes included have the required permission of the student. All the groups that submitted work were included in the analysis bar one group whose assignment in pdf format cut short some of the responses. Although the full document had been requested, this was not yet received when the analysis was done.

Assumptions

The paper assumes that the items the students refer to or query are those that appear significant to them. Evidence to support this assumption is the fact that, with a wide range of responses, no student commented on the sections including the definitions (Section 2), section 5 (Repeal of laws) or section 6 (Short title). These sections are explanatory rather than requiring critical engagement, and, as such, require no comment. Though important constituents of the document, these sections do not ostensibly affect the student's understanding of the content of the Code of Conduct.

Results

This section will present the results of the analysis of student responses submitted in their group assignment where they were required to annotate the ECSA Code of Conduct so as to "familiarize [themselves] with the contents of the ECSA Code of Conduct and to identify interesting or important areas of the legislation that will impact [their] understanding of [themselves] as an engineering professional" (Annotated Code of Conduct Assignment instructions, Vula site CIV4041C 2021). The assignment was seen as a preparatory exercise in advance of the students making contact with the professional engineers involved in a specific construction site and in anticipation of the more formal development of an ethics essay connecting their understanding of what it is to be a professional with their experience of a specific site.

In terms of the student responses in the assignments, all the 20 group submissions, bar group 16, were loaded on Nvivo resulting in 612 responses being captured. These responses were coded in three ways, in terms of:

- the relevant major section (1-6)
- the specific numbered item of the document which elicited comment from the students (effectively 50 alternatives) and
- content themes including "Norms of the Profession", "Accountability"; "Conflict of Interest", "Engineering Responsibility", "Public Interest"; "Corruption"; "Whistle-blowing"; "Triple bottom line" and "Sustainability". These were identified both apriori and as a result of students' comments and identification of issues – such as "Whistle-blowing" or "Triple bottom line".
- types of response including "Questions", "Responses" and "Proposed revisions to Code".

The following graph provide detail of the responses in terms of the six major sections of the Code of Conduct – where only sections 1, the Objective; 3, the Rules of Conduct and 4, Administrative, were commented on. The other sections, including 2, that provides definitions of key terms; 5, involving a repeal of the rules and 6, containing the official short title for the document, were not commented on. The second smaller pie graph shows the distribution of comments in terms of the five major sections of the Rules of Conduct, covering Competence, Integrity, Public Interest, the Environment and the Dignity of the Profession. These sections have clear links to the Objectives.

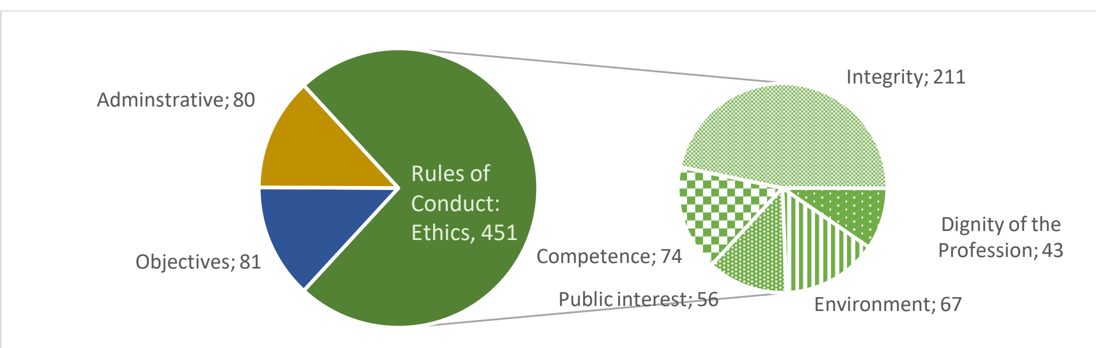

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Figure 1: Number of student responses to major sections of the ECSA Code of Conduct with breakdown of the five distinct areas of the Rules of Conduct

The graph provides a full breakdown of the individual numbered items of the Code of Conduct, down to third level headings and covering 50 possible items. Students had freedom to choose what appeared relevant or required clarity. While there were some groups who passed over entire sections (in addition to sections 2, 5 and 6), without any comments or questions – sections such as the Objectives; Dignity of the Profession and Administration – in general there was a fairly even spread of comments across the sections, with a significant, sustained attention on the items in the Public Interest and Environment sections.

This paper will analyse three topics that correlate to the sections that comprise a significant number of responses and that form the focus of much of the student exchanges. The first of these topics is the first objective (1(1)), that received more attention than the other objectives, requiring engineers to "apply their knowledge and skill in the interest of the public and the environment". This objective links to the sections on Public Interest (section 3(4)) and the Environment (section 3(5)) and confronts the responsibility of an engineer beyond that of responsibility to the client or employer.

The second topic that will be analysed is the "norms of the profession". This term appears in the third objective as "norms of professional conduct" (1(3)) and links with two other formulations: 3(1)(c) requiring that Registered Persons, "must, when carrying out work, adhere to the norms of the profession" and 3(2)(b) which specifies the Registered Person's responsibility is "to assess the conditions or terms of the work as potentially affecting their responsibilities in accordance with the norms of the profession".

The third topic that will be analysed is that of 3(2)(f) that requires that Registered Persons "must avoid situations that give rise to a conflict of interest or the potential for such conflict of interest". In this analysis, this will be examined as a stand-alone topic, although it would be possible to link it to the second objective (1(2)) and to items that profile bribery and corruption (3(2)(c/d/e) and that require the Registered Person to disclose to their employers and clients … in writing, any interest, whether financial or other … related to the work for which they may be or have been employed."

All three of these topics stood out in terms of having scored a significant proportion of student responses and representing more than one section of the Code. Consequently, the focus on the three selected themes that students profile as significant is presented so as to provide a fresh and complementary view to the familiar authority and "voice" of the document as constructed by experts.

Format of student responses

Student reflection is a type of discourse that engineering students may not expect to be assessed in as it falls outside of rigorous scientific method. In addition, the format may be unfamiliar to engineering educators, used to the discourse of engineering science that values objective and factual language. The analysis of the student responses examined the comments that students contributed to distinguish variations in form and function. The following forms of response were identified:

1. Providing information or additional elucidation on a specific item – an example of this would be this response to item 3(1)(b):
   16- Inexperienced professionals are a risk in the professional world. Likely to make major mistakes and not know the knowledge required to perform according to their title. In a job scarce country, nepotism is thriving in industry, often leading to inexperienced professionals who do not have the correct education necessary to fulfil duties accordingly.
2. Showing an understanding of the significance of the item in the Code of Conduct, requiring the exercise of judgment (**bold** emphasis added by the author), as in:
   55- After reading the [O]bjectives, **I think it's important** that any professional's purpose within the industry is made clear just so that they are able to reflect on whether they have met their primary objectives in a particular project as these ensure that no aspect is left behind when undertaking a project.
3. *Questioning* what the specific item means or asking for information as in 3(1)(a) (*italics* added by the author)*:*

22- “*How does the ECSA ensure the competency of a registered person*?” or in 3(4)(a):
35- “*How do you quantify “avoiding or minimising” impact on the environment? Are there specific guidelines?”*

4. Answering a peer’s earlier question, involving **exercising judgment or formulating an opinion.** This may involve agreeing or disagreeing with a team-mates formulation or *questioning* a team-mate’s explanation
36- “**It is extremely lenient**. …. **I believe** every engineer in South Africa would rather take a R40 000 fine than the supposedly equivalent year in jail.”
Or in 3(3)(a):
28- “**I agree** with your analysis. The engineering profession is entrusted to prioritize not only the improving the quality of life through sustainable development but also provide for a safe, rapid, efficient, comfortable, convenient, economical society and environment.”
5. Providing a practical example of the conduct that was referred to:
In relation to 3(2)(c), that is, “must not engage in any act of dishonesty, corruption or bribery” -
33- “One of the engineers found guilty of breaching this clause was merely reprimanded, cautioned, and fined R40 000, according to ECSA’s Disciplinary Action page… Do you believe this is a lenient punishment for the crime?”
6. Critiquing an item, or suggesting an addition or amendment to the current formulation of the code, such as in relation to 4(d) (recommendation underlined):
33- “Since advanced electronic signatures (AES) are authenticated via a face-to-face authentication procedure, ECSA should amend this clause to state that only electronic signatures approved by the South African Accreditation Authority are accepted.”

Combinations of these forms of response contributed to the level of critical engagement that were achieved. It was significant to see that groups who varied the format of their comments generally developed a more cohesive inter-action, developed from the rephrasing of the item to an extended discussion on issues impacting the relevance of the Code in a particular context. Without the posing and answering of questions, and the contribution of practical examples to illustrate points, comments remained very fixed to the specific wording of the item and did not develop the critical energy that characterized exchanges where the responses shifted through different formats. This demonstrated a difference between engagement in the form of a debate, where a specific point dominated or gained eminence at the expense of other contributions, and a discussion, where different voices contributed, expanding on understanding and relating it to experience.

The significance of this scaffolded discussion had not been anticipated. The requirements of the assignment provided a space where the different voices were encouraged to find a space to contribute to the discussion. In the discussion, a tentative reaching for meaning is evident, requiring student agency and the exercising of judgment. This can be positioned in contrast to the more formal lecture approach where authority was vested in an individual whose contribution was expected to dominate. In the lecture environment, the contribution of the student as recipient of knowledge rather than as maker-of-meaning can contribute to a giving up of power and agency – a passivity which may be seen to counter the journey to professional autonomy.

Table 1 below shows a cross section of comments from students responding to the first objective of the Code, that of “applying their knowledge and skill in the interest of the public and the environment”. Responses to group members is shown in the right-hand column. This objective received significant attention in terms of comments and student comments generally affirmed the prominence of this objective within the document. The students’ ability to integrate different aspects of the objectives of the Code and to apply the objective to their experience is evident. *Italics*, emphasis and **bold** are added by the author to show *questions*, examples and the **forming of opinions or judgments**. Individual pronouns that show the students identification with the professional community are ***bold italic***.

This extract of different responses effectively demonstrates the students engaging with Objective 1(1) in the light of the requirements of Graduate Attribute 10, “showing awareness of the need to act professionally and ethically and to exercise judgment”. Collaboratively, the students make connections and exercise judgment. Whereas the graduate attribute avoids requiring the student to demonstrate the actual exercising of judgement in a practical engineering context (which they are not

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effectively entitled to do independent of supervision until they are registered as an engineer), engaging critically with the Code of Conduct allows students to begin to exercise professional judgement in a theoretical environment and to learn to formulate opinions and argument in a way that may not have been a requirement of the degree thus far.

What may have been difficult for individuals to do on their own, is more easily demonstrated in the record of the group interaction and thus makes it possible for group members to undertake and achieve within the collaborative environment.

Table 1: Extracts from student comments annotating the first item (1.1) of the Objectives section of the ECSA Code of Conduct

55- After reading the objectives, **I think it's important that** any professional's purpose within the industry is made clear just so that they are able to reflect on whether they have met their primary objectives in a particular project as these ensure that no aspect when undertaking a project is left behind.	57-**I agree with you**. Objectives act as a guide to ensure professionalism in ***our*** work field and offers ***us*** a time to reflect on ***our*** shared goal as engineers.
39- It must be noted that the interests of the individual are not mentioned. There are many things that affect the decision making and ethics of an individual including upbringing, education and religion. But as stated here, an engineer's skills should be used to further the interests of the public and the environment, and not their own individual interests, and so their duty to society should be of greater influence than their personal gain.	
44-With the name "Civil" it is indicated that ***our*** profession is related to advancing civilization or humans. The component of taking care of the environment is not highlighted as much it needs to be - even in the teachings of the degree. The attitude in industry has to shift, especially, to emphasising that we have to protect the environment while ensuring we are completing our projects. Protecting the environment ensures that our future is protected which advances humanity.	46- **I agree with** the issues raised in this statement. In extension of this statement, it is important to note that the resources on Earth are finite and need to be used in a renewable and efficient way in order to maintain areas of conservation and reduce the negative environmental impacts that accompany construction and new projects. In terms of protecting the public, engineers can make sure that they adhere to all construction codes and do not cut costs with respect to public safety.
58-**I feel** like this is especially important for the environment. Currently, all the sources of pollution have placed the environment in a bad position so I believe that although the interest of the public is important, impacts on the environment should be considered even if it means that the public's interest may be slightly compromised (of course not compromising it too much).	55- **I think** this is where the triple bottom line comes into play and when it is achieved*. How do **we** bring social satisfaction when it is at the detriment of the environment? But surely nothing that harms the environment would be good for the public long-term?*
64- This is one skill that most engineers in both the public and private sector need to have. This is because at most basic level, there is a need to interact and engage with the public/community in order to understand their needs, otherwise as an engineer you will design an infrastructure that cannot be used by the public. (e.g designing infrastructure that does not accommodate people with disabilities).	61- **It is crucial** that professionals realise that their work will impact the public and environment. To have some amount of foresight in this regard would be beneficial so that short and long-term outcomes can have the greatest positive impact and any negativity can be minimised.
69- *How do we deal with a situation where the interests of the employer conflict that of the public and the environment?* i.e. There is an issue in Philippi Horticultural area where the public (community) wants to preserve the area and not allow any development due to that the area provided them with near jobs, and there is an aquifer that can be damaged when the development takes place in the area. However, the City of Cape Town wants to turn the area into a mixed developed area and in a case where the city wins the case and I work for the City of Cape Town as an engineer, *how do I integrate such [a] challenge?*	72- **I believe** that this is a conflict of interest as ethics as an individual and professional ethics are in disagreement. Even though it is a very challenging decision professional ethics often override personal morality.

What is evident is that the very requirement of a Registered Person to "apply their skill in the interests of the public and the environment" inherently requires both the exercising of judgement and the negotiating of vested interest in a way that contrasts with the neatly defined item in 3(2)(f) where a

Registered Person is required simply to “avoid situations that give rise to a conflict of interest or the potential for a conflict of interest”.

The second theme to be examined relates to the “norms of the profession” referred to in 3(1)(c). In table 2 below, showing student responses, **bold** and *italic* highlights have again been added.

Table 2: Extracts from student comments annotating 3(1)(c) that a Registered Professional must, when carrying out work, adhere to norms of the profession”

5- *What are the "norms of the profession"? Does it refer to engineering guidelines given in books or is it referring to how work is meant to be performed?*	6- In this case, **I'm assuming** the latter**. I think** it has to do with remaining professional in the work environment.
(Continued) 2- **I** honestly **think** it's both. Standard guidelines and social behavior patterns basically.	28- *Initially this first sparked questions within me of what are the norms of profession when it comes to engineering? How does duty, due diligence and ethical responsibilities marry professional responsibilities and conduct in executing their legal obligation to society?*
80- *What do they mean by “norms”? Professional conduct like being on time?* An example would be useful.	79- **I agree**, the clause could do with more precise language. **My assumption is** that they mean that codes of practice should be adhered to. If my assumption is correct then I feel they should state that they are referring to codes of practice.
59- The norms are to be adhered because practicing professionals have an obligation to ensure their work is not detrimental to the public, employers, clients and the environment. *However, does the strict conformity to the norms not hinder or stunt innovations?*	55- **I think** that anything that is detrimental to the above parties you mentioned should not be worth executing despite being innovative. *What excellence is there in something that harms when it should aim to inspire?*
Continued) 59- Well all innovations aren't necessarily detrimental. Engineers hold multiple lives at stake. …. So there should be no exceptions for the competency of an engineer, however, norms are generally a barrier for innovations of any kind. Innovation, now so more than ever, is important for the path to sustainable development.	

These examples demonstrate the way that the expression “norms of the profession” caused difficulty for the students. It raises questions of whose norms? And who decides on these? And whether there might be explicit and different, implicit norms that can complicate what is intended to clarify. Many groups queried this formulation and several made the connection with “norms” contrasting with “innovation” in a way that may not be in the interest of the profession. It is interesting to look back at the history of the document and to see that the 2013 version changed the wording from “engage in and adhere to acceptable practices” (ECSA, 2006), to: “adheres to the norms of the profession” (ECSA, 2013). The expression is not one of the terms defined in section 2 of Definitions in the Code. In the current 2017 version of the document, the 2013 formulation stands. Here the overriding impression of the student comments and exchanges is of considered and responsible opinion and reflection.

The third theme that is examined, is that of conflict of interest, profiled explicitly in section 3(2)(f) of the ECSA Code. In table 3 below, a selection of student responses are profiled.

Table 3: Extracts from student comments annotating 3(2)(f) of the ECSA Code of Conduct that requires that a Registered Person “must avoid situations that give rise to a conflict of interest or the potential for such conflict of interest”.

36- *What happens if the conflict of interest results in complications within the project. Who would be held liable for these complications. Would it be the employer if he/she made the final decision as to try "resolve the conflict of interest", or would the onus still fall upon the engineer in question?*	37- Any form of conflict in the workplace adds unnecessary stress and tension to the working environment, which is detrimental to productivity of the company. The engineer **has a duty** toward their business or employer to act in their best interest. Once the engineer decides to undertake work or activity motivated by personal gain, their work is deemed unethical.
38- This statement is true with regards to unethical behaviour, and how this behaviour can have severe consequences to the employee and employer. Conflict of interest violates the ECSA code of conduct and possibly that of the company. The engineer **must exercise**	

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judgement on possible conflicts of interests and must not choose to be naïve towards it.	
52- As we all know, our moral compass is influenced by various factors, and if one reaches a point those factors conflict each other, ***we*** as engineers should find a way to prevent that from happening or if its too late step down from the responsibility if that helps prevent the conflict.	72- I've heard of cases where the conflict of interest arises during the course of work (such as a project). *How does one go about reporting this? Who is it reported to?*
79-Very important, especially early in my career. **I can imagine** being put in a situation where I'm in charge of a site and the client requests me to construct a lucrative structure under impermissibly dangerous geotechnical conditions. This would put my value of public safety against that of my fiduciary responsibility to my employer. This would be an ethical dilemma.	81- *What if you can't avoid the situation? Are there guidelines to assist the Engineer in a case where such situations can't be avoided?*
100- It is always good to understand this principle as due to complexities in the modern firms, this is likely to occur. Whenever this happens, it really good to report this to both party's employers as this will protect both parties in case of corruption accusations if there aren't any. *However, what happens when both parties from different firms working in the same project find out at a later stage and one does not wish to accept this situation?*	102- I had exactly the same question. *What if a situation resulting in a conflict of interest is unforeseen or is unavoidable? Also, do you think that the conflict of interest should be dealt with by the registered person alone, or is there perhaps a formal code where guidance is provided to handle common conflicts of interest?*

"Conflict of interest" is identified as a potential danger lurking wherever the application of judgement is required. Students pick up on potential contradictions in terms of responsibility and effectively anticipate issues which are presented more explicitly in the Rules of Conduct, issues such as a dilemma between competing priorities and how to choose in a situation where both are important but apparent alternatives. Conflict of interest is envisaged by students as more prevalent than the specific challenge of financial interest. It is seen to be something that potentially biases decisions that engineers need to be equipped to deal with.

Discussion

The sample responses provided in the three tables above by no means exemplify a summative engagement with the ECSA Code or with engineering responsibility. Responses show instead a searching for meaning and a progressive building of meaning. Referencing context is seen to be necessary to gain clarity about potential meaning. Subsequent to this assignment and to their engagement with professionals on a construction site, students were once again required to engage with this document, building on their reflections to construct an essay relating their on-site experience to their understandings of their professional and ethical responsibilities in terms of the Code. In both the commentary on the Objectives and the section on Rules of Conduct, a major focus of student comments was the engineer's obligation to consider the interests of the public and the environment in both the design of projects and the implementation of projects. Student comments reflected both their appreciation of the prominence given to this aspect and concern that this focus was lacking in real-life projects where cost was seen to be a concern affecting decision-making.

"Ethics", "norms of the profession" and "conflict of interest" are terms that are not defined in the Definitions section of the Code of Conduct, but that are assumed to be self-evident in a way that student reflection and critical engagement with the code suggests may not be the case. Student engagement suggests that there is a need for these terms to be more clearly defined.

The requirement to demonstrate judgment and reasoning requires a different skillset from that of the mastery of technical process and theory. Students need to be provided with the opportunity to develop these skills. Exercising these skills in a low-risk formative assessment task, provides a valuable space to develop these skills in a way that builds the confidence and agency necessary to exercise judgement.

In this paper, in terms of Lave and Wenger's (1991) concept of legitimate peripheral participation, engineering students have been positioned as peripheral participants to the profession of engineering. Interesting things happen at the periphery. It is evident that student reflection on the professional Code of Conduct is generative and builds a clear sense of identity as part of the community of engineering professionals. Student reflection on the professional Code provides

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students with the opportunity to articulate their thinking using the discourse of the profession. Paying attention to the periphery of a community shifts the focus of the gaze from that of the familiar insider to those on the boundary. It prompts the question as to what can be seen from the periphery that cannot be seen from the centre? This research makes a space to examine what is familiar from a new position, thus allowing the professional engineering community to see better. Student vision thus contributes a valuable perspective complementing the existing understanding of professional responsibility and building onto what is already there.

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Threshold Concepts in the Engineering Educator's Journey: A Systematic Review

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ABSTRACT

CONTEXT

Many engineering educators recognize and emphasize the key concepts and skills that are considerably more difficult and that hinder their learners' progress through their undergraduate studies. Many of these topics are considered threshold concepts and make the difference in a student's ability to do engineering things versus being an engineer. What many engineering educators don't recognize is that they too encounter threshold concepts that hinder their own journey to becoming effective educators.

PURPOSE OR GOAL

Unfortunately, there is no analysis of studies of threshold concepts that identify those associated with teaching in either undergraduate engineering programs or post-secondary education in general. This study seeks to answer two questions about teaching-related threshold concepts: (1) what threshold concepts are identified as part of an educator's growth? and (2) what threshold concepts may cause a transformation in the way engineering educators carry out their day-to-day practices?

APPROACH OR METHODOLOGY/METHODS

This paper reports the findings of a qualitative evidence synthesis (qualitative systematic review) of 20 journal articles and conference papers that study threshold concepts related to teaching in the post-secondary system. An initial search for studies of any design that examined threshold concepts related to teaching practice identified 1011 potential papers, 82 of which met the criteria for initial review. A deeper secondary review narrowed the list to 20 papers.

ACTUAL OR ANTICIPATED OUTCOMES

Final review identified 14 threshold concepts associated with post-secondary educators' professional growth ranging from care and authenticity to course-related threshold concepts. These 14 threshold concepts were mapped to categories of Science, Technology, Mathematics and Engineering (STEM) educator practices and conceptions. Four clusters were identified in which mastery of the threshold concept could facilitate a change in day-to-day practice of engineering educators: teaching / pedagogy, learning, assessment, and teaching with technology.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This study fills a gap in the literature by identifying teaching-related threshold concepts that may hinder the instructional development of engineering educators. It is hoped that these results will encourage engineering educators, and those responsible for their educational development, to recognize and support professional growth related to these potential thresholds.

KEYWORDS

Threshold concepts, engineering education, teaching.

Introduction

Many engineering educators recognize and emphasize the key concepts and skills that are considerably more difficult for learners, hindering their progress through their undergraduate studies. What many engineering educators don't recognize is that they too often encounter gateway concepts that can hinder their own journey to becoming effective educators. This qualitative systematic review sets out to determine what, if any, threshold concepts are identified that pose intellectual barriers to post-secondary engineering educators in the way they perceive and perform their day-to-day teaching practices.

Background

Educators and researchers have long discussed discipline-specific topics that act as bottlenecks or choke points in a learner's progression. Students follow the steps they're taught but don't seem to understand. Then one day there is an 'aha' moment and everything makes sense; it becomes part of the learner's disciplinary way of thinking and practicing.

Threshold Concepts

Perkins introduced the term 'troublesome knowledge' to address the challenges that students experience in constructivist learning environments (Perkins, 1999). He recognized that there are different types of knowledge, each of which provides a unique challenge for learners. He proposed that knowledge that is 'inert', 'ritual', 'conceptually difficult' or 'foreign' can impede learners as they attempt to grasp concepts required in their profession.

Meyer and Land suggested that Perkins' types of troublesome knowledge should include 'tacit knowledge', the personal and practical knowledge that is shared within a community or discipline. This knowledge is often difficult to explain to others because it is ingrained into one's 'being' (Meyer & Land, 2003) (Hill, 2010). They realized that there are certain topics within every discipline that are gateway or key turning points. When students grasp those topics, they go from simply doing discipline-specific things, to thinking and practicing like a professional in that field. These turning point topics became known as threshold concepts.

A threshold concept has five characteristics that distinguish it from a core concept: (1) it is uniquely troublesome, challenging the way learners think, often making the concept mentally and emotionally uncomfortable to master, (2) it is integrative, pulling discrete concepts and ideas together into a new way of thinking or understanding, (3) it transforms the way learners think about their discipline, (4) it is considered irreversible, and (5) it is bounded to a one's discipline and dependent on context. Mastering a threshold concept is different for each learner. The experience of moving from not knowing to knowing is called liminality and is often quite disorienting (Meyer & Land, 2003) (Rhem, 2013).

Although many engineering educators may not refer to them as threshold concepts, most recognize and emphasize the key concepts and skills that are considerably more difficult to learn. Many of these topics are considered threshold concepts that can make the difference in a student's ability to merely carry out engineering duties versus thinking and acting as an engineer. And while focusing on student learning is understandable, many engineering educators don't recognize that they too encounter threshold concepts that can hinder their individual journeys to becoming effective educators.

Engineering Education Practices

Engineering remains one of the most traditional and didactic disciplines in higher education (Stains et al., 2018). The reluctance of many engineering educators to incorporate research-based instructional strategies is reflected in undergraduate student engagement rankings that place engineering lowest among the disciplines (Nelson & Brennan, 2019). Low adoption of evidence-based practices is common across Science, Technology, Engineering, and Mathematics (STEM) disciplines (Laursen, 2019). Extensive research finds that, while most

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STEM educators have tried at least some of these practices, many return to their traditional lecture-based approach (Henderson, Dancy, & Niewiadomska-Bugaj, 2012). Stains reports that fewer than 20% of engineering classes incorporate any student-centred instructional strategies (Stains et al., 2018) and Allen suggests that this may be attributed to an ingrained belief that sticking to traditional teaching outweighs the benefits that may result from such a change (Allen, 2018).

Dancy and Henderson developed a framework for articulating the instructional practices and associated conceptions of individual educators (Dancy & Henderson, 2007). This framework identifies ten categories of practices, differentiating between traditional and alterative instruction: (P1) interactivity, (P2) instructional decisions, (P3) knowledge source, (P4) student success, (P5) learning mode, (P6) motivation, (P7) assessment, (P8) content, (P9) instructional design, and (P10) problem solving. The ten categories of conceptions include: (C1) learning view, (C2) expertise, (C3) knowledge view, (C4) nature of the discipline, (C5) role of school, (C6) students, (C7) teacher role, (C8) diversity, (C9) desired outcomes, and (C10) scientific literacy.

Analysis of educators using this comprehensive framework found that the practices and conceptions of educators were often misaligned (Henderson & Dancy, 2007). While their conceptions about teaching and learning leaned toward evidence-based aspects of alternative instruction, their practices tended toward the traditional. This suggests that an educator’s transformation to an alternative instructional approach may require mastery of one or more teaching-related threshold concepts. Unfortunately, there is no present analysis of threshold concepts associated with teaching in either undergraduate engineering programs or post-secondary education in general. This study seeks to answer two questions about teaching-related threshold concepts: (1) what, if any, threshold concepts are identified as part of an educator's growth? and (2) what threshold concepts may cause a transformation in the way engineering educators perceive and perform their day-to-day practices?

Methodology

A qualitative systematic review (QSR), also known as a qualitative evidence synthesis (QES), was conducted to locate primary research studies that identify teaching-related threshold concepts. An initial analysis of the purpose, strengths, weaknesses, and methodologies associated with myriad review types indicate that a QSR/QES is the optimal review type for this research (Grant & Booth, 2009).

The processes used to conduct a QSR/QES are similar to those of a classic systematic review (Flemming & Noyes, 2021) and begins with question formulation. A modified version of the PICO criteria for framing a research question (Petticrew, Roberts, & Ebrary, 2006) (Borrego, Foster, & Froyd, 2014) established the qualitative review question to be ‘What concepts are identified as teaching-related thresholds in the professional growth of post-secondary educators?’

Criteria for the QSR/QES were defined for the type of study, data sources, and search keywords (see Table 1). The screening process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (PRISMA, 2021) using the inclusion and exclusion criteria specified in Table 1 item 5 (see Figure 1). A search of the SCOPUS database, performed in April 2020, identified and screened 163 primary studies. Of these papers, 25 were accepted for further review. Search of the online bibliography / repository was done in June 2020. 553 primary studies were identified and screened using the same inclusion and exclusion criteria with 59 accepted for further review. A search of the ERIC database was done in January 2021, with 22 of the 295 papers accepted for further review. Duplicate papers were removed from the list, leaving 82 primary studies for secondary review. Of the 82 reports sought for retrieval, 22 were not accessible, leaving 60 reports to be assessed. All screenings were done by the lead author.

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Table 1: QSR/QES Criteria

1. Primary research studies: a. must be peer-reviewed and published as a dissertation, in a journal, as part of a conference proceeding, or as a book chapter b. can be of any design: mixed, qualitative or quantitative
2. Data sources for: a. initial search must include: i. a social sciences research database (SCOPUS) ii. an education research database (ERIC) iii. threshold concept online bibliography / repository b. secondary search can include: i. peer reviewed papers cited in studies selected for secondary review
3. Database search of paper title, abstract and keywords must include: a. 'threshold concept' AND 'teaching' OR 'pedagogy' OR 'expertise' OR 'professional learning' OR 'transformation' OR 'professional identity' b. 'decoding the discipline' AND 'teaching' OR 'pedagogy' OR 'expertise' OR 'professional learning' OR 'transformation' OR 'professional identity'
4. Threshold concept bibliography / repository categories must include, but are not limited to: a. 'change', 'evidence-based practice', 'exploration', 'ways of thinking and practicing', 'pedagogic', 'professional development', 'expertise'
5. Screening inclusion and exclusion criteria state the title, keywords, and if necessary abstract, must: a. relate directly to threshold concepts, teaching, and post-secondary educators b. NOT focus on student-related threshold concepts c. NOT focus on educators recognizing or incorporating discipline-specific threshold concepts d. NOT focus on educational developer-related or curriculum-development related threshold concepts
6. Report assessment notes must include, but are not limited to: a. citation information (title, authors, date, journal) b. research question c. methodology/research design d. findings
7. Report assessment criteria: a. reports must be accepted, rejected, or marked as potentially accepted b. accepted reports must identify a teaching-related threshold concept using a qualitative, quantitative, mixed methodology or evidence-based argument c. reason(s) for exclusion must be specified for rejected reports d. concerns/reasons must be specified for potentially accepted reports

Sixty reports were assessed for eligibility in the study. Each paper was read in full and notes recorded using the criteria specified in Table 1 item 6. Application of report assessment criteria specified in Table 1 item 7 excluded 51 of these studies. Twenty-eight were excluded because they were not teaching-related threshold concepts, six were not threshold concepts, and 17 inadvertently made it through the screening process (see Figure 1). Eleven additional papers were identified from citations in the reviewed reports. These were retrieved, assessed, and included in the study resulting in a final count of 20 papers (see Table 2). All assessments were done by the lead author.

Authors of the final 20 papers were from eight countries in North and Central America, Australasia, Europe, and South Africa. Sixteen papers were published in Higher Education or

Academic Development journals, and two each as conference proceedings and book chapters. Publication dates ranged from 2010 to 2020 inclusive.

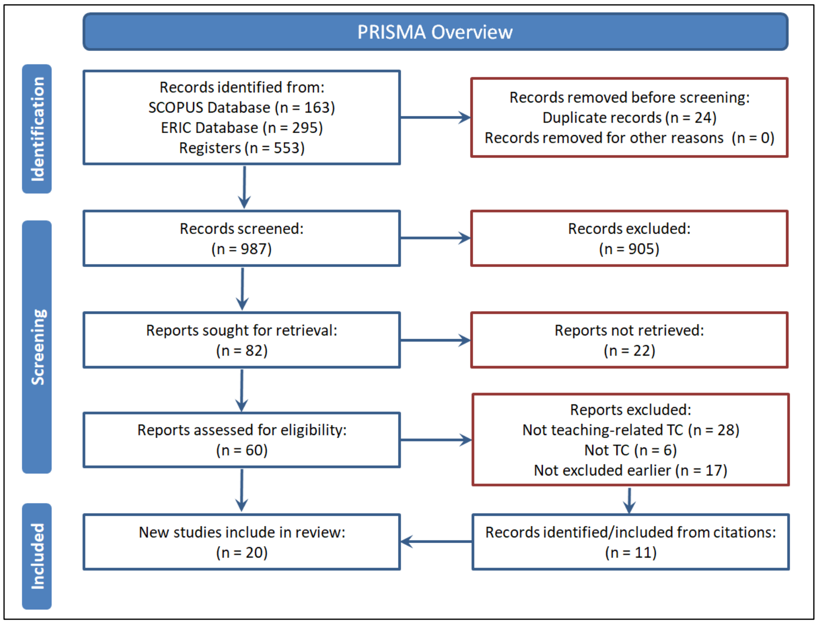

Figure 1: Overview of PRISMA screening process

Results

Final review identified 14 threshold concepts associated with post-secondary educators' professional growth ranging from care and authenticity to learner-centred practices and recognition of threshold concepts themselves (see Table 2). These 14 threshold concepts were mapped to Henderson and Dancy's categories of STEM educator practices and conceptions (Henderson & Dancy, 2007) (see Table 2).

Educator Practices

Ten of the 14 threshold concepts were categorized as educator practices, three related to instructional design, three associated with assessment, two related to teaching with technology, and one each connected to student learning and content.

Six studies report three threshold concepts related to instructional design: (1) inquiry into student learning, (2) teaching for transfer of knowledge, and (3) need for a growth mindset.

Four studies report that inquiry into student learning is a teaching-related threshold concept. Cook-Sather and her colleagues talk about the value of faculty-student partnerships when making pedagogical decisions. This shared exploration is troublesome because it "is at once counterintuitive for many faculty and contradictory to norms in higher education". While expanding educators' perspectives, the "partnership can be threatening, disappointing, and/or (potentially) productively unsettling" yet transformative (Cook-Sather, 2014, p. 189). For this partnership to work educators must "believe that students both know and care about their own learning – a threshold that represents a high, but most worthwhile, crossing to take" (Werder, Thibou, & Kaufer, 2012, p. 38). Howson and Weller recognize the distinctiveness of student perspectives, but note that the "benefit of student involvement in the enhancement of teaching is dependent on the perceived authenticity of student voice within a circumscribed idea of student expertise" (Howson & Weller, 2016, p. 10). Bunnell and Bernstein focus on an inquiry-based approach where the educator "serves not only as a source of knowledge but also as an active pursuer of knowledge about how learning progresses" (p. 15). This form of

Table 2: List of Threshold Concepts Identified in Primary Studies

Author, Year	Study Design	Teaching-Related Threshold Concept(s)	Mapping to STEM Educator Practices and Conceptions	Threshold Concept Category
Adler-Kassner, L., & Majewski, J. (2015)	qualitative - interview	acknowledging student threshold concepts	C9 – outcomes	Pedagogy – threshold concepts
Blackie, M.A.L., Case, J.M. and Jawitz, J. (2010)	argumentative essay	learner-centred focus	P5 – learning mode C9 – outcomes	Learning – learner-centred
Boyd, Diane E. (2014)	qualitative - reflective practice	growth mindset	P9 – instructional design	Pedagogy – knowledge types
Bunnell, S. and Bernstein, D. (2012)	qualitative - reflective practice	inquiry-based teaching teaching as public act	P9 – instructional design	Pedagogy – knowledge types
Cook-Sather, A. (2013)	qualitative - reflective practice	student-faculty partnership in pedagogy	P9 – instructional design	Pedagogy – knowledge types
Devitt, A., Kerin, M. and O'Sullivan, H. (2014)	qualitative - interview	learner-centred focus	P5 – learning mode C9 – outcomes	Learning – learner-centred
Howson, C. K., & Weller, S. (2016)	qualitative - interview	student expertise as learner	P9 – instructional design	Pedagogy – knowledge types
Kinchin, I. M. (2019)	argumentative essay	care	C7 – teacher role	Pedagogy – knowledge types
Kinchin, I. M. and Miller, N. L. (2012)	qualitative - concept mapping	learner-centred focus (structural transformation of knowledge)	P5 – learning mode C9 – outcomes	Learning – learner-centred
Kilgour, P., Reynaud, D., Northcote, M., Gosselin, K. P., & McLoughlin, C. (2018)	mixed method	online learning	P11* – teaching with technology	Teaching with Technology
McGowan, S. (2012)	qualitative - reflective practice	educational technology	P11* – teaching with technology	Teaching with Technology
Meyer, J. (2012)	qualitative - reflective practice	variations in student learning	C6 – students	Learning – learner-centred
Mills, R. and Wilson, A. (2014)	qualitative - interview	learner-centred focus	P5 – learning mode C9 – outcomes	Learning – learner-centred
Moore, J. L. (2012)	qualitative - concept mapping	teaching for transfer of knowledge (course to course)	P9 – instructional design	Pedagogy – knowledge types

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Author, Year	Study Design	Teaching-Related Threshold Concept(s)	Mapping to STEM Educator Practices and Conceptions	Threshold Concept Category
O'Brien, M. (2013)	qualitative - grounded theory	acknowledging student threshold concepts (theory of difficulty)	C9 – outcomes	Pedagogy – threshold concepts
Simper, N. (2020)	qualitative - interview	assessment – constructive alignment with learning outcomes assessment standards	P7 – assessment	Assessment – alignment & authenticity
Timmermans, J. A., & Meyer, J. H. (2019)	argumentative essay	acknowledging student threshold concepts	C9 – outcomes	Pedagogy – threshold concepts
Timmermans, J. A., Bruni, C., Gorbet, R., Moffatt, B., Stubley, G., Williams, D., & Holmes, T. (2018)	qualitative - reflective study	care	C7 – teacher role	Pedagogy – knowledge types
Werder, C., Thibou, S., & Kaufer, B. (2012)	qualitative - reflective practice	student-faculty partnership in pedagogy	P9 – instructional design	Pedagogy – knowledge types
Wilcox, S., & Leger, A. B. (2013)	qualitative - questionnaire	formative assessment learner-centred focus context-driven practice student diversity	P7 – assessment P5 – learning mode C9 – outcomes P8 – content C6 – students	Assessment – formative Learning – learner-centred Pedagogy – knowledge types

*items marked with an asterisk are not included in Henderson and Dancy's categories of practices and conceptions. They were added to fill gaps

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reflective practice implies that educators “have much greater responsibility for students’ learning than has traditionally been assumed” (Bunnell & Bernstein, 2012, p. 16).

One study reports context-based practice as a threshold concept. Wilcox and Leger note that to gain a “better understanding of what kind of learning is required by students” there is “no one best way to teach in all circumstances” (Wilcox & Leger, 2013, p. 7).

Educator Conceptions

The remaining four threshold concepts were categorized as educator conceptions, two related to an educator’s role, and one each connected to outcomes and students. Three studies report two threshold concepts related to educator roles: (1) care, and (2) teaching as a public act.

Two studies report care as a threshold concept. Kinchin identifies that Clouder’s phases in the development of care (Clouder, 2006) “may be helpful in supporting contextually appropriate levels of teacher development of a caring perspective” (p. 3). He notes that “students regard care as a key marker of good teaching, and good teachers as people who care about their discipline, about teaching as a professional activity and about their students” (Kinchin, 2019, p. 4). Timmermans and her colleagues report that care could be a teaching threshold concept “transforming the ways we conceive of, design, and enact initiatives”. They suggest care includes care for the discipline, care related to students and their learning, and care among Faculty Learning Community (FLC) members (Timmermans et al., 2018, p. 371).

Bunnell and Bernstein report that teaching as a public act, or making the teaching and learning visible, is a threshold concept. It challenges educators to recognize that “content knowledge is not sufficient” and opening their classrooms to peer feedback is a “challenge to a professor’s identity as an expert” (Bunnell & Bernstein, 2012, p. 16).

Three studies report acknowledgement of threshold concepts as a threshold concept. Adler-Kassner and Wardle report that educators’ “realization that there are threshold concepts critical for understanding and practicing their discipline was itself a threshold concept (Adler-Kassner & Wardle, 2015, p. 188). O’Brien identifies that “theories of difficulty are woven into the pedagogical thinking and reasoning of teachers” and “can vary between teachers, in ways that potentially influence significant differences in the student learning experience” shedding light on how educators practice and teach (O’Brien, 2013, p. 39). Timmermans and Meyer note that as “teachers do the work of uncovering TCs (sic), we have noticed that some experience transformative shifts in their conceptions of their disciplines, their teaching, and their understanding of their students’ learning” (Timmermans & Meyer, 2017, p. 360).

Finally, two studies report variation in student learning as a threshold concept. Meyer reports that crossing this threshold “opens up a new and empowering theoretical perspective of reflexive teaching practice” based on “how and why students vary in their engagement of the content and context of learning” (J. Meyer, 2012, p. 10). Wilcox and Leger report that in appreciating “the variation in students’ learning needs, capacities, styles” (p.7) there must be recognition of an “accommodation for diversity” (Wilcox & Leger, 2013, p. 8).

Discussion

These 14 threshold concepts identified in the practices and conceptions of post-secondary educators can be clustered into four categories of teaching-related threshold concepts: teaching or pedagogy, learning, assessment, and teaching with technology (see Table 1).

Pedagogy-related Threshold Concepts

There are seven pedagogy-related threshold concepts: (1) inquiry into student learning, (2) teaching for transfer of knowledge, (3) need for a growth mindset, and (4) context-based

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practice, (5) care, (6) teaching as a public act, and (7) acknowledgement of threshold concepts.

Shulman identifies four type of teaching knowledge required by proficient educators: (1) subject-matter expertise, (2) pedagogical knowledge (PK), a grasp of the general principles of teaching, (3) pedagogical content knowledge (PCK), the ability to organize, represent, and convey discipline-specific knowledge and skills in a way that facilitates student learning, and (4) curricular knowledge (CK), the way specific topics can, and should, be taught depending on where and when they appear in a program of study (Shulman, 1986). The threshold between competent and proficient educators requires acquisition of PCK and CK which encompass the seven pedagogy-related threshold concepts.

Engineering educators begin with subject-matter expertise, but the majority receive little or no instructional development, reporting that they learned to teach by teaching and through informal discussions with their peers (Nelson & Brennan, 2018). The same study reports that 40% of these engineering educators place some to no emphasis on continued development of their teaching skills. The same percentage rarely or never attends workshops offered by their teaching and learning centres. Such low participation may be caused by a lack of incentive or a perceived lack of relevance to their courses, subjects, students, or challenges (Felder, Brent, & Prince, 2011). Felder and his colleagues note that engineering educators are more likely to participate in instructional development workshops that are designed for them and delivered by a teaching expert with an engineering background. Any opportunities for engineering educators to explore pedagogical and pedagogical content knowledge will facilitate their crossing of the pedagogy-related thresholds and provide an educationally-sound learning experience for their students.

Learning-related Threshold Concepts

There are two learning-related threshold concepts: (1) learner-centred focus, and (2) variation in student learning. Educators who cross these thresholds provide effective learning environments for each of their students.

Research into effective learning environments identifies six broad themes for ensuring student success and value-added learning: (1) academic rigour, (2) a focus on learning, (3) supported instruction, (4) quality of teaching, (5) relationships, and (6) student engagement (Nelson & Brennan, 2019). The focus on learning brings together myriad benchmarks associated with “active and collaborative learning, learning strategies, reflective and interactive learning, higher order thinking, skills development and quantitative reasoning. Each of these directly involves students in, and with, their learning” (p, 2). For students to be successful, educators must make instructional decisions that are “informed by a deep understanding of the learners, along with their active involvement in selecting solutions that work for them” (Higher Learning Commission, 2018, P. 7). Any opportunities for engineering educators to explore how students learn, what motivates them, and ways to offer different pathways to success will facilitate crossing learning-related thresholds resulting in a more effective learning environment for each student.

Assessment-related Threshold Concepts

There are three assessment-related threshold concepts: (1) constructive alignment of assessments with learning outcomes, (2) differentiation of standards and minimum competence, and (3) formative assessment. Educators who cross these thresholds objectively and authentically assess clearly-defined learning outcomes. They also provide ongoing, informative feedback to their students.

In their critical review of assessment practices in engineering education, Subheesh and Sethy report that “most of the engineering faculty members across the globe have a little or inadequate experience in formulating measurable course objectives, assessing students’ performance, and providing appropriate and unambiguous feedback to students” (Subheesh

& Sethy, 2020, p. 13). They recommend engineering educators access appropriate educational development opportunities to help them move from norm- to criterion-referenced assessment practices and provide prompt, appropriate and unambiguous feedback to help students become self-regulated learners and achieve course learning objectives.

Teaching with Technology-related Threshold Concepts

Finally, there are two teaching with technology-related threshold concepts: (1) experimentation with educational technology, and (2) online learning. Educators who cross these thresholds stretch their current pedagogical models and broaden their approaches to teaching to include technological solutions to learning challenges.

Koehler and Mishra extended Shulman's construct of pedagogical content knowledge to include technological knowledge. "The interaction of these bodies of knowledge, both theoretically and in practice, produces the types of flexible knowledge needed to successfully integrate technology use into teaching" (Koehler & Mishra, 2013, p. 62). A review of the use of educational technology in engineering education reports challenges in STEM programs with a "lack of faculty members with the right digital skills and the aversion to change by some" (Hernandez-de-Menendez & Morales-Menendez, 2019, p. 715). They note important benefits for using educational technology including improved acquisition of technical knowledge, better use of pedagogical strategies, and increased student motivation.

Limitations

This QSR/QES is not free from limitations. Although the exploration of threshold concepts is fairly new, there are many papers related to threshold concepts in tertiary education. Few, however, focus on the thresholds that educators themselves encounter in their teaching practices, and none are specific to engineering educators. The review, conducted from April 2020 to March 2021, was limited to three primary sources, and may inadvertently exclude studies relevant to this work. Exclusion decisions, mapping and clustering represent a single point of view and may vary if analyzed by different researchers.

Conclusions

This study fills a gap in the literature by identifying 14 teaching-related threshold concepts that may hinder the instructional development of engineering educators. Recognizing that these pedagogical, learning, assessment, and teaching with technology related threshold concepts exist may facilitate a transformation in the way engineering educators perceive and perform their day-to-day practices.

This research lays the foundation for further work. Study could be done to determine if these threshold concepts are equally important and necessary for the growth of engineering educators, or if certain thresholds hold the key to transformative teaching practices. This study could also provide the basis for an engineering- or STEM-focused educational development program that helps educators consider and cross any or all of these thresholds.

It is hoped that adding these results to the existing body of evidence will encourage both engineering educators and those responsible for their educational development, to support professional growth related to these potential thresholds.

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LENS: A Model for Engineering Faculty Development

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ABSTRACT

CONTEXT

Engineering educators could benefit from a faculty development model that meets them where they are, in both their discipline and their journey as educators. It is often difficult to get academics to talk about their teaching as it relates to educational research, and research shows that those in engineering programs, even with a pandemic-imposed accommodation to delivery, participate in fewer educational development opportunities than their colleagues in other disciplines. This reluctance to develop as educators may help explain why student and faculty surveys of student engagement rank engineering educators lowest in the categories of effective teaching practices and providing a supportive learning environment.

PURPOSE OR GOAL

This work presents the LENS (Learning Environments Nurture Success) model of engineering faculty development. The six "lenses" represented in the LENS model align with the evidence-based characteristics of an effective learning environment for engineering students: (1) academic rigour, (2) focus on learning, (3) instructional support, (4) quality of teaching, (5) student-faculty relationships, and (6) student engagement.

APPROACH OR METHODOLOGY/METHODS

The LENS model is based on a conceptual framework that draws on five key areas: (1) student success in engineering programs, (2) change and innovation in Science, Technology, Engineering and Mathematics (STEM) teaching, (3) threshold concepts associated with post-secondary teaching, (4) an educator's journey from novice to expert teacher, and (5) the findings of myriad studies in research-based instructional strategies (RBIS), discipline-based education research (DBER) in STEM programs, and engineering education research (EER). Each of these research areas shares a social constructivist viewpoint with a vision of students who are engaged, successful, and value their learning.

ACTUAL OR ANTICIPATED OUTCOMES

Following a literature review, each lens is defined, identifies commonly used instructional strategies, and suggests evidence-based strategies that can be implemented to enhance one's teaching practice. The breakdown provides level-appropriate recommendations for faculty at three stages of development: first-order change for those wanting to do things better, second-order change for those choosing to do better things, and third-order or epistemic change for those primed to make a transformational shift in their teaching.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The LENS model contributes to the body of scholarly work associated with engineering faculty development by (1) offering a practical framework that supports educational development and planning for all forms of delivery (face-to-face, remote, blended, or hybrid) that can be used independently, in consultation with an Educational Developer, or in collaboration with colleagues, (2) threading educator-related threshold concepts associated with learning, pedagogy, and assessment through each of the six lenses, and (3) linking interdisciplinary research focused on facilitating the success of engineering students.

KEYWORDS

Faculty development, instructional development, engineering education

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Introduction

A recent study describes the culture of engineering to be solution-focused, but with a "strong attachment to tradition" (The Royal Academy of Engineering, 2017, p. 3). This traditional approach is enacted every day in myriad undergraduate engineering classrooms around the world. Engineering educators are reluctant to change their methods, despite mounting evidence that innovative teaching practices improve student learning and engagement. Studies show, however, that there are ways to increase the appeal and relevance of educational development to engineers. This qualitative inductive work provides a research-informed and evidence-based model of faculty development for engineering educators that meets them where they are in both their discipline and their journey as educators.

Development of the Model

This work-in-progress draws upon and integrates the findings of research into five key areas: (1) student success in engineering programs, (2) change and innovation in Science, Technology, Engineering and Mathematics (STEM) teaching, (3) threshold concepts associated with post-secondary teaching, (4) the journey from novice to expert educator, and (5) the findings of myriad studies in research-based instructional strategies (RBIS), discipline-based education research (DBER) in STEM programs, and engineering education research (EER). Each of these research areas shares a social constructivism viewpoint with a vision of students who are engaged, successful, and value their learning. Starting with the instructional triangle as its core, this section outlines the interdependence of these research areas in the shaping of a faculty development model for engineering educators.

Instructional Triangle

For the past five decades, the instructional triangle has provided a way for science educators to focus on the interactions between the three core aspects of education: the student, the teacher, and the content (Hawkins, 1974). The beliefs, attitudes, identity, and actions of the teacher shape the relationships and level of respect established with the students, and the way in which content is prepared and shared with them. Likewise, the beliefs, attitudes, identity, and actions of the student shape the way they interact with the content. A broader learning community extends this triangle to include teaching colleagues who may influence teaching practices, a curriculum that encompasses the content, and a student community that may affect student success.

Student Success and Effective Learning Environments

A student-centred approach is "an organizational process and mindset around success for the students served, informed by a deep understanding of the learners, along with their active involvement in selecting solutions that work for them" (Higher Learning Commission, 2018, p. 7). A literature review identifies two significant requirements for student success in engineering: a need for students to be actively engaged in their learning, and quality interactions between educators and students both in and beyond the classroom (Boles & Whelan, 2017). A survey of engineering students reiterates these findings. It reports that while classroom practices remain lecture-based, students recognize that active involvement is beneficial to their learning, and that their instructor can have a significant impact on the learning experience (Nelson & Brennan, 2019b).

Effective learning environments are those that ensure success through value-added learning. The benchmarks used in myriad studies can be categorized into six broad themes: (1) an appropriate level of academic rigour, (2) a focus on learning, (3) supported instruction, (4) quality of teaching, (5) development of strong relationships, and (6) student engagement (Nelson & Brennan, 2019a). Each of these themes represents one or more interactions on the instructional triangle.

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Change and Innovation in STEM

Educational researchers have been advocating for STEM reform for decades. Despite their efforts, engineering continues to rank at or near the bottom of all disciplines (Quality Indicators for Learning and Teaching, 2017) (National Survey of Student Engagement, 2018) (UNISTATS, 2018), particularly in areas associated with learning strategies, effective teaching practices, and a supportive environment (Nelson & Brennan, 2019a). Myriad researchers confirm that teaching practices in STEM remain didactic, and lecture-based (Laursen, 2019) with fewer than 20% using evidence-based teaching practices in their classroom (Stains et al., 2018). Suggested reasons include a lack of formal training on how to teach (Nelson & Brennan, 2018), lack of incentive and a perceived lack of value in educational development (R. Felder, Brent, & Prince, 2011), and not seeing the benefit of moving to a more student-centred approach (Allen, 2018). STEM educators rank barriers to teaching innovation higher than all other disciplines, noting in particular that "Active learning takes too much class time causing the coverage of content to suffer" (Allen, 2018).

Felder and his team reviewed the content and structure of instructional development programs and recommend a framework for designing faculty development for engineering educators (R. Felder et al., 2011). They propose that five factors are needed to increase the appeal and relevance of educational development to engineers: (1) the expertise of the instructor in subject matter and ways of teaching, (2) relevance of the content, (3) choice in whether, when, and how to apply the instructional practices, (4) the opportunity to observe, try, and reflect on what's being taught, and (5) sharing experiences with peers. Literature reviews note that effective change strategies must align with, or work to adjust, individual beliefs, require long term interventions, and be compatible with institutional goals (Henderson, Beach, & Finkelstein, 2011). They also report that educational innovation is best served by engaging early and often with educators (Froyd et al., 2017). Finally, most studies on STEM teaching practices do not "address the key issue of what makes the STEM disciplines difficult to learn and challenging to teach" (Winberg et al., 2019, p. 940).

In spite of instructional development efforts, a recent study of novice engineering educators ranks their teaching skills and delivery lower than colleagues in all other disciplines (Nelson & Brennan, 2020). Significant differences exist in the organization, pace, and planning of classes, and the way material is presented to students (Nelson & Brennan, 2021b). Even during the pandemic-induced period of forced change, engineering educators took significantly less advantage of myriad opportunities to learn new teaching-related concepts and skills than their colleagues in other disciplines (Nelson & Brennan, 2021a). This reluctance to develop as educators may explain why student and faculty surveys of student engagement rank engineering educators lowest in the categories of effective teaching practices and providing a supportive learning environment (Nelson & Brennan, 2019a).

Teaching-Related Threshold Concepts and an Educator's Journey

There are many teaching-related concepts and skills that distinguish a competent educator from a great educator. Many of these are threshold concepts which are defined as "portals" to a new way of thinking about, mastering, and practicing one's discipline. These concepts are characterized as troublesome to learn, integrative in the way they pull together key concepts, transformative, irreversible, and context-bounded (Meyer & Land, 2003). A qualitative literature review identifies four clusters of threshold concepts that, when surmounted, could facilitate a change in the day-to-day practice of engineering educators: pedagogy, learning, assessment, and teaching with technology (Nelson & Brennan, 2021c). Threshold concepts in teaching range from reflective practice, care, recognition of student-related threshold concepts, a focus on learning, and constructive alignment of assessments, to experimentation with educational technology.

Much is written about the journey professionals take from novice, through competence and proficiency, to expertise within their discipline (Dreyfus & Dreyfus, 1980) (Benner, 1982)

(Lyon, 2015). While engineering educators are considered experts within their discipline, many do not move beyond competence as educators because there is a “transformation, a qualitative leap, from the competent to proficient levels of performance” (Benner, 1982, p. 406). These transformative leaps most likely correspond to teaching-related threshold concepts.

Engineering Education Research (EER)

The application of education, learning, and social-behavioural sciences research is one of five key shifts in engineering education over the last 100 years (Froyd, Wankat, & Smith, 2012). Although formalized EER is still considered to be in its infancy (Borrego, Foster, & Froyd, 2014) it is well supported by societies across the globe such as REEN (international), ASEE (USA), CEEA-ACEG (Canada), SEFI (Europe), and AAEE (Australia).

Rigorous research in engineering education can be categorized into one of four levels of inquiry: (1) excellent teaching, (2) scholarly teaching, (3) scholarship of teaching, and (4) rigorous research (Streveler, Borrego, & Smith, 2007). These levels recognize the benefit of both theory- and practice-oriented research. Whether it is called DBER, common in STEM-related publications, RBIS, a more generic term, or Scholarship of Teaching and Learning (SoTL), common to practice-based work, there is still, as previously noted, a gap between EER and its use in the engineering classroom.

Bridging this gap requires renewed educational development efforts that: (1) align with current motivation theories for adults, (2) inform and help shape faculty practices and conceptions about teaching and learning, (3) recognize the cultural and organizational norms as part of a strategic shift to evidence-informed teaching, and (4) address the barriers that impede changes in teaching practice (Singer, Nielsen, & Schweingruber, 2012).

This work-in-progress presents the LENS (Learning Environments Nurture Success) model of engineering faculty development that shifts the focus away from ‘learning to teach’ toward providing a more effective learning environment. It recognizes, integrates, and builds on the research into student success, change and innovation in STEM, threshold concepts and the educator’s journey to expertise, and EER. It can be used independently, in consultation with an Educational Developer, or in collaboration with colleagues, and supports all forms of delivery (face-to-face, remote, blended, or hybrid).

The LENS Model

The LENS model encourages engineering educator to use an agile approach, making small, level-appropriate, and evidence-based change in their teaching practices. This requires a willingness to learn, experiment, and reflect on one’s teaching. LENS consists of six “lenses” that align with the characteristics of an effective learning environment: (1) student engagement, (2) student-faculty relationships, (3) instructional support, (4) focus on learning, (5) academic rigour, and (6) quality of teaching. These six lenses can help shape a longer-term educational development program for individuals or programs, or be used for just-in-time, interest- or needs-driven development.

The description of each lens identifies the associated aspects of teaching and learning, and commonly used instructional strategies. It then suggests evidence-based strategies for enhancing one's teaching practice with level-appropriate recommendations for faculty at three stages of development: first-order change for those wanting to do things better, second-order change for those choosing to do better things, and third-order or epistemic change for those primed to make a transformative shift in their teaching (Sterling, 2003).

Student Engagement Lens

Figure 1a shows the instructional triangle, the core of the LENS model. It frames the relationships between the student, the teacher, and the content. Student engagement is the

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primary means of connecting students to the content (see Figure 1b). It is characterized by the time and effort students put into their studies and learning activities, student motivation, and the success initiatives provided by the institution. There is a strong relationship between student engagement and all four clusters of threshold concepts, so increasing the quality and level of student engagement will improve both teaching and the learning environment. Common practices for novice to competent engineering educators include using grades as motivators, and assuming students have well-developed learning strategies and are responsible for their own success.

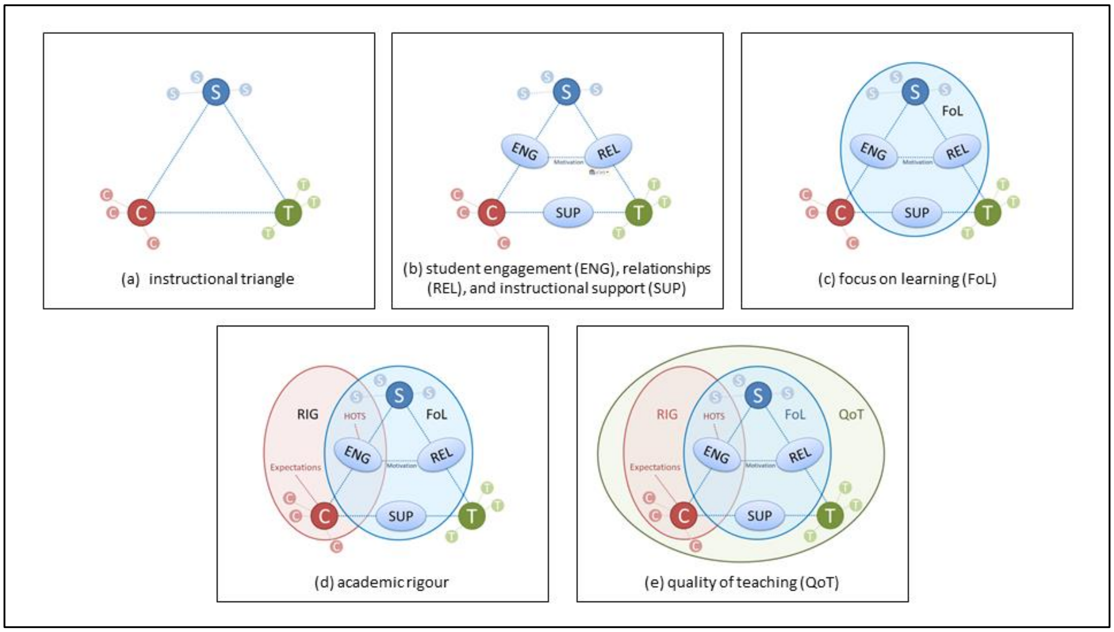

Figure 1: Evolution of the LENS faculty development model – the six lenses

Evidence-based strategies for less experienced educators who want to do things better could include taking a few minutes before introducing a topic to establish its context within the discipline and explain why it is important to know. Choosing discipline-specific examples and problems over more generic ones will help demonstrate its value. Students are more attentive to things that are relevant, important and useful, so will be motivated to engage with the content (R. M. Felder, Woods, Stice, & Rugarcia, 2000). Faculty who have reached a point in their career that they want to do better things could choose assessments that emulate the problems encountered in the workplace (Biggs & Tang, 2011). Finally proficient or expert educators could incorporate high impact pedagogies such as problem- or project-based learning, flipped learning, or service learning (Evans, Mujis, & Tomlinson, 2015).

Strong Relationships Lens

Strong relationships connect students to the teacher (see Figure 1b). This lens considers the interactions between students and their professors, how accessible educators are to their students, openness of educators to hearing the student voice, and their support of learning communities. There is a strong link between this lens and the pedagogy threshold concepts. Common practice for novice to competent engineering educators generally places a teaching assistant (TA) between the student and professor, signalling an implied distance.

Evidence-based strategies for those who want to do things better include providing informal, virtual opportunities for students to ask questions and/or clarify their understanding of the content (Smith, Chen, Berndtson, Burson, & Griffin, 2017). Faculty who are ready to do better things may consider asking for, and responding to, constructive feedback from the students partway through the term. A Stop, Start, Continue survey is an effective method to

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gather this qualitative feedback (Hoon, Oliver, Szpakowska, & Newton, 2015) Finally proficient or expert educators should ensure their classrooms are culturally responsive and respectful. This includes minimizing biases and the perpetuation of norms, policies, and practices that may cause educational inequality (Wlodkowski & Ginsberg, 2017).

Instructional Support Lens

Instructional support connects students to the content (see Figure 1b). This lens encompasses things that are ‘for’ the student. This includes the selected instructional method(s) and the materials used to support that delivery. It establishes the learning opportunities the students will have, and the effectiveness of the classroom experience. There is a strong relationship between instructional support and all four clusters of threshold concepts. Common practices for novice to competent engineering educators include a lecture, slides, prescriptive labs, an assigned text book, and additional resources linked through a learning management system.

Educators trying to do things better may want to calculate the student workload in their courses; it is often much higher than assumed (Barre, 2016). Faculty ready to do better things may consider breaking their classes into 15-20 minutes segments, each of which gives learners the opportunity to actively engage with each level of complexity as it is delivered (Collins, 2006) . Proficient or expert educators may consider experimenting with technology in the classroom. Adding strategic elements of simulation, gamification, and formative feedback may increase students’ depth of learning (McGowan, 2012).

Focus on Learning Lens

The Focus on Learning encompasses the student community, their engagement, motivation, relationships and the way their learning is supported (see Figure 1c). This lens focuses on things that are done ‘by’ the student. This includes active and collaborative learning, opportunities for skill development, and metacognition. There is a strong relationship between this lens and all four clusters of threshold concepts. Common practice for novice to competent engineering educators is to structure learning time around in-class worked examples, labs, and homework.

Educators looking to do things better might consider spreading in-class exercises throughout each class. Each time a new concept is introduced and modeled, follow it with a similar problem for students to try (Collins, 2006). Faculty who are ready to do better things could incorporate retrieval practice into their course to increase across-semester knowledge retention (Lyle, Bego, Hopkins, Hieb, & Ralston, 2020). Finally proficient or expert educators could move to a learner-centred perspective that appreciates how students construct their knowledge of the discipline (Kinchin & Miller, 2012) (Devitt, Kerin, & O’Sullivan, 2014).

Academic Rigour Lens

Active rigour intersects the Focus on Learning lens and shares the student engagement lens (see Figure 1d). This lens ensures students are appropriately challenged to maintain standards established by the institution and any accrediting bodies. There is a strong relationship between academic rigour and the pedagogy, learning, and assessment threshold concepts. Common practices include content coverage during transmission-based classes, labs, homework, and exams that expect students to integrate what they have learned.

Educators trying to do things better can use a requirements prioritization method like MuSCoW to differentiate key topics within a unit from those that are nice-to-know (Hulshult, 2019). They can use this analysis to focus on topics that require rigorous study. Faculty ready to do better things may consider aligning their assessments with course learning outcomes (Biggs & Tang, 2011). Proficient or expert educators could seek out course-specific threshold concepts and ensure students actively explore those transformative concepts throughout the course (Male et al., 2012).

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Quality of Teaching Lens

The Quality of Teaching lens encompasses all other lenses (see Figure 1e). This lens focuses on the teaching practices, attitudes, and beliefs of the educator. There is a strong relationship between the quality of teaching and all four clusters of threshold concepts. Common practices for novice to competent engineering educators include fast-paced, content-heavy classes, the assumption that students understand even if they don't ask questions, and minimal chance for students to provide ongoing feedback.

Evidence-based strategies for those looking to do things better may include slowing down to a pace where students can think about and assimilate what they're learning. They may also want to handwrite in-class notes so students can keep up (Nelson & Brennan, 2019a). Those who are ready to do better things should consider using an evidence-based lesson planning template to ensure that each class is organized, interactive and focused on the key outcomes (Nelson & Brennan, 2021b). Finally, proficient or expert educators may want to practice reflective teaching to explore ways in which they can further improve their teaching (Biggs & Tang, 2011).

Concluding Thoughts

The LENS model offers a practical framework that encourages an agile approach to the educational development of engineering educators. With a focus on learning, it informs and helps shape faculty practices and conceptions about teaching and learning. It aligns with current motivation theories for adults, recognizing that individuals are each at a different stage in their professional growth as educators. It inspires movement from competent to great teaching by threading elements of educator-related threshold concepts through each lens. The LENS approach narrows and directs the engineering educator's instructional development efforts to the most impactful practices in today's engineering classroom.

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From Students of Engineering to Students of Engineering Education Research and Practice: A Collaborative Auto-ethnographic Study

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ABSTRACT

CONTEXT
The growth of engineering education research (EER) as a research discipline has led, amongst other things, to an increase in dedicated academic departments and degree programmes. The recently introduced MSc Engineering and Education at University College London is one such example. Current research suggests that the transition from professional practice and undergraduate disciplinary education to graduate level research and education is often accompanied by experiences of dissonance and discomfort. However, research on the necessary transformational learning pedagogies to support students undergoing this transition is still in its infancy. This study seeks to address this research gap.

PURPOSE OR GOAL
The literature on engineering education research (EER) suggests that individuals from engineering backgrounds who are moving into EER often find the transition daunting, as they have to learn new terminologies and to adapt to new ways of conducting research. In this study we seek to identify the challenges that students on the MSc Engineering and Education programme face, and the strategies they deploy as they undergo the transformation from a graduate engineer identity to an identity as an engineering education practitioner or researcher.

APPROACH OR METHODOLOGY/METHODS
In this study, a student-staff partnership comprising four current students on the MSc Engineering and Education and two academics teaching on the programme engage in collaborative autoethnographic research to explore the perceptions and experiences of the students on their learning journey on the MSc. Working together as a team of equals, we engage in online discussions, share personal narratives about our experiences on the programme, and collectively examine these shared personal narratives using thematic analysis.

ACTUAL OR ANTICIPATED OUTCOMES
This research will shed light on the motivations of students from engineering backgrounds to embark on engineering education research and practice, as well as the challenges they experience in adapting to a social science inquiry mindset. Specifically, the research will explore student experiences as they encounter and integrate new norms and worldviews inspired by social science perspectives, as opposed to the engineering-centric worldview that they were inducted into during their undergraduate engineering education and training.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
Little has been written on developing transformational learning pedagogies for students from engineering backgrounds seeking to gain competence in engineering education research and practice. In this study, the student-staff research partnership works collaboratively with each other to identify the issues faced by students from engineering backgrounds to embark on engineering education research and practice.

KEYWORDS
Engineering education, collaborative autoethnography, student–staff partnership, threshold concepts, transformative learning pedagogy

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Introduction

The growth of engineering education research (EER) as a research discipline has led, amongst other things, to an increase in dedicated academic departments and degree programmes (Borrego & Bernhard, 2011; Jesiek, Newswander, & Borrego, 2009). The recently introduced MSc Engineering and Education at University College London (UCL) is one such example. However, whilst there is a growing body of research looking at pedagogic and epistemological practices in EER-focussed graduate level programmes (see, for example, Adams, Pawley, and Jesiek (2012), Lopez and Garcia (2020) and Finelli and Mondisa (2019)), research on the necessary transformational learning pedagogies needed to support students is still in its infancy. This study seeks to address this research gap.

In this study we set out to identify the challenges faced by students on the UCL MSc Engineering and Education programme (hereinafter referred to as the MSc), and the strategies they deploy as they undergo the transformation from a graduate engineer identity to an identity as an engineering education practitioner or researcher. The MSc is offered simultaneously and flexibly in both online and face to face modes, and is made up of two compulsory core modules, Learning and Teaching in Engineering, and Practice, Innovation and Leadership, which introduce students to sociological and educational debates about engineering. Students also select two optional modules from the engineering and education faculties at UCL and complete a Dissertation. A key feature of the programme is the online discussion forum, and the dominant pedagogical approach is dialogic and interactive: typically, students are given materials, discussion questions and brief writing tasks before the synchronous sessions, which consist of presentations by a wide range of contributing academics, followed by questions and discussion. Our study is informed by recent work in research into doctoral education (see, for example, Adorno, Cronley, and Smith (2015) and Tyndall, Firnhaber, and Kistler (2021)) and in the fields of discipline-based education problems research (DBER) and SoTL (see, for example, Adendorff (2011) and Smit, Meyer, Crafford, and Parris (2017)) which suggest that the transition from professional practice and undergraduate disciplinary education to graduate level research and education is often accompanied by experiences of dissonance and discomfort. Potential reasons for why this transition can be daunting include dealing with issues and problems which are more social than technical, typically qualitative and not well-defined, ie ‘swampy’ problems’ (Schön 1983).

Methodology

In this study, a student-staff partnership comprising four current students on the MSc Engineering and Education and two academics teaching on the programme engaged in collaborative auto-ethnographic research (Chang, 2013) to explore the perceptions and experiences of the students on their learning journey on the MSc. According to Chang, auto-ethnography is an autobiographical method whereby the researcher uses their personal experiences as primary data to expand the understanding of social phenomena. Collaborative auto-ethnography extends auto-ethnographic research by enabling multiple researchers to gather and analyse auto-ethnographic and self-reflective data about themselves systematically and collaboratively (Roy & Uekusa, 2020). The research methodology was approved by the UCL Institute of Education Ethics Committee.

All four students self-identify as female and had graduated in the previous academic year from undergraduate engineering degrees prior to enrolling on the MSc. Two of the students had obtained their bachelors degrees from China, one from the USA and the fourth one from the UK. The two academics self-identify as male, and one has a social science background whilst the other is a teaching-focussed engineering academic who has transitioned to EER via an education doctorate.

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The ensuing discussion took place in an online focus group conducted via MS TEAMS. Due to the collaborative nature of our research method, the focus group was the most ideal option as it enabled the students to engage in discussion, with the two academics serving as facilitators. The discussion was guided by the research question:

> *What are the students' perceptions of their experiences throughout their learning journey on the MSc?*

The following specific questions structured the 90-minute focus group:

> *Why did you choose EE after your engineering degree?*
>
> *What challenges have you faced on the MSc?*
>
> *How have you felt when you received feedback on your assignments?*
>
> *Did you feel at any time that signing up for this course might have been a mistake?*
>
> *Has your understanding of 'critical thinking' changed since the start of the course?*
>
> *To what extent so you now think of yourself as an independent thinker in Engineering Education?*
>
> *Has anything changed for you as a result of this degree: ideas, outlook, ambitions, plans for the future?*

Students were encouraged to share personal narratives about their experiences on transitioning from an engineering student identity perspective to an EER researcher perspective over the course of their studies on the MSc. Following the focus group discussion, the two academics and the students individually examined the focus group transcript to identify students' changes in perception as they increasingly engaged with EER practices on the MSc.

Then, using a data-driven thematic approach (Braun & Clarke, 2006), all six of us – the four students and the two academics - individually read the focus group transcript, inductively identifying themes from the data. We then compared the identified themes and sub-themes that we had individually identified, and then working on a shared copy of the original transcript, we collaboratively re-read and re-coded the transcript to reflect our shared understanding of the emerging themes.

Findings from the Study

Why did students enrol on the MSc Engineering and Education?

Findings from the focus group suggest that students enrol on the MSc Engineering and Education for a variety of reasons. Some students enrol on the programme to enable them to study and explore the social and economic aspects of engineering in more depth. In response to why she chose to enrol on the MSc, one participant said

> *"… I don't only want to learn about engineering and science subjects, but also I feel interested in some social problems.*"

Another participant said that she had always harboured an interest in the social sciences but when she decided to pursue an engineering career whilst still in high school, she had to drop all other subjects and focus only on science and mathematics which would enable her to qualify for entry into engineering degree programmes.

The study also revealed that some students decide to enrol on the MSc after having developed an interest in engineering education during their undergraduate engineering studies. One participant was dissatisfied with the quality of teaching on her engineering programme, and this prompted her to take an interest in engineering education. Explaining her desire to study engineering education, she said

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"So I found that in my institution, there were many teachers with excellent scientific research ability, but relatively less good at teaching … and I began to think about what I would do if I were a teacher to improve the quality of teaching and make students more interested in the subject. So I wish to, uh, kind of understand more in this, uh, engineering education. So, um, and I think this, uh, master programme kind of, um, this is my - this part of interest."

Another student joined the MSc, her interest in engineering education having been sparked by her involvement in the staff-student teaching committee during her undergraduate engineering programme:

"So, um, while I was studying the engineering major, I took part in the staff student community, and that was an important role to communicate with, uh, teaching faculty and students. I found something that was really different from my imagination to be, uh, an engineering student. I realised how much I didn't like engineering like the technical stuff and like, how much I prefer the educational side of things."

Challenges faced by engineering students enrolled on the MSc Engineering and Education

Findings from the focus group suggest that most students enrolling on the MSc Engineering and Education from undergraduate engineering degree programmes experience difficulties with the academic writing style required on the MSc. One participant had this to say:

"I think writing the academic writing is one challenge for me, because when I am at the undergraduate, um, my dissertation is – I use the experiment's data to support what I want to explain. But now, um, the engineering and education I need to use, uh, not so much data, but just use some literature to support what I want to explain to the readers. So I think it's a little challenging for me to just use the literature to explain what I want to say."

One student indicated that they were struggling to adapt to the teaching style required on the MSc because it was quite different from the learning and teaching approaches used on undergraduate engineering programmes and they had not had the opportunity to engage in the form of academic writing required on the MSc*:*

"And for me, I think it's the change of the teaching styles. And, for example, during my undergraduate period, I studied various mathematics, physics, data structures or algorithms and then programming, coding and developing software. So I had few opportunities to participate in the academic writing or, uh, writing of paper or like that. So, um, so I think it's, um, a little difficult for me to engage in this kind of teaching style rapidly."

Students also struggled with assessment formats that were different from what they were used to on their undergraduate engineering programmes. For instance, one student said:

"Evaluation or the assessment is quite different. Um, for example, before I have had to pass the exam or the mathematics exam, the physics exam. But, um, there was less opportunity for me to write a paper or doing something like that, it's so different in the assessment way or the teaching style." Another student had this to say: *"Um, I think for me like, the major thing was, um, just doing more writing in general. Um, so my whole undergrad degree, I'm pretty sure we did, like, … everything was exam based, or like some project. Um, so for me, it was like, kind of different."*

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Student initial experiences and coping mechanisms

Most students were initially excited to be on the course, however as they started experiencing challenges with the required learning and assessment practices on the MSc, this often turned to a sense of confusion and disorientation. One student put it as follows*:*

> *"I was quite excited at first. I quite like challenges and the writing for me. … Uh, my instant thinking was to find a lot of evidence for me in this major. I have to find a lot of literature background. I have seen some problems already. So, um, so it was like an initial excitement [turning] to some confusion."*

Some students struggled to adapt to the learning and assessment styles on the MSc and this led to feelings of inadequacy and incompetence. One student expressed this as follows:

> *"And I felt, um, I felt that I was, uh, like, uh, less uh uh, for, uh, I think just less [confident]."* Another student also confirmed that *"… it was also a challenge for me and because I was not very confident about, um, I didn't know if I was doing well or not, and I …. I wasn't sure about this."*

To cope with perceived learning and assessment difficulties on the MSc, some students felt that they had to re-learn how to learn, as one student said:

> *"It was kind of hard, um, going back to doing like, um, literature review that wasn't like, um, for, like, research purposes. So, like, go, like, literally reading, like, educational purpose, education, educational, like papers and stuff. That was, like, a brand-new thing to me."* Another student also stated *"So learning how to do that was kind of, um it wasn't difficult, but it was definitely like, um, something I had to learn over the terms"*

Student insights into their struggles on the MSc

Looking back across the academic year, students reported having difficulties with self-management and self-evaluation when it came to self-directed studying. This was not the case with undergraduate engineering where the study goals were more explicit. One student observed*,*

> *"While I am studying, uh, this programme, I always feel like I have I have not achieved any goals. My assignment, it's quite different. When you were studying engineering course, you could set later goals for every day. So, you study this and practise this. But now here, when I try to do a little bit of research, you don't know what you're going to know. And then you couldn't probably control the time. But you cannot control the thing that you can't understand, or you can't see. … I feel very, very, uh, like, depressed because I have not achieved [my study goals]."*

Students feel that assessments on the MSc are tougher than the assessments on undergraduate engineering programmes. This is because unlike in undergraduate engineering programmes, MSc assessments have no definite answers. One student said,

> *"Um, it's just a lot tougher because it really doesn't seem like there's a right answer for, like, a lot of the assignments like, um, so it's like a lot of it is like our analysis of literature."*

Because of this, students feel that they can never be certain whether they have done well in a piece of assessment. Instead, they feel that the grades they attain are ultimately in the hands of the readers, and not solely under their control. Referring to this, one student said,

> *"I guess, Um, obviously you want the best grade possible, but it becomes a little like, um, I guess, like, um, it gives me a bit of anxiety just like writing it, because I don't know if it's going to be received the way that I wanted it to be received and even though, um, like I could put like, You know, all this effort in, it's, uh like at the end of*

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the day it's up to the reader, and I think if they're like, 'Oh, this should have been added …'"

In general, students felt unable to predict their performance on the MSc, something which they could easily do in their undergraduate engineering studies. One student said,

> *"That's like there's - there's no like predicting, like [in] technical engineering, if you like. For the most part [in undergraduate engineering], if you study and you know, you practise some of the problems, more than likely you're going to be Okay on the test. It's predictable. Versus this is up to the interpreter."* A second student also agreed with this, saying, *"For me as an engineering student, I know if I was doing it right or not, and for example, there was only one answer to a Maths problem, and I would be relieved that my code works. But, um, now, I don't know if I did the writing well. I have no idea. It's because the criteria or the metrics for assessment or other things are different."*

Critical thinking as a marker of progress on the MSc

The students felt that "critical thinking" was one of the key concepts that needed to be mastered on the MSc, and this was discussed at length. This statement is representative of the thoughts shared by the students,

> *"Based on my understanding, I think that we need to write the assignment as critical as possible. Um, maybe, like add some comparison, or maybe just dig more on one topic, have some deeper thoughts. Um, And I think, um, I try to do better in doing more critical assignment. Um, and I think there it's a long way for me to go to be critical, but I am trying."*

Describing her journey towards mastering the concept of "critical thinking", one of the students said she had started off with basic understanding of critical thinking, and she had now developed a deeper, more nuanced understanding of the concept. Even then she was still not certain whether she had fully mastered the concept. This is how she put it,

> *"Um, at first I think critical thinking just means that, um, I need to talk about the, uh, optimistic aspect of this thing and then the negative aspect of this thing. That's my original thought about critical thinking. But then I think that, um, maybe I need to, uh, use different aspects to explain one thing and add more comparison from one perspective to another. And that's what I'm thinking. Uh, I don't know whether it's right, but I'm trying to do it better."*

Other students expressed that they were also still struggling with the concept of critical thinking, even though they were almost at the end of the MSc. One of the two academics in the focus groups agreed with the students, suggesting that understanding critical thinking, just like trying to understand any other concept in the social sciences, is a never-ending process, unlike mastering certain engineering concepts, something which the students must adapt to. In the opinion of the academic, this marks a shift in the development of the students from a fixed engineering mindset to a more fluid, open-minded conceptual understanding.

Legitimate Peripheral Participation in the Engineering Education Community

The students viewed their year on the MSc as a form of initiation into the community of Engineering Education Researchers, and they were proud of their growing confidence as EER researchers as they progressed through the course. One student outlined her progression as follows,

> *"Um, I think, like, uh, in the beginning, I felt like I guess I don't have any authority to, like, say, I think about, like, these. Like, um, like literature that has been, you know,*

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written by the professionals, like in the sector. So, in the beginning, I was very much like, I guess, regurgitating what other people have said rather than what I think. I think as the course progressed, um, I guess I built up my confidence and, um, as I read other things, I had the confidence to say, 'Oh, this isn't really like that good an idea. This idea is better, like, kind of, um, being able to formulate my own thoughts and have that, like, confidence. Like learning more and more that I do have the authority to, like, say that, 'Um oh, I think this is more influential.' Like, especially in, um, like in getting girls to participate in all that. Um, I did, um, say that 'I don't think some of these ideas are that good.' Um, and I wouldn't have said that in the beginning, so yeah, I think definitely, I guess over time I, like, gained more of my bearings and became more outspoken."

This statement is consistent with the Legitimate Peripheral Participation view of how newcomers become experienced members and eventually old-timers of a community of practice or collaborative project (Lave & Wenger, 1991).

Transformational impact of the MSc

The MSc has encouraged some students to consider new career opportunities and directions beyond traditional engineering roles. One student remarked,

"So, I guess doing this course taught me that there is, like, other ways to apply my bachelor's degree."

The student went on to say that this was in line with the reason she had opted to enrol on the MSc instead of applying for a graduate engineering role,

"And that was the reason I joined in the first place was because I was kind of I didn't really feel like I fit in or wanted to pursue a career in, like, corporate like industry, which is what I would have done if it wasn't for this course."

Another student stated that the MSc had introduced her to the social science side of engineering. She had also taken the opportunity to take economics and psychology as option course modules in her MSC studies because, in her own words,

"… that was the knowledge that I have not, uh, learned like, uh huh, from teenage years. You know, sometimes I even think I should have learned those things earlier so that I could choose a different career path."

For some other students, the MSc had reinforced their reasons for choosing engineering as a career in the first place. "I think I quite enjoy the experience because I think it helps me to know what engineering means and what engineers can contribute for society. We, uh, begin to know the impact of letting more engineers to contribute to solving real problems, real projects. So, I think that's what I want." As a result, she was now looking forward to finding a role as an engineer after graduation.

From the focus group discussion, it was also apparent that the MSc had influenced some students' intention to pursue doctoral studies in quite different ways. A student who had wanted to go on to a PhD in a technical field had changed her mind and was now seeking to enrol on a PhD in Engineering Education:

"… I wanted to take this course and then, um uh, do a PhD in a technical field. But after this course, I have decided I want to go more into the education side of things."

In contrast, the MSc had instilled doubts in another student's mind regarding her desire to pursue a PhD in Engineering Education. She now felt that engineering education research was not for her. She was however still uncertain whether she would prefer to go into engineering practice after the MSc. Instead, she was opting to take up any suitable job following graduation to enable her to think about her long-term career goals.

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Have students on the MSc experienced transformational learning? It is evident that the MSc has had a transformative effect on the students who participated in this research. Students have gained a heightened awareness of the social aspects of engineering, and they have also gained insights into some of the problems relating to engineering education, including gender imbalance, lack of diversity, and learning and teaching methods that are ill-suited to the needs of the 21st century.

At a personal level, the MSc has transformed the worldview of the students from a hitherto limited engineering-centric viewpoint to a broader worldview with broader perspectives and awareness of the world and its complexities. This has led to a re-evaluation of worldviews and perspectives, and an appreciation of the challenges and realities of the world and of their own impact as engineering professionals. For some, this has tampered the techno-optimism inculcated in engineering school, leading them to re-evaluate their career options, and adopting a more nuanced, mature, informed approach to career planning and career expectations.

Discussion

Students in our study speak of experiencing a sense of uncertainty and confusion as they struggled to adapt to the learning and assessment practices on the MSc. This finding is consistent with findings from other researchers. The study by Adorno et al. (2015) indicates that the transition into doctoral studies is characterised by uncertainty and chaos as the new doctoral students struggle to adapt to learning practices on doctoral programmes. The study of healthcare professionals on an MPhil in Health Professions Education at a South African university by Smit et al. (2017) also reveals that the transition from a health sciences perspective to the educational paradigm is accompanied by experiences of dissonance and discomfort.

The students on our study also report difficulties adapting to academic writing, critical thinking, and preparing and writing assignments. The studies by Adendorff (2011), Smit et al. (2017) and Tyndall et al. (2021) concur with these findings. Tyndall et al. (2021) conceptualise all these elements that students struggle with as threshold concepts, a term that suggests that a student’s progress on the course ultimately depends on whether they have understood these concepts. Failure to understand the concepts would indicate that the student’s difficulties with the course will persist, whilst mastering the concepts will open the student to an entirely new perspective and understanding of the course. Threshold concepts therefore serve as a gateway to mastering a course and they have been defined as learning concepts that signify *“a transformed way of understanding, or interpreting, or viewing something, without which the learner cannot progress, and results in a reformulation of the learners’ frame of meaning”*(Land, Meyer, & Baillie, 2010).

Some of the findings from this study highlight the unintended consequences of an educational system in which academic pathways into STEM or the social sciences and humanities are decided early on in secondary school. One case in point is the student who enrolled onto the MSc to re-engage with her interest in the social sciences, she had been forced to abandon when she opted to follow a STEM pathway into engineering. The realisation by one of the other students during her undergraduate studies that engineering was not for her, may also be indicative of an education system that forces students to decide which career to follow early on in high school before they have had time to explore and engage with the full breadth of available career options.

Concluding remarks and Future work

This study focusses solely on the UCL MSc Engineering and Education and is based on a collaborative auto-ethnographic study comprising four students and two academic staff members; hence the findings may not be generalisable to all academic settings. However, the findings concur with those from other studies focussing on early career academics

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transitioning into discipline-based education research, including engineering education research, as well as studies focussing on professionals embarking on graduate level DBER studies.

The MSc, which was launched in 2018-19, is continually evolving, particularly in relation to its pedagogical approaches. Changes over this period align well with the findings of this study: the most important have been an increasing emphasis on brief writing tasks throughout the programme which are not formally assessed, on encouraging and supporting regular and meaningful contributions and interactions on the online discussion forum, and more time given to informal tutoring. In general, since the programme started, pedagogy and course design has shifted towards a flipped-learning and learner-focussed approach, and this trend has accelerated as a result of the pandemic. This study suggests that these shifts and developments reflect the needs and preferences of students, as well as helping serve the future needs of the industry.

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An exploration of capacity development of journal reviewers through a mentored reviewer program

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ABSTRACT

CONTEXT

The Journal of Engineering Education Transformations (JEET) is a scholarly, peer-reviewed journal committed to the advancement of theory, research and practice in engineering education. The journal is international in its scope, inviting scholars and experts from across the globe to share their theoretical insights, research findings, and innovative practices to enhance and transform engineering education. In addition to publishing high-quality articles, the JEET editorial team is committed to developing authors as researchers through their review process. JEET is growing at a consistent rate and is actively seeking ways to increase its pool of reviewers, enhance the quality of reviews and build capacity amongst researchers and practitioners. To support this goal, in 2020, JEET started a mentored reviewer program modeled after a similar program that was run by the Journal of Engineering Education (JEE).

PURPOSE

The broader purpose of this study is to build capacity in engineering education research in India through a mentored reviewer program. The purpose of this paper is to outline the design of the mentored reviewer program, discuss anecdotal findings from the first round of delivery and describe the plans for a research study that will be employed to gather data from an upcoming second round.

APPROACH

Observations from the first round of the program were reviewed by the authors to find recurring themes. In addition, the authors, who were also the organizers of the program, reflect on their own experience.

OUTCOMES

Anecdotal evidence from the first offering of this mentored reviewer program suggests that besides providing training for becoming better reviewers, the program has successfully built a broader research community. Several participants expressed how the program has helped them to grow, not only as reviewers but also as authors and researchers.

CONCLUSIONS

This paper provides a comprehensive design of a mentored reviewer program to develop engineering education researchers. The paper also provides a critical evaluation of the first round of program delivery, highlighting opportunities for further refinement. The paper concludes with recommendations for a research study that will be carried out on the second round of the program to explore the experiences of mentees and mentors in relation to the community of practice framework. Furthermore, the study starts to challenge some of the existing paradigms in traditional review process, suggesting a more collaborative approach.

KEYWORDS

community of practice, engineering education research, mentoring, review process

Introduction

Background

JEET is a scholarly, peer-reviewed journal committed to the advancement of theory, research and practice in engineering education. Published in India, (the journal) is international in its scope, invites scholars and experts from across the globe to share their theoretical insights, research findings, and innovative pedagogical practices to enhance and transform engineering education. JEET is consistently growing and actively seeking ways to increase its pool of reviewers, enhance the quality of reviews, and build capacity amongst researchers and practitioners in this space. In addition to publishing high-quality articles, JEET's editorial team is committed to developing authors as engineering education researchers through their review process of articles submitted to the journal.To support these goal, in 2020, JEET started a mentored reviewer program modeled after a similar program that was run by the Journal of Engineering Education (JEE).

The JEE program (Mentored Reviewer Program, 2020) started in 2019, primarily designed to address the many challenges that exist in the reviewing space of academic journals (Benson, 2019). JEE recognized the frequently destructive (Benson, 2019) and toxic atmosphere (Silbiger and Stubler, 2019) that can exist in the peer review process for journals. They also acknowledged that the peer review process creates opportunities for fostering discussion amongst colleagues (Nature, 2020) and providing feedback that can strengthen and enrich academic work with the peer-review process forming a mentorship role (Martin, 2020). Therefore, the JEE program was designed to build up reviewers to provide constructive peer feedback (Benson, 2019). A reflection from mentees on the first round of the JEE mentored reviewer program highlighted additional benefits, describing the "ripple effect" that the program has more broadly on their identities as engineering education researchers and their contributions to the broader research community (Jensen et al, 2020).

Engineering Education Research (EER) is a relatively new field of research, particularly outside of Europe and the United States. It is also a complex field of research as the researchers in this field frequently transition from discipline-specific engineering research. Beddoes (2014) has identified the new disciplinary perspective that needs to be navigated as researchers enter the engineering education research community. Researchers need to develop a new identity as they make this transition, and developing and refining this identity is neither a straightforward nor a linear process (Gardner and Willey, 2018).

Engineering Education Research (EER) is also frequently misunderstood specifically by these transitioning researchers as they move from engineering education, through scholarly teaching and learning to scholarship of teaching and learning (SoTL) to engineering education research (EER) (Richlin, 2001). Understanding this evolution is an important aspect of the journey of most engineering education researchers.

Based on our experience working with the journal for a number of years, scholarly research itself seems new to a large portion of authors and reviewers of the journal. With an increase in the number of institutions over the last 30 years from about 300 to more than 2000 (All India Survey on Higher Education, 2019), as well as a shortage of qualified candidates, many institutions hire instructors with Masters in Engineering (ME) degrees. Government mandates and ranking systems are incentivizing faculty to pursue PhD degrees, but these are often viewed as end goals rather than the beginning of a career involving research and scholarship.Consequently, there is an opportunity and a need for capacity building in research in general, and research in engineering education specifically. This need spans the entire research spectrum from research planning, grant writing, paper writing to paper reviewing.

More broadly, Engineering Education Research (EER) itself is an emerging field of research in India. As a result, many of the papers published by (the journal) are considered "practice"

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papers that engage in the engineering education and scholarly teaching and learning space. However, an increasing number of faculty at engineering institutions are becoming engineering education researchers, embarking on this journey across these various practitioner and research spaces.

Building on these thoughts,JEET saw the initiation of a mentored reviewer program as a unique opportunity to develop reviewers to provide constructive reviews while concurrently developing reviewers as engineering education researchers.

Anecdotal evidence from the first round of the program confirmed the findings by Jensen et al (2020) and again highlighted the emergence of identity development and the role that communities of practice played in this transition. The researchers identified an opportunity to explore these further through this research study in relation to established literature on communities of practice (CoP) (Wenger, 1998).

Purpose of the study

The broader purpose of this program is to enhance the research capacity of engineering educators in the field of engineering education research. This paper, in particular, will describe the development of the program and anecdotal feedback and evidence from the first round of the program. This evidence is then analysed in relation to literature and ends with the description of an interview protocol grounded in the CoP framework. This protocol will be used after the second round of the program, to be run in 2021, to explore the development of mentees and mentors as reviewers and educational researchers through participation in (the journal) mentored reviewer program.

The design of the JEET mentored reviewer program

In May 2020, JEET launched the mentored reviewer program. This process started with a small team drawn from the editorial board of the journal. Setting the program up for the first time required a number of steps to ensure that the necessary building blocks were in place and that appropriate engagement and buy-in was obtained before the launch. This section describes these preliminary steps, the design process used and the mechanics of the first round of the program that was run from November 2020.

Setting the stage

As noted earlier, the primary purpose of the program was to develop reviewers and improve the quality of reviews and submissions. To this end, a thorough review of supporting documentation was required before the program was launched. This included reviewing and updating the submission template, instructions for authors and reviewers, and the review criteria. This process took several months but the team felt that this was a critical first step to ensure that clear and consistent guidelines and expectations were available to associate editors, authors and reviewers before the program was launched. Furthermore, it was expected that this supporting information would reduce the potential for failure demand by minimising unnecessary misalignment and double work.

Developing the program

Although the program was modeled on the JEE mentored reviewer program, the team designed a tailored model that was able to meet the contextual needs of this journal. This model and the revised supporting review material was shared with the Associate Editors (AEs) from the journal for feedback and comment through two, one-hour, workshop sessions. The model and supporting material was revised over these two sessions based on input from the AEs. The team believes that this was also an important step in the design process to familiarize and orientate the AEs and gain their support but also to incorporate their thoughts on the practicality and suitability of the program for the context. The following sections introduce the model for the first round of the program including the purpose, format and content.

Purpose of the program

The primary purpose of the program was defined using the following objectives:

- To develop reviewers
- To develop authors (through the review process)
- To improve the quality of papers published in the journal

Secondary objectives included:

- To improve the quality of EER papers in the broader community
- To create an inclusive and supportive EER community

Format of the program

An overview of the format of the program is included in Figure 1. The program consists of the following elements: training workshops, the review of two journal submissions in mentor-mentee pairs, group feedback sessions and reflective assignments.

The program was designed to run over 3 months to allow sufficient time for workshops and engagement, give mentor-mentees time to review both papers and to maintain the momentum and energy that was built during the workshop sessions.

A learning management system site was created using Canvas to share resources and update mentors and mentees using announcements.

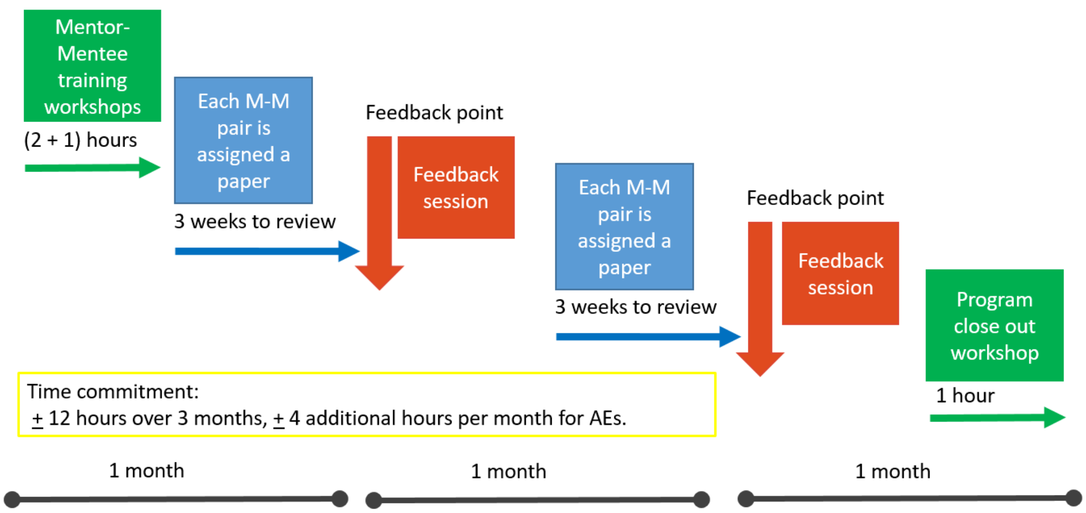

Figure 1: Overview of theJEET mentored reviewer program

The program started with two, one-hour workshops run on two successive Saturdays. All mentors and mentees were asked to attend these workshops although recordings were made available for those who were unable to attend. The workshops were designed to be interactive and centred around the following topics:

- Introduction
  - Introduction of mentors and mentees
  - The purpose of the JEET mentored reviewer program
  - Description of the logistics of the program
- Reviewing
  - Stakeholders in the review process

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    - Purpose of reviewing
    - What makes a good review
    - Discussion of EER sample reviews
    - JEET reviewer guidelines
- Next steps and expectations on the program

Interestingly, the introductions of mentors and mentees on the program took a significant portion of the first workshop. It was found that this was a key activity on the program particularly in building networks and a community.

After the two training workshops, each mentor-mentee pair was then required to review one of the submissions to the journal. The process for this is included in Figure 2. Some flexibility was allowed in this process with each pair deciding how they would meet, discuss and write up the review. Pairs were also able to request feedback on their reviews from the program team. Group feedback sessions were held after all pairs had reviewed their first paper. These sessions provided a space for mentors and mentees to share their experiences and ask questions about the review process or the papers that they had reviewed. This process was then repeated for a second and new submission to the journal. A final close-out workshop was held at the end of the program to celebrate the contribution of everyone who participated in the program and to discuss any final feedback and experiences.

Two reflective assignment tasks were also assigned to the mentees on the program. Both of these tasks were completed using a GoogleForm. The first took place before the first training workshop and the second took place after the first submission was reviewed. Both of these tasks required mentees to reflect on their identity, sense of community in the EER space and their understanding of the review process.

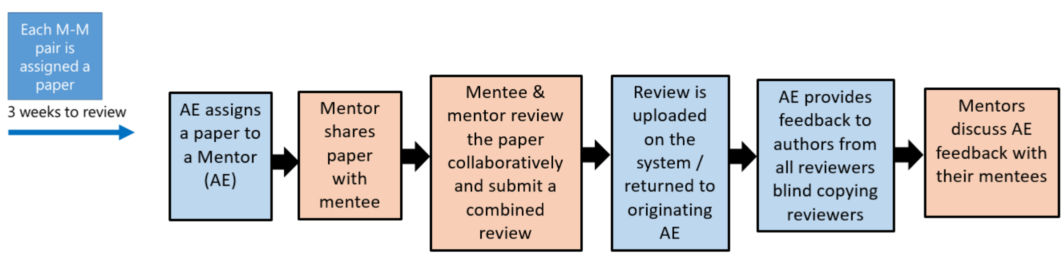

Figure 2: Overview of the program review process

Launching the first round

For the first round of the program, mentors were recruited from the pool of associate editors for the journal. After the initial workshops to set up the program, AEs were invited to participate as a mentor. AEs were also asked to recommend a current JEET reviewer or a new reviewer to be their mentee. Most mentors identified a mentee, for those mentors who did not, a mentee was assigned from the existing pool of reviewers. Identified mentees were then sent an invitation email, explaining the purpose of the program and expectations of participants. At the end of the recruitment process, ten mentor-mentees formally signed up for the first round of the program.

Practical observations from the first round of the program

It is noted that setting up the first round of the program did require a significant amount of time and effort from the core team which consisted of the five authors of this paper. As described however, much of this work was done to address matters that were of universal value to the journal. This was also once-off work that would not need to be repeated every time the program is run. The program was also designed in a way that materials were created and curated so that future rounds would require less work on the part of the core team.

For the mentors and mentees, the time and effort that was required was again significant but this effort enabled mentors to tackle existing reviewers for their assigned papers and mentees were able to tackle actual reviews that were assigned to them. Furthermore, AEs acknowledged that the development of reviewers (mentees) has the potential to reduce the time spent on future submissions as they are a part of growing the quality and number of reviewers.

Indeed, the program does require commitment and dedication of the core team, mentors and mentees but because the extended value and purpose is communicated and understood, there is a sense that the program is actually enabling sustainability of the journal and the JEET community. Interestingly, we are about to launch the second round of the program and many mentors have signed up to be part of the program again and several mentees have agreed to participate in this round as mentors.

Reflections from the first round of the program

Participants (mentors and mentees) provided feedback on the program in two sessions, for a total of about one hour of discussion across the two sessions. All authors of this paper participated as mentors for the first round of the program. Below we summarize the observations and experiences of the authors. Note that the description below is anecdotal and is not a result of any data collection or analysis.

One of the the most frequent and thus important takeaways was how the program itself resulted in doing joint reviews and created a connection between the mentors (associate editors) and mentees (reviewers). Community building was not at the forefront when we planned the mentored reviewer program - our primary purpose was to improve the quality of the reviews. However, it was clear to the participants and the organizers that the human interaction, not just through the sessions of the program itself, but also from the meetings that occurred between mentors and mentees, some in person, some via video calls, some through phone calls, resulted in better reviews and more motivation for AEs and reviewers to complete their tasks. This prompted us to consider the community of practice framework as our theoretical framework for asking our research questions and setting up data collection for round two of the program. Another outcome from the observation of community building was to reconsider the relationship between the associate editor role and the reviewer role. Traditionally these roles operate in isolation, with the reviewer acting as a subject-matter expert. Indeed, the review process entails anonymity and impartiality, but why should there be an isolation of reviewers? As a direct result of the mentored reviewer program, the journal now offers monthly office hours from the Editor-in-Chief for all AEs. These have been fairly successful, and there is a proposal for each of the AEs to hold office hours for their existing and potential reviewers, where they might discuss specific reviews and overall improvements to the review process. In the months following the first round of this program, the Editor-in-Chief has held office hours each month. The office hours are open for anyone who wishes to discuss any issues in reviewing or editing a paper or bring up logistical issues on navigating the journal website for submitting reviews or communicating decisions to the authors. Given JEET is a relatively new journal, the office hours also serve as a forum for people to offer and discuss constructive suggestions on how to make the reviewing process smooth and useful for everyone involved. To accommodate different time zones, the EIC, who is based in Milwaukee, USA, has held the meeting at different times and sometimes on different days of the week.. Attendance has varied, and recordings of the meetings that had particularly robust and useful discussions were made available to all AEs.

Another idea that came up frequently during the feedback, especially from the mentees, was the idea of providing structured and constructive feedback. Most mentees commented on how they had earlier perceived a review to be a summary judgement of whether to accept or reject a paper, with relatively little feedback to the authors. However, the mentored reviewer program altered their view about this, and taught them how to provide detailed constructive feedback, using the review as an opportunity to anonymously mentor the authors.

A third common observation was how useful the mentored reviewer program was in terms of the participants' growth not just as a reviewer, but as an author. A number of the participants, both mentors and mentees, pointed out that learning how to do more structured reviews, laying down expectations from each of the sections, and considering the logic model and flow from section to section from the perspective of a reviewer, immediately resulted in improvement in writing their own papers. One of the participants was in the final stage of writing a PhD dissertation, and applied these learnings to revise the dissertation with positive results.

Other observations were around better utilizing the time spent on the review process, writing reviews in a manner that would not insult, demoralize or demotivate reviewers, reviewing from the perspective of the reader of the journal article, and creating some sort of routine for both reviewing as well as carrying out the duties of an Associate Editor.

Design of the follow up research study

Theoretical framework

The anecdotal evidence from the first round of the program prompted the organizers to design a systematic study for the second round of the program to explore how the program develops both the mentors and the mentees as reviewers and engineering education researchers. For this future study, we decided to use the community of practice (CoP) framework (Wenger, 1998) as the starting point to design our data collection protocols. While the anecdotal evidence from the authors' observations point to the program participants learning about the process of review and engineering education research through participation in the community of other mentors and mentees, the literature on community of practice also supports our decision to use it.

Wenger's model consists of four interdependent components – community, practice, meaning-making, and identity. In our program, we can see all four being manifest. We are trying to build a community of reviewers and AEs in the field of engineering education. The new reviewers engage in the practice of conducting educational research reviews and learn about both conducting educational research and paper reviews from more experienced AEs in the process. As they are learning the practice of educational research and conducting reviews, they are also developing an understanding of what educational research is or how to write effective reviews. Finally, these experiences lead to an identity shift (or development) in the mentees.

This framework has been previously used by researchers to explore how novices learn the intricacies of a new profession. For example, Cuddapah and Clayton (2011) have used it to show how new teachers, through interaction within a cohort of other new teachers, learn about the practice of teaching, meaning making in the profession, develop their identity as teachers, and eventually start belonging to the community of teachers through interactions and providing support. Similarly, Jimenez-Silva and Olson (2012) present findings from a study about how a teacher-learner community helps shape english-language teachers' beliefs and perceptions about english-language teaching. In terms of learning professional engineering work, Gibuena et al. (2015) demonstrate how interactions with the engineering design coach help students have a better understanding of professional skills in engineering and provide them with insights into how disciplinary and industrial communities of practice function - thus improving their professional engineering competence. More recently, and relevant to our work, Pitterson et al. (2020) the CoP framework to explore the development of new engineering education researchers through a training program.

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Proposed data collection

Guided by the CoP framework, we designed our data collection process to explore mentors' and mentees' development as reviewers and engineering education researchers. Data will be collected in the form of recordings of the meetings of the cohort, documents submitted by mentees on Canvas in the form of reflections and reviews and semi-structured interviews with mentors and mentees at the end of round 2 of the program. The recording and artefact data will be analyzed to understand how the participants engage in the four components of CoP - community, practice, meaning-making, and identity. Similarly, the interview protocol is designed to elicit participants' responses around these four components. Table 1 presents a selection of the proposed interview questions.

Table 1: Sample interview questions

Theme	Sample questions
Meaning making	• How would you describe a good review? Follow up: Has this understanding shifted through participating in the mentoring program (i.e., attending the sessions and conducting the reviews)? How? • What did this experience of participating in the mentoring program (i.e., attending the sessions and conducting the reviews) teach you about the purpose of review? How did you develop this understanding?
Practice	• Based on your learning from the mentoring program, how would you describe the role of the reviewer and the AE/editor? What led to you developing this understanding of your and editor's roles? • Is there something specific that you learned about the review process in education research? If yes, can you describe that? If no, can you tell me why?
Identity	• After this program, how do you see your role with respect to a paper that comes to you for review? • How do you see yourself as an engineering education researcher? How has the program helped shape the way you see yourself as an engineering education researcher?
Community	• How would you describe the connections that you made with your mentor, other mentees, and the organizers of this mentoring program? • What role do you believe that the community will play in your own EER career?

It should further be noted that this proposed study has been approved by the ethics committee at the North-West University in South Africa.

Conclusions

Anecdotal evidence from the first offering of the JEET mentored reviewer program suggests that besides providing the actual training for becoming better reviewers, the mentored reviewer program has been successful in building a broader research community. Several participants expressed how the reviewer training helped them to grow, not only as reviewers but also as authors and researchers. We expect that the results from the proposed future study will support this preliminary evidence and provide insights into the mechanisms that support the development of the community amongst this network of reviewers.

We believe that the findings of the study will make a valuable contribution to the peer-review process for academic journals in engineering education research. We anticipate the findings to reveal important characteristics of the journey of becoming an engineering education researcher and the role played by communities of practice. Furthermore, the findings from this study may also serve as the starting point for other journals to initiate similar programs to support their reviewers. Ultimately, we anticipate that this program and study will start to challenge many traditional review practices, provoking thinking that explores more

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collaborative approaches to creating and building engineering education research communities.

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Building Research Capabilities at the Intersection of Engineering Education, Systems Engineering, and Writing Studies

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ABSTRACT

CONTEXT

Since Borrego et al. first analysed collaborations between engineering faculty and social science researchers, engineering education doctoral programs have grown globally to build research capabilities. But even with these doctoral programs, engineering faculty continue to transition from technical to educational research through collaboration. Yet little recent work has examined how these collaborations contribute to engineering education capabilities.

PURPOSE OR GOAL

To explore the impacts of interdisciplinary collaboration on engineering education research capacity, this practice paper reports on an ongoing collaboration that involves researchers from systems engineering, writing studies/ rhetoric, and engineering education. Funded by the U.S. National Science Foundation under a program designed to build EER capacity, the collaboration centres on the ways embedded writing assignments build students' engineering identities. Using our collaboration as a case study, we examine how our exchange of theoretical frameworks, research methods, and prior literature has shaped our shared work and our identities as researchers to ask, "How does an interdisciplinary research collaboration contribute to the development of engineering education research capability?"

APPROACH OR METHODOLOGY/METHODS

We use Wenger's Communities of Practice (CoP) to capture the process of ongoing mutual engagement as we share knowledge, methods, and research interests across fields. Wenger's framework is particularly useful because it recognizes how newcomers do not simply conform to existing practices, but instead contribute to and reshape the community. Data includes meeting notes, paper drafts, and individual reflections.

ACTUAL OR ANTICIPATED OUTCOMES

Our work provides a contemporary understanding of the ways interdisciplinary collaborations expand engineering education research capabilities, not only through training new researchers but also through integrating new disciplinary perspectives that reshape the field through mutual engagement in joint enterprises. Our findings will help identify practices that support (or hinder) such collaboration.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Our experiences point to the ways in which developing research capability is not simply a one-directional process of training new researchers, but rather an ongoing dialogue that expands the capacities and identities of all collaborators. These findings echo and extend earlier work by highlighting the dialogic processes by which all collaborators build capacity. Even as the field has grown over the last decade and a half, with many new researchers coming up through engineering education doctoral programs, the field itself continues to shift and expand through interdisciplinary engagement beyond our disciplinary borders.

KEYWORDS

communities of practice, interdisciplinary collaboration

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Introduction

In their 2008 study of cross-disciplinary collaborations in engineering education, Borrego and Newswander (2008) identified the dominant model as one in which engineering faculty brought the problem (including "problem statement, context, and motivation" (p. 128) while the social science researcher "provide[d] structure by applying theory and methods relevant to the problem at hand" (p. 128). Using interdisciplinarity as a conceptual framework, the study examined the ways in which collaborations between engineers and social scientists led each collaborator to expand their understandings of world views and intellectual traditions as they learn from one another, though often that learning seemed to be primarily centred on the engineers learning theory and methods and the social scientists learning context. These findings echo a previous study in which Borrego (2007) found that engineers learning education research experienced significant conceptual difficulties in terms of the openness of research questions, the use of theoretical frameworks, the inclusion of qualitative methods, and the complexity of defining and measuring key constructs.

But much has changed since 2008. Though engineering education has a history dating back decades (e.g., the *Australasian Journal of Engineering Education* began publications in the mid-1990s, the *European Journal of Engineering Education* began in 1975, and the U.S.-based Journal of Engineering Education is now in its second century), the early 2000s marked a significant growth in the formalization of this research into its own "internationally connected field of inquiry" (Borrego & Bernhard, 2011, p. 14). While Jesiek et al. (2009) highlighted the lack of "a shared body of knowledge, standards of convincing evidence, and terminology" (p. 47) at the first REES conference (then called ICREE – International Conference on Engineering Education Research), the growth of theories, methods, and journals in the intervening years have moved us closer to a defined discipline than a generalized community. Perhaps most notably, while Borrego and Bernhard noted that in 2011 most engineering education researchers were trained as engineers, the growth of engineering education doctoral programs has rapidly increased the number of EER scholars with PhDs in engineering education; the Engineering Education Community Resource wiki (Carberry & Yasuhara, 2021) currently lists 30 doctoral programs around the world specifically in engineering education, with many more in STEM education broadly.

While doctoral programs have proliferated in ways that have structured – and possibly narrowed – the field's disciplinary identity, engineering faculty continue to transition into educational research, either as a complement to or a replacement for their technical research. Indeed, the U.S., the National Science Foundation's Research Initiation in Engineering Formation program (Engineering Education and Centers Division, 2020) is designed specifically to "[enable] engineering faculty who are renowned for teaching, mentoring, or leading educational reform efforts on their campus to develop expertise in conducting engineering education research" by conducting such research under the mentorship of experienced scholars. But although the late 2000s saw several studies on such cross-disciplinary collaborations, little work has emerged since then to consider how the development of the field has reshaped these collaboration and, perhaps even more importantly, how the collaborations continue to reshape the field. To that end, in this paper we report on the ways a recent cross-disciplinary collaboration supported with funding from the U.S. National Science Foundation has built capacity in engineering education research.

Background

The Project: WRI^{2}TES: Writing Education Initiating Identity Transformation in Engineering Students

Several years ago, the U.S. National Science Foundation launched a funding program called Research Initiation in Engineering Formation (RIEF) designed to build engineering education research capacity by pairing engineering faculty with an interest, but little or no experience, in

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the field with experienced researchers (Engineering Education and Centers Division, 2020). Teams of faculty that include the emerging researcher as Principal Investigator (PI) and at least one experienced educational researcher are invited to submit proposal for two-year projects; the proposals must include not only a description of the proposed research, but a detailed explanation of the mentoring plan through which the PI would learn key practices in engineering education research (e.g. research design, data collection, data analysis) and be introduced into the community (e.g. through conference attendance and manuscript publication). The expectations for the proposal suggest that the project is envisioned through a one-way transmission model: new researchers will be brought into the field by learning from more experienced colleagues.

In 2018, we began developing a proposal anchored in Francis' experiences of teaching writing in his advanced systems engineering courses and his previous collaborations with Riedner, who was then serving as director of the campus writing program. Paretti was invited into the project because reviews of a previous proposal submission strongly recommended adding a researcher with experience in engineering identity. The project seeks to understand how writing assignments help engineering students develop their identities as engineers, particularly in terms of enacting and justifying engineering judgement. Using artifact-based semi-structured interviews, the study employs thematic analysis to understand how students' experiences of writing throughout a project intersect with instances of engineering judgement (i.e. places in which students had to make decisions about project scope, direction, options, designs, etc. for which there was no single right answer) and their perception of themselves as engineers. The initial design of the study was grounded in Gee's (2000) framework for identity in educational research, Tonso's (2006a, 2006b) use of cultural production theory to understand identity, and Lea and Street's academic literacy approach (1998, 2006).

Our team brings together researchers from three diverse fields that all include human-subject research, though with varying methodological approaches. We share an interest in the relationship between writing and identity, but bring diverse expectations and perspectives to this issue:

- Francis was trained in civil and environmental engineering, and engineering and public policy. He primarily has experience in quantitative research through experiences in infrastructure systems risk analysis. Recently, his research has explored infrastructure and risk management using qualitative methods, in addition to the engineering education research described in this paper.
- Riedner was trained in rhetoric and composition with a focus on writing in the disciplines pedagogy. She also has an interdisciplinary background in the humanities with expertise in women's, gender, and sexuality studies. She is an interdisciplinary research with publications in writing studies and in feminist rhetorics. Her publications explore how public discourse and disciplinary discourse shapes student learning.
- Paretti's training includes an undergraduate engineering degree and graduate degrees in English (including work in writing studies and identity). She is a qualitative researcher who came into engineering education through research on the teaching and learning of writing in engineering. Grounded in situated learning theories, her work includes research on engineering communication in school and at work as well as on engineering identities in both contexts.

The team has been meeting biweekly for the past two years – primarily virtually since Paretti is at a different university, but we have had two in-person meetings as well (one prior to the pandemic and one in early summer 2021). Francis has also been a regular virtual participant in Paretti's research group, reading and commenting on the work of other emerging engineering education researchers as well as sharing his own work in progress. The team collectively developed an interview protocol, and Francis has conducted 11 interviews with participants. To date, the team has presented findings at two engineering education conferences, one National Science Foundation PI meeting, and writing in STEM community of practice meetings at Francis and Riedner's institution.

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Conceptual Framework: Communities of Practice

To explore our collaboration systematically, we ground this discussion in Wenger's concept of learning as joining a community of practice (Wenger, 1998). In Wenger's terms, a community of practice (CoP), is not simply an group of individuals, but rather a group engaged in a *joint enterprise* characterized by *mutual engagement* and a *shared repertoire*. The joint enterprise refers to the larger set of goals, negotiated among participants, shaped by the context, and supportive of mutual accountability. For example, in an academic field, the joint enterprise is the set of concerns and questions that shape and drive the field. In a given research project, it is the overall research goal and specific questions the team seeks to address. Mutual engagement refers to the ways in which the community members interact as they pursue that enterprise, reflecting a high degree of interdependence and ongoing interaction as individuals negotiate their work together. At the field level, it includes interactions at conferences as well as ongoing dialogue through journals; in a project, it includes both the regular meetings among researchers as well as the joint productions of papers and articles for those conferences and journals. Finally, the shared repertoire refers to individual actions and practices as well as tools, concepts, stories, and language that individuals use to engage with each other. In research at both the field and project level, this repertoire includes methods of inquiry and theoretical frameworks, as well as the larger epistemological world views that guide our work both as a field and within a given project.

In this context, learning is not acquiring knowledge in one place and transferring it to another. Instead, it is a process characterized by *legitimate peripheral participation* in a community of practice (Johri, 2011; Johri et al., 2014; Newstetter & Svinicki, 2014; Wenger, 1998). That is, learning happens as new members engage in the authentic work of a given CoP, coming to understand the enterprise, interacting with other members of the community, and learning the shared repertoire. Such learning that implicitly undergirds NSF's RIEF program in the U.S.; the mentoring plans required by the program solicitation require, in fact, that the research team detail the ways in which the new researcher will be brought into the engineering education research community.

Two other facets of Wenger's framework are relevant to our exploration of capacity building. First, Wenger frames learning not simply as the acquisition of knowledge, skills, and abilities – i.e. learning to *do* engineering education research - but a matter of identity – *becoming* an engineering education researcher. Second, CoPs are not static. Instead, the nature of the enterprise, the forms of engagement, and the repertoire are continually renegotiated in practice among community members – including the new members. New researchers, that is, do not simply absorb research goals, methods, frameworks, or epistemologies from engineering education. They also bring goals, methods, and frameworks from their home fields, their prior research, their scholarly identities, and their classroom experiences. This continual renegotiation among all community members makes the process of building capacity more than simply adding new researchers to a reified field and offers ways to expand and redefine the field itself.

While recent research on capacity building in engineering education is scarce, several other scholars have drawn on CoP in this context. Following the first REES (ICREE) conference, Jesiek et al. (2009) explored participants conceptions of engineering education through the lenses of discipline, CoP, and field, with "emerging field" as the more common and neutral term. Engineering education scholars have also drawn on Wenger et al.'s ((2011) value creation framework to examine what an engineering education research initiative brings to an engineering school (Williams & Carvalho, 2011). Wenger et al. identify five types of value created In related work, Berthoud and Gilester used the value creation framework to explore the impacts of a multi-university network focused on teaching and learning in particular technical domain. Such studies

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demonstrate the ways in which the concept of value creation can be used to explore larger-scale impact of CoPs. In this practice paper, in contrast, we are interested in learning and the transformations that are occurring within our communities and within our identities as scholars and educators, and the potential implications of such transformations for capacity building in engineering education research.

Findings

This section begins with a reflection from each author describing their experiences of learning in this project, then uses CoP to synthesize the ways in which our experiences collectively have helped reshape our conceptions of engineering education research and our identities as researchers to build capacity in the field.

Francis

This collaboration with Rachel and Marie has changed my perception both of engineering education and 'technical' engineering research by giving me the opportunity to gain some familiarity with qualitative research design. As a scholar of infrastructure resilience, I was often frustrated by the focus on mathematical modeling of the cyber-physical systems when it seemed to me that the main factor influencing a system's resilience was the network of human stakeholders interacting through it. This network, in my opinion, could only be effectively studied using qualitative and mixed-methods designs, and while I believe two of my PhD students successfully learned these methods, I always looked on from the outside. This collaboration—and the engineering education literature more broadly—opened my eyes to a range of research designs and methodological perspectives that seemed immensely useful in that space, including phenomenology, grounded theory, and thematic analysis.

More importantly, this collaboration has helped me to more patiently look into my own frustrations and misunderstandings when interacting with my students in the classroom. Often, the disconnects I experience with them partly arise from the ways I've designed my course objectives, classroom activities, assignments and projects, or a combination of all of those. Through the intentional engagement with the engineering education literature, I've become aware of the many avenues I could begin to seek insight into my classroom practices through this body of scholarship, while also contributing my own insights by carefully designing my own inquiry into my failures.

Finally, this collaboration has set me along a path of understanding the range of ways students come to identify with engineering through their undergraduate education. This has led me to wonder how we can best strengthen students' professional judgment, as some of my conversations with students have led me to believe that the development of engineering judgment is closely related with students' professional identities. Both Riedner and Paretti have extensive experience with identity theories and have guided me patiently through an initiation to this space. I have also learned from them how writing can be useful in engaging students at the intersection between identity and judgment, and their expertise in writing scholarship has helped me immensely through this project and in revising my classroom approaches.

Riedner

As a writing scholar and former director of a writing in the disciplines program, I came to this project with an interest in understanding how threshold concepts from writing studies can enhance student learning in engineering fields. I've worked with faculty across disciplines who find that introducing concepts from writing studies and honed classroom practices from this field into their curriculum enhances student learning. In my experience, faculty find that focus on the writing process can improve student writing, and attention to threshold concepts from writing studies (i.e. genre, audience) improves student learning and success (Anderson et al. 2017). Moreover, in my experience working with STEM faculty, qualitative research on student writing enables faculty to understand and develop effective assignment design that meets their curricular goals. This focus is particularly important in engineering where writing assignments can guide students towards developing disciplinary and professional judgement.

This NSF funded collaboration with Royce and Marie enabled me to expand my understanding of how assignment design in systems engineering that introduces students to disciplinary genres can begin the process of students learning professional judgement. Discussing scaffolded assignments with Royce that guide students through complex decision-making process, has helped me understand how writing assignments are means for students to practice and articulate professional judgement. The role of writing feedback (both learning to give good feedback and learning to judiciously incorporate feedback), enables me to understand how writing scholarship on peer review can benefit engineering pedagogy, but also to understand how engineering's focus on judgement opens up new horizons for writing pedagogy. Marie's expertise in engineering education has opened up my understanding of research and scholarship on the transition from university to professional work in STEM fields. Marie's discussion of research in engineering in this area has helped me understand how to prepare engineering students for post-graduate work (Winsor 1996).

Collaboration with Royce and Marie has expanded my understanding of how different disciplines approach student learning and how writing studies scholarship can expand this learning. My collaborators have also expanded my understanding of discursive constructions of disciplinary identity in engineering that has opened up new areas of inquiry and new areas for research.

Paretti

Although I entered this project as the "engineering education research mentor," it has also been a significant learning experience in two particular dimensions: conceptions of engineering judgement and re-engagement with writing studies. First, talking and writing about the question of engineering judgement have reshaped my understanding of what the terms means and how it can be enacted in discourse. Although I'd begun thinking about decision-making among engineers in a previous project, my definitions and understanding of the term were naïve and simplified. But as the three of us collaborated on a recent literature review paper and Royce brought in a range of studies about the concept of professional judgement, I began to understand more and more about the complexity of decision-making through systems engineering and cognition. For example, while engineering education researchers talk about close-ended problems as highly constrained with a single solution path and solution, closed-looped decision is characterized by the presence of feedback, uncertainty, ambiguity, and conflicting objectives. Thus open-ended problems such as those seen in industry involved closed-loop decision making. The role of feedback, in particular, has reshaped much of my thinking about how engineering students do, and might, learn to develop the judgement needed for making decisions in professional, open-ended contexts and created not only new avenues for research, but potentially new frameworks for exploring salient research questions.

Second, though I have background in writing studies, much of my recent work in this space has centered only on engineering students and the transition to professional work. discussions surrounding our analysis of the interview data have not only re-engaged me with the broader field of writing studies, but also helped me re-think the relationship between writing and identity through a closer examination of authorial stance. The kind of dramaturgical (Miles et al., 2014) and thematic coding we have been working on together, as well as number of sources introduced or re-introduced to me through Rachel's work, in particular, have challenged me to look beyond a familiar set of frameworks to see where current research in writing studies is taking the field as well as how strands of research from other related fields inform what we do. This mutual engagement has also pushed me to think again about the ways in which close readings of texts reveal the ways in which authors position themselves relative to their work and their fields. Dramaturgical coding, in particular,

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though detailed in a common methods reference for engineering education research (Miles et al., 2014), is not widely used in the field and offers potentially interesting avenues for re-examining discursive constructions of identity not only in terms of engineering judgement, but in terms of a full range of engineering practices.

Both of these transformations have involved not simply new knowledge, but shifts in my own identity as an engineering education researcher, expanding my focus, re-establishing connections to the community of writing researchers and opening doors into new segments of that broad field.

A Negotiated Community of Practice

Across the experiences of the three authors, our mutual engagement with one another over the course of this project has markedly shifted both the joint enterprise and the shared repertoire of our work. Both the research questions and underlying constructs (i.e. what we mean by engineering judgement, identity, writing, discourse) have been continually negotiated and redefined as we each brought literature from different fields to the group for shared reading and learning as we collect, analyze, and interpret the data. The processes of both writing the literature review paper and analyzing the interview transcripts through multiple lenses have not simply enculturated Francis into "engineering education ways of doing things." Rather, the synthesis of literature from a wide range of fields, the negotiation of codebooks as well as application of codes, and the processes of constructing meaning by bringing the literature and the coding into dialogue with one another to support the process of making meaning have all contributed to the ways in which we understand this joint research enterprise and the repertoire of terms, frameworks, and methods relevant to this and future studies. And these shifts, in turn, have shaped our own identities as scholars – in engineering education, but also in engineering and in writing studies. We have seen our individual and our shared work through new eyes, with new research questions and new research frameworks that we can now bring not only to this project, but to future projects inside and beyond engineering education.

Implications and Conclusions

More than a decade ago, Borrego et al. characterized collaborations between technical engineering and social science scholars as a process in which the engineers brought the problems and the social scientists brought the methods and frameworks. New engineering education researchers thus learned the research practices of the field, while established education researchers developed deeper understandings of the context and the nuances of engineering teaching and practice. In our collaboration, the process has been far more complex. At the heart of this complexity has been a rich and varied practice of mutual engagement in which we have engaged in practices that support joint learning and ongoing negotiation of the research project itself, including

- explicitly discussing our epistemological background and perspectives, looking at points of convergence and divergence to better understand both one another and the nature of the research questions at hand;
- reading and engaging meaningfully with prior research from one another's fields;
- maintaining openness to ways of analyzing data, including attending to both alternate methods and alternate frameworks for addressing the research questions
- testing out varying methods and frameworks in different conference papers, including conferences in both engineering education and writing studies;
- discussing research design and preliminary results with other writing-in-STEM researchers in a learning community to better understand the breadth of potential uses of our chosen frameworks in other fields.

The results of these practices has helped to build engineering education capacity in multiple ways, expanding not only who does this work (including Francis and Riedner), but also, for all three authors, what the work is and how we might ask and answer questions in ways that

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contribute to the practice of engineering education and expand our knowledge of what engineers do and how they learn to do it. In our experiences as a community of practice, the transformations moved well beyond Francis and Riedner learning “engineering education research methods” and Paretti learning “classroom problems.” Instead, our collaborative work has helped redefine for each of us what engineering education research is, how we do it, and how we understand our own relationships to it.

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Colonial Antecedents Influencing the Current Training and Practice of STEM Educators in Sub-Saharan Africa

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ABSTRACT

CONTEXT
Since the 1950s, a period known for the mass decolonization of Africa, thousands of policy documents, philosophy papers, and strategic plans have been published to map out a path for independent states' approaches to sustainable national development (Birmingham, 1996; Welz, 2021). The common narrative is that education goals and the training of educators need to be aligned to individual national priorities for sustainable development (Kivunja, 2017). This objective is perhaps best illustrated through the steps taken to capitalize on the affordances of technical and vocational education and training (TVET) and science, technology, engineering, and mathematics (STEM) education.

GOAL
The overarching goal of this paper is to use a postcolonial lens to identify antecedent factors influencing the current form of STEM teacher education in sub-Saharan Africa (SSA). Understanding these factors and the ways that they overtly or covertly influence current forms of teacher education and practice is crucial if sub-Saharan African countries are to succeed in their efforts to achieve their sustainable national goals. Specifically, in this work-in-progress paper, we ask "*what are the antecedent factors that influence the current approach to STEM teacher training and practice in sub-Saharan Africa?"*

METHODOLOGY
To answer our research question, we conducted an extensive review of the literature surrounding postcolonial education in sub-Saharan Africa. Over 60 documents were included in our review, spanning several disciplines including history, philosophy, psychology, social sciences, and engineering education. We performed a thematic analysis to identify factors that authors had identified in over 7 decades of postcolonial research. To report our findings, we employed a sociological framework that identified micro-, meso-, and macro-level factors using structural-functionalism, interactionism, and conflict theory.

OUTCOMES
The review is still a work-in-progress. However, the findings thus far have identified major colonial antecedents that still influence the training, certification, and teaching practices of STEM educators in SSA today. These include (1) using colonial language fluency as a measure of meritocracy, (2) reifying professional expectations that are colonially subservient, (3) normative deidentification of culture, (4) hegemonizing indigenous knowledge and culturally relevant teaching, (5) reclaiming student-centered teaching as a posited alternative to the religious history of teacher-centered pedagogy, and (6) deconstructing the notion that the scientific method is an irrefutable, universal, legitimate way of knowing.

CONCLUSIONS
We emphasize that a review of the pre-, and post-colonial forms of STEM education as it relates to teacher training and practice unearths exciting findings: cultural values that have a rich history, pedagogical techniques that were learner-centered, pedagogical tools that served as cultural mediators, and an African indigenous knowledge that predates the introduction of western scientific thoughts. This paper seeks to contribute scholarship that will enable stakeholders to rethink their ways of knowing, doing, practicing, and sustaining STEM education in SSA

KEYWORDS
Postcolonial, STEM teacher training, Sub-Saharan Africa

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Introduction

"Those who do not know (their) history are bound to repeat it." (Santayana, 1905, p. 284)
This paper is a contribution to a series of studies that argue that developing the teaching and research capabilities of educators in sub-Saharan Africa is one of the most effective ways of improving the state of education, and indirectly, the quality of life of Sub-Saharan African citizens (Johnson et al., 2000; Lan & Kisjes, 2014). In a previous literature review, the authors posited that effective teacher development requires an intricate understanding of the current state of science, technology, and engineering education, practice, and research in the subcontinent (Olayemi et al., 2021). Our previous study investigated the modalities and impacts of various programmatic interventions for developing the competency of STEM teachers in SSA. This study ushers the conversation forward by taking a step back to recognize the history behind current practices that are characteristic of the sub-Saharan STEM education landscape. We expand on the rationale for this study in the following sub-section.

Education in Sub-Saharan Africa

The history of education in SSA is a checkered one; glorious on one end with records of advances that assert that this was home to some of humanity's earliest known civilizations (Chu & Skinner, 1990), marred on the other with the realities of and consequences associated with western colonialization (Mosweunyane, 2013). We argue that the history of education has a significant role to play in the development of any civilization. Engineering and technology feats that shaped civilization and continue to do so today are tied very closely to the system of education of the time (Pacey & Bray, 2021). These connections have been extensively discussed in other studies. In this study, we are curious about the history of science and engineering education in SSA, particularly the ways that current forms of teacher development have their roots in colonial and neocolonial practices and objectives. There is perhaps no better space to investigate these antecedents than in STEM education. As the bulk of SSA moves gradually into the realm of self-directed and sustainable national development, we recognize the value of producing scholarship that enables stakeholders (policymakers, thinkers, teachers, students) to rethink their ways of knowing, doing, practicing, and sustaining STEM education in SSA.

The Postcolonial Lens

The connotation of postcolonialism is most frequently used to describe a period "beyond" the events of colonialism and imperialism (Ivison, 2020). Oftentimes, the goal of reviewing events, actions, and processes through a postcolonial lens is to illuminate the aftermath of colonialism. However, several studies have nuanced this definition as being misleadingly simplistic because it supposes that the legacy of colonialism has been surpassed (Huggan, 1993; Shohat, 1992). Shohat (1992), for example, problematizes the term along spatial and temporal dimensions, arguing that it fails to hold the same meaning across different contexts and cultures even within the same subcontinent (e.g., for Nigeria, South Africa, and Sudan). According to the author, while colonialism and the new forms of colonialism (neocolonialism) impose dichotomies, the term postcolonial is characterized by an ambivalence that posits simultaneously close and distant relations to the "colonial" (1992, p. 107). This structural ambivalence served as a helpful lens through which this study was conducted. We recognized in our review of articles centered around postcolonial education in Sub-Saharan Africa that there is no consensus about the definitions of pre-, post-, and neo-colonial practices. Thus, we defined pre-colonial as activities that preceded colonialization and postcolonial as the activities that happened during colonization and existed afterward.

Research Question

The research question motivating this literature review is as follows: what are the antecedent factors that influence the current approach to STEM teacher training and practice in sub-Saharan Africa?

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Methods

Literature Search

We conducted a systematic search of four electronic databases – Education Source, ERIC (EBSCO interface), Professional Development Collection, and PsycINFO between December 2020 and March 2021.

Search String: (STEM education OR science OR technology OR engineering OR mathematics) AND (Sub Saharan Africa OR sub-Saharan Africa OR sub-Sahara OR sub-Sahara or SSA) AND (educators OR instructors OR teachers) AND (training OR education OR development OR learning) AND (postcolonial OR neocolonial OR colonial)

We also conducted a follow-up manual search using Google Scholar and ProQuest in April 2021 using keywords such as colonial education, sub-Saharan Africa, and STEM teachers.

Inclusion and Exclusion Strategy

Our strategy for including articles in this study started with an initial assessment of the title and abstracts of the articles. Articles that fit the scope of the study as agreed by author one were listed for discussion with author 2. The authors met early on to discuss the alignment of the articles with the research agenda. Articles that did not have clear abstracts and titles were marked for full-text screening. To meet the criteria for inclusion in this review, articles were required to: (1) have a subject matter of STEM and TVET education in a post-, neo-, or pre-colonial frame; (2) be published in English language; (3) be available in abstract form; (4) be accessible in full-text version. To fit within the scope of this paper, we added an additional criterion of papers that have a subject matter of African education in a post-, neo-, or pre-colonial frame. This literature review followed the procedural guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Moher et al., 2009).

Data Extraction

We created a template to report the data extracted from the articles. Each article had separate columns for authors' names, paper titles, research questions, and methodology. We also created additional columns to report the main ideas of each article, cross-references to other articles in this review/articles outside of this review, relevant quotations from the articles, and comments that we as a team of researchers made as we carried out our review.

Quality Appraisal

The heterogeneous nature of the articles included in this review presented a challenge of quality appraisal. In this article, we were most concerned with reducing as much as possible any bias related to selective outcome reporting (Borrego et al., 2014). The research team engaged in regular meetings to address the alignment of the findings we were drawing from the articles with the original authors' intentions. Being a work-in-progress paper, our future goal is to use the Scale for the Assessment of Narrative Review Articles (Baethge et al., 2019) to evaluate the quality of the articles included in this review. This scale assesses the quality of articles using the following criteria: justification of article's importance to readers, statement of concrete aims/formulated questions, description of literature search, referencing, empirical reasoning, and presentation of data.

Results

Literature Search

In total, our initial search strings yielded 889 records [Education Source (885), ERIC (4), Professional Development Collection (312), and PsycINFO (4)] between December 2020 and March 2021. We also conducted a follow-up manual search using Google Scholar and ProQuest in April 2021. Using manual search with more targeted key words, we added 5 records to the total number. The first stage of screening focused on identifying articles that fit the scope of the research (see 4 criteria above) based on titles and abstracts. This screening stage left the research team with 71 records. Using our inclusion and exclusion criteria, in particular relevance to STEM/TVET, we were able to scope down the list of articles to 48.

Findings

We reviewed the selected articles by referring to the research question shaping this literature review (Borrego et al., 2014). The review is still a work-in-progress. So far, we have identified major colonial antecedents that still influence the training and certification of STEM educators in SSA today. To report the findings of this literature review, we debated the merits and demerits of different sociological perspectives. No single framework seemed perfectly adequate. From a structural-functionalism perspective using a sociological framework (Kuh et al., 2006), it was helpful to categorize the findings based on the roles that social institutions like the respective national governments of SSAn countries, education systems, community structures, religions, and local economies played. However, using this macro-level lens involved trading off the sensitivity associated with demarcating between the manifest and latent functions of these social institutions as they vied for the control of local, economic, and human resources known to be extant (China in Africa: The New Colonialism?, 2018; Plange, 1984; Schmidt, 2013). Conversely, while we attempted to analyze and report our findings from a micro-level interactionist perspective, we noticed that social institutions and structural constraints which were so prominent in the first analytical frame became less so in the second. Exclusively focusing on the meso-level helped us identify how the competition for economic, political, and human resources shaped not only the interests of colonial powers but also those of the local actors who continue to negotiate conditions in a post- or neocolonial era. Rather than constrain the reporting of our findings to a particular perspective, we opted instead to report on all three, using micro-, meso-, and macro-level lenses, identifying “structures of relationships linking social actors” (Marsden 2004, p. 2727).

At the micro-level, we focused first on the actions of and interactions between “the African” and “the African”. Next, we focused on the interactions between “the African” and “the Other”. We operationalized “the other” as actors that were outside the African context. At the meso-level, we identified the interactions between “the African” and “the field”, the “field” being Science, Technology, Engineering, and Math disciplines. These interactions manifested specifically in terms of how STEM teachers were taught, trained, or led to reconceptualize what “professionalism” looks like in their field. From an interactionist perspective, the field is continually shaping the identities of STEM teachers, and they in turn shape the identity of the field. The narrative that follows considers both the interests of colonial powers and the local actors who continue to negotiate conditions in a post- or neocolonial era, between citizens and their educational systems or political governments. Finally, at the macro-level, we categorized the findings of this literature review as interactions between complex social systems and structural apparatuses like education systems, national interests as reflected in education policies, and STEM workforce globalization efforts.

To address the theme of this conference, “Engineering Education Research Capability Development”, and fit within the limited scope, we present our findings only on the second and third units of analyses (micro-level interactions between the “African” and the “other” and meso-level interactions between the “African” and the “field”).

Discussion

Micro-level Unit of Analysis: Interactions between the African and the Other

In this conference paper, first, we focus on the actions of and interactions between “the African” and “the Other”. Many authors described the advent of colonial rule and the events that followed with respect to the African’s interactions with others. This lens explores the nature of interaction between the African STEM teachers and their non-African peers. It explores the nature of the relationship between STEM teachers and their non-African trainers. It unveils the steps taken to develop autonomy, agency, and professional legitimacy in reference to others outside sub-Saharan African contexts. The main factors that surfaced from the literature review under the micro-level analysis of the interactions between “the African” and “the Other” are Scholarship, Content, Mentorship, and Professionalism (Table 1).

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Table 1: Table of findings (factors in the colored cells are not discussed in this article)

Analysis level	Actors	Factors	Precolonial	Postcolonial	Discussion points
Interactions at the individual level (micro)	The African and The African	Philosophy	Community-based, values and respect	Individualistic, competitive	Cultural values & character as contents, social utility as objective, Western competitive individualism versus African cooperative communalism, Axiology versus epistemology.
		Structure	Gender-based	Gender-based	Differential treatment of boys and girls in both pre and post.
		Curriculum	Served the ethnic majority	Served the colonialists	Curriculum as a reflection of the needs of the dominant group, Language as a reifying form of epistemic and political power.
		Pedagogy	Student-centered	Teacher-centered	Mutual respect between teacher & student in pre-, student subjugation & corporal punishment evident in postcolonial education, Power differential between teacher and student in both.
		Metrics for merit & success	Intrinsic, character, practical (handwork)	Extrinsic, language fluency, rote memorization & recall, (bookwork)	Cognitive achievement as substandard to affective achievement? Revisiting neocolonial structures and practices like western-style high-stakes/standardized tests, Colonial language fluency as a measure of meritocracy, External indicators as rubrics of successful STEM teaching.
	The African and The Other	Scholarship	African indigenous knowledge	Western empirical thought	Western ways of knowing, western culture as examples, rote memorization & recall.
		Content	Contextually relevant	Misaligned with local context	Are indigenous knowledge and culturally relevant teaching being hegemonized? Did colonial education intentionally exclude critical thinking?
		Mentorship	Culturally-consonant apprenticeship	Racially incongruent mentorship	Recognizing implicit assumptions, beliefs, and biases about knowledge (double image), Racially incongruent mentorship as reimagining colonialism.
		Professionalism	Embedded in everyday life, recognized by the community	Distinct, demonstrated by an ability to “stand out”	Recognizing professional expectations that are colonially subservient, Deconstructing claims of the teaching profession being white normative.

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Interactions at the disciplinary level (meso)	The African and the Field	Method of inquiry	Observation of natural environment	Scientific empiricism	Challenging the irrefutability, universality of the Scientific Method, African indigenous observation and understanding of natural environment predating the introduction of western scientific thought.
		Professional expectations	Culturally mediated, teachers as custodians of cultural knowledge	Approved by a separate board, demonstrated through colonially subservient expectations	Normative deidentification of culture, Hegemonizing indigenous knowledge and culturally relevant teaching, Recognizing professional expectations that are colonially subservient, Deconstructing claims of the teaching profession being white normative, External indicators as rubrics of success, STEM language fluency, and paper authorship as new metrics of professionalism
		Pedagogical structure	Active, situated learning, practical, Apprenticeship	Classroom-based, theoretical, memorize, recall	Reclaiming active learning as the mode of African education, Relocating the restrictions that learning only takes place in the classroom, Revisiting the dialectical debate of bookwork versus handwork
		Pedagogical tools	Cultural mediators	Western concepts	Codeswitching; Local metaphors as pedagogical tools for postcolonial STEM education (Probyn, 2006)
Interactions at the National level (macro)	Social Institutions	National development	Localized, community-based	Reliant on external aid	From forced migration to voluntary immigration); External aid as neocolonial structures that benefit expatriate STEM teacher trainers and western private companies

Several articles in this review discussed the difference between precolonial STEM education and western ways of knowing, how postcolonial STEM education became tied to western culture, and how “the African” responded to this new way of learning from “the other”. School content was differentiated for boys and girls in ways that served the economic goals of the colonialist. Postcolonial curriculum contents were based on examples that Africans could not resonate with (Dei Ofori-Attah, 2006). For example, a study designed around a first-year astronomy course in a South African university found that most black students in the course struggled to reconcile the content with their spiritual and epistemological backgrounds (Cameron, 2019). Through this action, indigenous knowledge was initially excluded, the justification being that there was a lack of scholarship (Anthony-Stevens & Matsaw Jr, 2020).

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Meso-level Unit of Analysis: Interactions between the African and the Field

Some of the main factors that surfaced from the literature review under the meso-level analysis of the interactions between the African and the field are listed in the table below. Several articles included in this review posit that the African way of knowing, interacting with, and experiencing the world predated colonialism (Boaventura de Sousa Santos, 2014; Fomunyam, 2017; Woolman, 2001); we highlight this thematic finding in order to problematize it and illustrate potentially persistent colonial mindsets in engineering education scholarship Through the postcolonial lens, we also find a fundamental difference between the philosophies of education. This begins first by revisiting the notion that culture, values, and character were the contents of African education before colonialism (Assie-Lumumba, 2012). Epistemology in itself was valid as long as it fit into the axiological views of the community (Higgs, 2008). However, with the advent of colonialism, some authors described the differences as the intentional marginalization of African indigenous thought, the battle of western competitive individualism versus African cooperative communalism (Khalifa et al., 2014; Woolman, 2001), and challenging the notion that the scientific method is a universal, irrefutable way of knowing. Using our review, we trace the influence of colonialism, the introduction of western thought, and the postcolonial effects of negotiating identities as STEM teachers in SSA.

African indigenous observation was a critical way of interacting with and understanding the natural environment. Many authors argued that this way of knowing predated the introduction of western scientific thought (see Boaventura de Sousa Santos, 2014; Gates & Davis, 2001; Khumalo & Baloyi, 2017; Woolman, 2001). Their argument entertains historical evidence which shows that this was home to some of the world's earliest civilizations and the world's oldest university (Assie-Lumumba, 2012). The objective of education, however, was to serve a social utility function. The mode of education was by active learning, being immersed in the context, and being mentored by learned others who were often experienced in the culture, education, practices, and history of the community (Marom, 2019). In this guise, teachers were seen as custodians of cultural and traditional knowledge, and teaching was seen as a way of ensuring the continuity of culture and community (Assie-Lumumba, 2012). Furthermore, teaching was not restricted to the school environment. Because the community was so integrally connected to the means of education, a child could learn from any experienced elder.

Western ways of knowing brought distinctions between the actors of education (Woolman, 2001). The teacher had a specific role and a place in the classroom. That role was to serve as the creator, transmitter, and assessor of acquired knowledge. That place was in the front of the classroom. Primarily, empiricism served as the foundation for scientific thought. Rationality and logic were elevated above cultural values. Further, western competitive individualism began to hedge out African cooperative communalism (Khalifa et al., 2014). Progenitors of the colonial form of education argued that there were no literary texts to celebrate African STEM. Directly and indirectly, the field took shape as one that marginalized indigenous knowledge and culturally relevant teaching. Many papers that made it into this review argue that actors in STEM fields in postcolonial contexts need to challenge the notion that the scientific method is a universal irrefutable way of knowing (Anthony-Stevens & Matsaw Jr, 2020; Fataar, 2018; Ryan, 2008; Ziegler & Lehner, 2018). Learning in African contexts should be re-centered on the African but not to the complete exclusion of other ways of knowing.

Like every field, STEM has its language, one that oftentimes appears invisible for those who are deep in the field. Actors within the field demonstrate their mastery through their command of the language. This was the case when it came to training STEM teachers. Command of theory was considered superior to practice. Through these actions, successful teachers were judged as those who could demonstrate command of the STEM language. In a sense, bookwork was again considered superior to handwork. Slowly but surely, the demarcations became more apparent – external indicators came to be reckoned as the rubrics of successful STEM teaching (Khalifa et al., 2014). Teachers demonstrated their professionalism through the ways they spoke, dressed, and acted (Marom, 2019). By talking in the language and by acting more like the colonialists, the African could be distinguished

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from their peer. Language was still a reifying form of epistemic power. And by changing the way teachers appeared in the class, there ensued a normative deidentification by appearance (Marom, 2019). It suggested to African STEM teachers that the teaching profession was white normative. In a way, not only was school a social and physical representation of the distinction between the weak student and the strong, the same could be said of trainee teachers who wanted to make it in the field as professional teachers (Domínguez, 2019; Johnson et al., 2000; Martin & Pirbhai-Illich, 2016). These professional expectations, we thematically surmised, were colonially subservient.
Many papers that made it into this review still problematized these historical antecedents to the current professional STEM teaching practice. STEM trainee teachers are still trained to master content that is not culturally relevant (Marom, 2019), conditioned to view their African peers as competition who stood in their way of getting coveted resources that come with job security and promotion (Tabulawa, 2013), and judged on their ability to memorize and transmit as much knowledge as they can (Williams & Grierson, 2016). Pedagogically speaking, teacher-centered class control is seen as evidence of classroom management (Mogari, 2017). The teacher is expected to demonstrate professionalism at all times, sometimes through their ability to remain objective, rational, and uninvolved in student affairs (Marom, 2019); at other times, through their command of English, Latin, and whatever language showed that they were scholars. Promotion is still based on external indicators which serve as the rubrics for successful teachers, such as high student scores in external examinations (Banya, 2005), and the ability to demonstrate command of western thinking by engaging in scientific thought and publishing findings in a language that their African peers do not understand but their academic peers in the field do (Brock-Utne, 2016; Mchombo, 2016).

Limitations

The limitations of this paper are intrinsically connected to the chosen methodology. This paper is not representative of the whole sub-Saharan African context, a complex tapestry of over 2000 different spoken languages and unique cultures just as diverse. A critical review will reveal that we did not report our findings by regions or by countries of historical colonial influence (e.g., British, French, German, Portuguese, Spanish, Italian). We remind readers of the fact that this paper fails to capture articles, documents, or policy papers that were published in languages other than English language, a limitation that continues to surface in our scholarship. Furthermore, as a work-in-progress paper, we do not report the results of quality assessment of the articles as prescribed in the SANRA process.

Conclusion

In this paper, our goal was not to merely criticize the influence of western education on the training and practice of STEM educators in SSA or provide a silver bullet solution that would serve as an alternative to current practices. Our goal was to identify colonial factors that have historically influenced the training and practice of STEM educators in the sub-Saharan African context and continue to do so today, sometimes unbeknown to the populace. We argue that understanding how current practices and approaches to STEM teacher education and practice came to be is crucial in the ongoing efforts to achieve sustainable self-directed indigenous education. Using a postcolonial lens, we reviewed over 60 articles in this study and categorized our findings by identifying micro, meso, and macro-level factors. While our review categorizes the overall findings on four levels, in this work-in-progress paper, we discussed only (micro-level interactions between “the African” and the “other” and meso-level interactions between “the African” and “the field”). We emphasize that a review of the pre-, and post-colonial forms of STEM education as it relates to teacher training and practice unearths exciting findings: cultural values that have a rich history, pedagogical techniques that were learner-centered, pedagogical tools that served as cultural mediators, and an African indigenous knowledge that predates the introduction of western scientific thoughts. This paper seeks to contribute scholarship that will enable stakeholders to rethink their ways of knowing, doing, practicing, and sustaining STEM education in SSA.

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Peering into the Black Box of Peer Review: From the Perspective of Editors

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ABSTRACT

CONTEXT

The peer review process plays a critical role in ensuring the quality of work published within a field and advancing the knowledge within the research community. However, for many members of the community, the process of peer review largely remains a black box to many scholars, especially those with less experience within the community. Therefore, there is a need to illuminate the peer review process for the research community.

PURPOSE OR GOAL

To more transparently reveal the contents of the black box around the peer review process, we interviewed editors (associate and deputy editors) for the Journal of Engineering Education (JEE) to provide editor perspectives on the overall peer review process. The goal of this paper is to clearly articulate the behind-the-scenes processes of peer review as well as the expectations and perceptions of the editors with respect to publishing within JEE. By bringing these processes to light, we hope that more members of the field will be aware of the overall process and the associated expectations for contributing to the field.

APPROACH OR METHODOLOGY/METHODS

To meet the goals of this study, we conducted semi-structured interviews with six editors of JEE who worked in the field of engineering education research (EER), as a part of a larger project exploring the boundaries of the field as expressed within the peer reviews process. The interviewer from the research team followed a protocol but also asked additional questions to elicit more details in some cases. The interviews were recorded, transcribed, and thematically coded using an open-coding process.

ACTUAL OR ANTICIPATED OUTCOMES

Based on the analysis of the editor interviews, we present three critical aspects of the peer review process: the types of editors, the process that editors typically conduct to identify reviewers, and the types of decisions through the process. Additionally, we highlight considerations and advice from the editors to help members of the EER community develop.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The current study makes the editors' perspectives and decision-making processes more explicit to readers. These decision-making processes are full of careful considerations and also challenges. By doing so, we hope to help the members of the EER community gain a better understanding of what is going on backstage of the peer review process.

KEYWORDS

Peer review, engineering education research, boundaries of the field.

Introduction

The peer review process of academic journals is a key way that new knowledge is accepted into an academic field. However, many members of a field may not be familiar with the behind-the-scenes processes that facilitate the peer review process. To help a wider range of scholars within the field of engineering education research (EER) understand these processes and the expectations of the Journal of Engineering Education (JEE), this paper highlights the perspectives of a set of six editors. *The editors* were interviewed as part of a larger study exploring the peer review process. These editor perspectives are focused on *JEE*, which is one of the most prestigious journals within the larger field of engineering education. The perspectives and processes discussed here are not universal across all journals, but do help to provide a general understanding for how the peer review process is conducted at one journal within the field of EER.

This work builds on a number of programs facilitated by multiple journals to help the field of EER become more familiar with the peer review process. For example, the *Australasian Journal of Engineering Education (AJEE)* hosted workshops at the AAEE annual conference in 2020 and 2021 to help the Australasian community understand AJEE's peer review process and how to publish in that journal (Male et al., 2020, Under review). *JEE* has also begun a mentored reviewer program (https://cecas.clemson.edu/jee/) to aid new members of the field in the expectations for performing a peer review for *JEE*.

The purpose of this paper is to clearly articulate the peer review process, challenges, and considerations from editors in one context within engineering education.

Methods

This study is part of the larger project exploring the field of EER by analysing peer review experiences in the publication process for *The Journal of Engineering Education* (JEE). Findings from other parts of the study can be found elsewhere (Beddoes, Croninger, & Cutler, 2020; Beddoes, Xia, & Cutler, Under review; Cutler, Beddoes, & Croninger, 2019a; Cutler, Beddoes, & Croninger, 2019b; Cutler, Xia, & Beddoes, Accepted).

Six editors, including Associate Editors, Senior Associate Editors, and Deputy Editors, were interviewed in the Spring of 2019. Throughout the results, we will not be attributing any quote from the editorial board to a specific editor or editor role (Associate or Deputy Editors) to better ensure anonymity of the participants. It is important to note that these interviews were conducted in Spring 2019. There have been significant changes to the JEE editor board since then including editors stepping down and new editors coming on board. The overall leadership of JEE has been consistent with Lisa Benson acting as editor of JEE. Keep in mind that each individual editor brings their unique perspective and that the information discussed here is subject to change as part of the ever-evolving field of EER as well as continual changes to JEE.

All participants were interviewed individually via Zoom by a trained graduate research assistant. The interviews were approximately one hour long and were semi-structured in that the interviewers followed a protocol but also followed up with additional questions to elicit additional details in some cases. All interviews were recorded and transcribed for later analysis.

For the current study, we conducted in-depth analysis on the transcripts of the six interviews through multiple rounds. The coding results were discussed in our research group's weekly meetings to further develop the codes and reach inter-rater reliability of each code across interviews.

Findings and discussion

To articulate the behind-the-scenes processes of peer review, we organize the findings into the following sections: the types of editors, the process that editors typically conduct to identify reviewers, the types of decisions through the process, and lastly, considerations and advice from the editors to help members of the EER community develop.

Types of editors

To aid in contextualizing the experiences and perceptions of the editors interviewed here, we are providing an overview of the peer review process for JEE. This paper presents one example of the peer review process; however, many of the practices here are standard and used by other journals. The peer review process of JEE involves the following editorial roles: Editor of JEE, Deputy Editors, Associate Editors (including senior Associate Editors), a copy editor, and an editorial assistant. After the author has prepared and submitted the manuscript to the journal, the Editor, Deputy Editors, and Associate Editors take up different responsibility to initiate the review process. According to one of our participants, “by and large, the role of the Deputy Editors is the same, in terms of the review process and the manuscript submission process, as the Editor…the Associate Editors are the one that actually seek reviews and then synthesize the reviews. The Editor is the one that reviews the reviews and makes a decision.” The Editor or Deputy Editor reviews each manuscript as it is received. They then decide to either reject the article outright or send it to an Associate Editor for review. The Associate Editor recruits an average of three reviewers for each manuscript, and then reads the article and the reviews to make a summary recommendation to Editor or Deputy Editor. The Editor or Deputy Editor then makes the final decision for the manuscript. The decisions for the manuscript are reject, major revisions, minor revisions, or accept. Once a manuscript is accepted, the authors work with the copy editor and editorial assistant to finalize the article for publication.

When asked about the qualifications for a good editor, the editors responded with the following: First, editors need to have extensive background in engineering education research, more specifically, about theories on knowledge and learning, research methodologies in both qualitative and quantitative approaches, and topics. This background knowledge helps the editors “develop some sense of what are the kind of comments and what are legitimate criticisms and not legitimate criticisms.” Effective editors tend to be those who are experienced in the field, especially experience with educational research, rather than novice researchers. Second, it is better that editors have experiences with publishing in the specific journal, as well as remain active in the field to know the landscape, “the big picture”, and development of the field. This knowledge can help editors see how the submission/article is situated in the field and beyond, if the article’s contribution will potentially push the field forward. Third, editors need to understand the review process and the role of editors in the process. Other qualifications include being fair and open-minded, organized, having good time management skills (“getting stuff back to people in a timely manner”), communication, the ability to synthesize reviews. In synthesizing reviews, they should be able to “reconcile conflicting reviews or come down and make a judgment.”

Finding reviewers

One of the author perceptions that the editors were specifically asked about was that “Some authors perceived that reviewers were not qualified to review the type of engineering education methods, either qualitative or quantitative, used in their study.” Editors agreed that reviewers may not have specific expertise with respect to the methods used in the article they are reviewing. This is a challenge that may be unique to engineering education as new interdisciplinary field and may not be as much of a challenge for more established disciplines. Specifically, one of the approximately three reviewers may not be qualified to comment on all elements of the article. Editors also believed that the responsibility lies more with the editors, who faced the challenge of finding reviewers who have the needed

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qualifications. When talking about the challenge of finding reviewers, one editor stated that “I think as our field tries to move to understanding different things and welcoming more things, it is challenging.” In addition, editors when communicating with authors also need to weigh in to send a message, talking about reviewers’ backgrounds and expertise.

Diving deeper into the challenges of finding qualified reviewers, editors were specifically asked about their process for identifying reviewers for a manuscript. The peer review process is reliant on identifying and recruiting appropriate reviewers. Most importantly, all editors highlighted that author recommendations are very helpful in the reviewer identification process. One editor suggested that “we just require everyone actually upload a cover letter to help editors identify reviewers that are the most likely to give helpful reviews.” However, author recommendations are not helpful when there is a conflict of interest, and the recommendation cannot be used. If there is no conflict of interest, the editors tend to choose one or two from the suggested reviewers, but recommended reviewers will not constitute all reviewers. That is, even when editors choose from the reviewers recommended by the author, they will make sure to include at least one reviewer who was not on the recommendation list.

Other approaches Associate Editors use to identify reviewers include: using the reference list of the manuscript to identify names that have relevant research background; use the journal’s manuscript management system ScholarOne that contains a database that recommends reviewers; ask colleagues they personally know to suggest reviewers; search Google or Google Scholar for reviewers with expertise in the area of the manuscript. ScholarOne does not work well for every editor and some editors sometimes “include a message with people I'm asking to review to ask them to suggest people if they're not able to complete the review themselves.”

All of these considerations around reviewers are intended to help the review process by giving constructive feedback to authors and help develop the submitted manuscripts. Recently, JEE has started a mentored reviewer program (https://cecas.clemson.edu/jee/) to aid new members of the field in developing their reviewer abilities and grow the pool of potential reviewers for JEE. As a field, EER creates new knowledge through the peer review of manuscripts. Each member of the field, especially authors who publish within the journal, should see their participation as a critical service to the field and regularly act as a reviewer. The field of EER is not as large as many others, which places a higher responsibility on each member to contribute through the review process. One important tip (from personal experience) is to make sure that your email is up to date in the ScholarOne system. If you change institutions, you may never know that you were asked to review because it was sent to the wrong email.

Types of decisions

There are multiple types of decisions from the editors at the end of a round of peer review, including Reject, Major Revisions, Minor Revisions, and Accept. Generally, most papers complete multiple rounds of reviews to move the paper forward through the process. JEE is a highly competitive journal with a high rejection rate of approximately 90% over the last 5 years (personal communication with Lisa Benson, Editor of JEE). Many manuscripts submitted to the journal will be rejected. For the rest of this section, we will be reporting the editor perspectives on each type of decision.

Reject decisions fall under two typical cases. First is called a desk rejection, where the manuscript is rejected by the Editor/Deputy Editor without sending it out to reviewers at all. Second includes those manuscripts that are sent out for reviews and then ultimately rejected. There are a few types of articles that are commonly not sent out for reviews, but some editors try to be open and to give authors the opportunity to revise and improve the manuscript.

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The submitted manuscripts that editors decided not to send out for reviews but reject right away tend to have the following challenges. The manuscript may have challenges that are too severe and determined to be “not savable.” A first type included manuscripts that are about topics that have nothing to do with education at all, for example “traditional engineering research like developing a new widget or research about something totally not related to education.” That is, the article discusses research that is completely outside of the scope of the journal. A second type were articles about interventions but they “may or may not even have any kind of data about how good it is” or it is hard to “understand the relationship between the intervention and the outcome.” A third type of challenge included articles that were perceived to have “fundamental flaws” and thus not to be high-quality enough, for example, “a fundamental flaw in the design and implementation of the study that you are not going to be able to overcome,” or “it's the way the data was collected or what was collected in the data, it's just not ever-- that data, you are never going to be able to answer those research questions.” That is, if the design and methodology are perceived to be flawed, the article is not considered to be salvageable. A fourth type of challenge concerns the overall organization of the manuscript. In short, “the research doesn't include the key elements of an actual research project.” These key elements include theoretical frameworks, or solid research questions, or research methods well-aligned with the question(s). Or, “there's no solid chain of reasoning between the beginning and the end of the article.”

However, editors said that they tried to be supportive of authors, when possible, by trying to provide opportunities to address reviewer concerns using the major revisions decision to allow for a second-round submission. There are a few different types of common problems in submissions that were recommended major revision. Initially, the first submission lacked the necessary details to make an informed decision, “you can't even tell if it's a poor research design or if it's just written up poorly.” In this case, editors said they made the decision of major revisions based on the reviews with the intention of giving the authors a chance to clarify what they did in the paper, and then during the next round of reviews “we [editors and reviewers] might have a completely different set of feedback and questions for you [author(s)].” Second, the key elements of a research paper were included but not strong, that is, “If it's that the lit review is off, or the discussion is not strong, or the writing is not clear, or there's a bit of a mismatch, or you didn't fully talk about trustworthiness, or maybe you needed another calculation and statistic would really add to this or demonstrate validity or something at that level, then that's going to be a major revision.”

One editor commented on how reviewers did not necessarily share the same understanding of difference between major revision and minor revision, in terms of how these two decisions are handled when they come back in. This editor stated that “most of the people [reviewers] will say minor revision and I'll say, ‘No, let's call that major,’” and further pointed out that “a lot of people don't know what the difference is… Minor revision usually means unblinded and it doesn't go back out for review.” Taken together, for submissions that editors decided to send out for reviews, the most common cases would be major revisions. After revisions, if the authors unfortunately showed that “they really didn't understand [the research or literature]” and “there may be additional problems that come up… and it's actually worse,” this would lead to a rejection. Also, the submission might be ultimately rejected if the major concerns are not addressed as described by an editor saying “but if that part didn't ever get addressed, I would reject it ultimately. I'm not going to have something go out [be published] that looks like it's giving legitimacy to something that is not.” However, if the concerns are resolved and the manuscript improved greatly to meet the criteria, the manuscript would ultimately be accepted.

Considerations for Editors/Reviewers/Authors

As editors noted, there is a need to provide “support and training for the people doing the review process.” There has been recent effort to help members of the field learn to be reviewers, but it is still a change that the editors look forward to. Editors believe it is important

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to help people understand the point of a peer review and to have resources “so that reviewers knew what a good quality review looked like.” As such, for reviewers, learning how to write reviews should be an intentional learning process. Resources such as mentored programs (e.g., https://cecas.clemson.edu/jee/) should benefit the community by providing a space where young researchers in the field of EER learn from experienced researchers how to review peers’ work. Besides developing review skills in the long run, for any specific review project, one editor commented that “I think it's part of a reviewer's job to say my expertise is in this part of the paper” to help editors organize the review process.

For authors, one editor talked about the authors’ responses to reviews and commented that “there's a really disrespectful way to not do things that people ask you to do, and there's a much more respectful way to do it.” This comment highlighted how the review process needed to be a respectful conversation between reviewers and authors toward the same goal of improving the manuscript, rather than a one-way talk. In this conversation, it is author’s responsibility to respond well.

As there are often more than one round of reviews, some editors noted that the first round of review would not be helpful to include detailed proofreading comments, since the paragraphs might even be deleted given other comments. The editors advised that reviewers know that in the first round of review, “pointing out typos and word choices things is really not a productive use of your time as a reviewer,” and general statement about the overall word choice or clarity is fine.

Toward the end of the interview with editors, we asked them what messages they would like JEE readers to hear and know. The editors talked about the multiple aspects involved in the efforts of publishing in JEE, including the authors’ work, reviewers, and editors’ responsibility, JEE as one of the top journals in the field, and the field itself, while the comments from editors showed how these aspects were interconnected.

For authors, editors encourage people to try and take risks, and not be overly influenced by others’ negative experiences and hard feelings. Authors need to take the responsibility to communicate their work to the audience. At the same time, authors should know that everyone is getting hard feedback from time to time and use reviews to strengthen the work. Untenured faculty might also want to seek other venues when the number of publications is prioritized.

For reviewers and editors, our editor participants believed that they need to communicate feedback in supportive ways.

In terms of the journal (JEE), it is changing and evolving and there is space for change. Multiple editors commented that JEE is welcoming and inclusive of new theories, methods, and topics, but authors need to make sure to communicate the contribution that new work is making to the literature and the field and explain how that effort to push boundaries is useful to advance the field. JEE is not the “end all be all”, and not designed to accept everything. It is okay for JEE to “develop a more defined identity and that identity can be complemented by other journals in better ways.” In other words, JEE is not the only place to publish in the field. There need to be efforts from the community to create more space for dialogue. The field “opens up opportunities for new journals that may want to be more accepting of these other kinds of papers.” That is, the publication venues within the field need to grow and fill those niches.

Conclusion

In this study, we aimed at illuminating the black box of peer review process by eliciting the perspectives of the process custodians, i.e., editors for JEE, for the purpose of informing the members of the field of EER. The editors’ perspectives should be able to help the members of the research community, especially novice scholars, to better understand the backstage of the process to help them grow in the community. The findings revealed the responsibility for members in the EER community when participating in the evolving field, specifically how that responsibility lies with editors, reviewers, and authors. However, as a limitation in this study, we only interviewed a small number of editors and they also have worked for one particular journal, i.e., JEE. Though some of the editors held multiple editorships with different journals, the interviews were oriented around one journal only. Some editors talked about their experiences as editors for other journals but that was not the focus of the interviews. As such, our findings reflect the six editors' perspectives only and should be interpreted with caution against generalizations over the entire field of EER.

First, there are different types of editors with different job responsibilities in the review process. One of the main responsibilities for the editors is to search for qualified reviewers to review a manuscript. As a typical manuscript requires a variety of expertise to review the different elements of the manuscript (topic, methods, theory, etc.), this variation in expertise can create challenges in finding qualified reviewers within the new, interdisciplinary space of engineering education. Additionally, the editors close the communication loop between reviewers and authors by synthesizing and highlighting key elements across multiple reviews. To aid editors in this process, we encourage reviewers to note their expertise in the "Comments to the editor" alongside their review.

When thinking about the reviewers as part of the peer review process, there are a few considerations. First, we would like to encourage members of the field to actively participate in the peer review process, especially those who publish within JEE. With a higher population of reviewers, the field can grow to include more diverse perspectives and gain additional expertise in reviews. We would also encourage reviewers to consider how they compose their reviews. Many academics can relate to the perceptions of "that one reviewer" that feels overly harsh and not helpful in improving the manuscript. We hope to bring attention to this element of academic culture within engineering education and encourage future reviewers to be mindful of their tone. We are currently working on peer review guidelines to help reviewers reflect on this process (Cutler, Xia, & Beddoes, Accepted).

Manuscript authors also play a key role in the peer review process. Common remarks from editors highlighted that authors need to emphasize clarity and transparency in their writing. The authors are very familiar with their study and may develop an expert blind spot in the writing of the manuscript that reviewers often highlight. A related point emphasized by the editors was that clarity and transparency play an even more important role in manuscripts that are presenting new or innovative elements.

At its best, the peer review process should be a developmental process in two senses. That is, it can serve as a development process for the authors to improve their work and hopefully to finally get their work published to a broad readership. At the same time, it is also a developmental process for the research community to disseminate and advance new knowledge. This process involves editors, reviewers, and authors who should have the same goal of advancing the author(s)' research as well as the field's development. With this goal explicitly stated, we feel the need to again emphasize the importance of including positive feedback and using supportive tone in giving reviews and responses. The field could flourish if its members support each other in the peer review process.

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Undergraduate Student's perceptions of factors that enable and inhibit their professional skill development.

KEYWORDS

student perceptions of professional skills, professional learning and development, integrated engineering

Background

The need for Engineering graduates who can balance strong technical competencies with broader professional and transversal capabilities has been well recognised for at least 20 years (National Academy of Engineering, 2004, King, 2008, Royal Academy of Engineering, 2007, Confederation of British Industry 2009). More recently, this has seen critical analyses of the specific competencies that are desirable (e.g. Passow & Passow, 2017) and the approaches that are suited to the development of these skills (e.g. Winberg et al, 2016)

In response to calls from industry and recognition by universities of underdeveloped professional skills in their students, there has been a move towards a more integrated approach to preparing undergraduate students for professional practice. This often involves the integration of professional skills training and development within the more traditional engineering science curricula. This has also been reflected in the strengthening of professional skills development criteria within various engineering accreditation frameworks (ABET, 2011; Engineers Australia, 2018).

In part to address these issues various institutions have introduced integrative curricula (Lowe and Goldfinch, 2021). Two of these institutions, the XXX, Australia and the YYY, London both have introduced integrated engineering programs that are embedded through all years of students' engineering degree programs. At the XXX integrated engineering consists of four multidisciplinary units typically undertaken in consecutive years as students' progress through their degree. The units use online instruction and a series of workshops to undertake multidisciplinary engineering projects to address authentic, real world projects and workplace challenges and practices that require the integration, application and demonstration of students' technical and professional skills. Brookfield states that learning that challenges and stretches students, asks them to think critically or use their judgement to deal with uncertainty and complexity, often induces resistance (Brookfield 2017).

Similarly, engineering students tend to have diverse reactions to the teaching of broader professional competencies, with many students reacting negatively to the elements of their degree that focus on their broader professional development.

This study explored the nature of these student reactions and in particular aims to move past the common assumption that student's attitudes relate to their perception that professional elements are not "real engineering". Understanding students' views on what enables and inhibits their engagement with learning activities associated with these competencies will enable universities to adapt their curriculum to maximise the quality of demonstrated learning outcomes related to professional skill development.

APPROACH and METHODS

As part of a broader survey on student reactions to the development of professional skills (with N ≈ 568), we asked an open-ended question at the end of the survey, seeking the respondents' comments: are there "…any other comments …. that you think might be helpful to us in understanding your views and experiences?". There were 118 of the students who provided a response to this question, averaging 48 words per response.

The survey required students to reflect on and think about their views on learning of professional competencies. Given the optional and open-ended nature of this final question, we believe that it was most likely to capture those aspects that students thought were most significant and/or were most important to convey to us.

We identified the dominant themes that emerged from these comments using a thematic analysis (Guest, MacQueen, & Namey, 2012).

Because of the different timing of semester sessions between XXX and YYY the survey was released at different times at both universities. At the time of writing the vast majority of responses (more than 90%) were from XXX undergraduate and graduate students. To reduce the potential for institutional or national differences to be a confounding factor it was decided in this paper to only considered the data from the XXX respondents. A subsequent analysis will consider the YYY data and will explore the extent to which different themes emerge in different institutional (or national) contexts.

All the coding for the research reported in this paper was conducted by a single person (one of the authors). All student responses were read first and a number of central codes (themes) were identified. NVivo was then used to code all of the student responses. During the coding process a number of additional codes (nodes) were identified and added. After a period of two weeks the coding was reviewed and refined.

Findings

The thematic analysis revealed a number of themes, however two themes were easily the most dominant. These two themes relate to what we have categorised as authenticity and value. In discussing the nature of these two themes, we will provide (anonymous) extracts from the student comments used in the thematic analysis.

Authenticity

Authenticity relates to students' perceptions regarding the extent to which their learning associated with developing their professional skills is representative of what they believe occurs in industry (or the "real world"). It is interesting that even many first year undergraduate students, despite lacking any significant industry experience, still have strong beliefs and perceptions as to what working as an engineer in industry is like, what type of work they will be doing and what skills are important and how they should be learnt. In a future study we intend to interview first-year students to investigate the origins of these strong perceptions.

A common perception of students is that professional skills cannot be successfully taught and developed in the University context and are best developed in the workplace.

> *The best place to learn such skills is in the workplace. There is no way to consistently equip students with such a toolkit from drilling theory into their heads. Squeezing your way into the workplace and learning from there experience is the best way to gather such knowledge in my opinion.* ***(Participant 1, male, under 20, international student, middle year undergraduate, spent 1 to 3 months in any work and less than 1 month working in a professional job)***

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*The way some competencies such as "team work" are taught at university are inherently flawed by the fact that there is always a deadline to the group assignment/project and that no one is getting paid to do good work like they are in the workplace. This means the kinds of pressures on teams that are "randomly put together so that students can learn to work with a wide array of people" are *significantly different* to a professional work context. Group members are always forced to pick up for people who slack off, forced to spell/grammar check entire sections from other students to avoid getting deductions, or forced to rewrite entire sections when other group members blatantly plagiarise to finish their section of the work* ***(Participant 2, female, 21-25 years old, international student, middle year undergraduate, 1 to 3 years in work, three to 12 months in a professional job)***

Personally, I feel as though professional conduct is something that is better taught through first-hand experience than something that is taught theoretically i.e. from a textbook. Despite being professional in a workplace requires some inherent skills which can be summarised, the amount you learn from say a professionalism subject or component is minimal compared to hands on experience - if you are looking for a job and realise that your actions don't really fit in professionally or culturally, you're going to realise pretty quickly what you should or should not have done. ***(Participant 3, Male, Under 20, domestic student, first year undergraduate, three + years in work, less than one month in a professional job)***

Other students commented that the way universities taught and expect students to develop professional competencies didn't relate to (their understanding of) the real world. That is, the University environment doesn't authentically simulate the work environment and/or doesn't teach and develop the skills in an authentic or meaningful context.

I don't believe that the university places enough emphasis on the professional skills that employers of undergraduates and graduates are looking for. Although the university is very aware that employers at these stages are interested in the professional skills that we have, the approaches to developing those skills in students seem misguided and disingenuous. ***(Participant 4, male, 21-25 years old, domestic student, middle year undergraduate, 1 to 3 years in work, no work in a professional job)***

I think it is important to consider that most of the current structure involves students and academics interacting with engineering principles and practice within a vacuum of sorts - there is very little real-world applicability of projects and learning within the university environment at the moment, which limits the job-readiness of professional engineering graduates. ***(Participant 5, male, 21-25 years old, domestic student, final year undergraduate, 1 to 3 years in work, 3 to 12 months in a professional job)***

I know this may be a radical idea, but I think university should replace any in-curricular engineering units focused on "professional development" that simulate "project management" and have students work in teams with a mandatory participation in an organic project, such as Formula SAE or the rocketry club. This will ensure every student has skills and personal experience that every employer will value, as they developed within an organic, extracurricular "real" environment. Some, if not most, employers disregard in-curricular coursework as evidence of competencies, therefore, university should make engineering extracurricular activities mandatory or at least schedule a unit in which students have the opportunity to focus on such activities. ***(Participant 6, male, 21-25 years old, international student, middle year undergraduate, less than one month in work, no work in a professional job)***

There were also concerns expressed by students that having a separate set of units to develop professional skills wasn't their preferred option and that it would be better to integrate their professional development within their technical subjects. Interestingly, the Integrated Engineering and professional practice programs at the XXX were explicitly introduced to address this exact issue. However, at least for some students, it appears that the naming and identification of these programs means they are seen as somewhat separate, rather than embedded with their technical knowledge development and hence not grounded in what they regard as real engineering.

> *professional skills seem to be developed in tandem with technical skills, such that they should seen as holistic and their development should be approached in a way that can develop both at the same time (sic).* ***(Participant 3, Male, Under 20, domestic student, first year undergraduate, three + years in work, less than one month in a professional job)***

These views from an undergraduate student were supported by a recent graduate who had more than three years work as a professional (though it is is worth noting that this student would not have been exposed to the Integrated Engineering program).

> *It would have been even more beneficial to be mentored in the professional skills while studying the technical subjects. This is where you write reports, work with others, interact with staff/seniors and have to listen to the problem set (customer), ask questions, develop appropriate solutions and then "sell" them.* ***(Participant 7, female, over 30 years old, was domestic student, employed professional, 3+ years in work, 3+ years in professional job) (note: completed undergraduate degree before the introduction of Integrated Engineering and PEP)***

Other students expressed doubt as to whether academics were in a position to teach them or model professional skills relevant to industry, as many of them were seen as having limited or no prior industry experience.

> *I think it's difficult for some of the lecturers and researchers to discuss some of the professional competencies required for industry, particularly if they themselves are not privy to the industry. …. generally, the lecturers are not at the university to be teachers, but to be researchers, and that I think is a fundamental flaw in tertiary education: the educators don't have teaching as their focus.* ***(Participant 8, male, 21-25 years old, domestic student, final year undergraduate, 1 to 3 years in work, 3 to 12 months in a professional job)***

Value

Students also expressed a range of concerns reflecting that they felt that the University didn't value developing their professional skills.

Typically students undertake four, six credit point units a semester. The Integrated Engineering program at the XXX consists of four units. The first-year unit is a six-credit point unit () while the second, third and fourth year units are only two credit point each and are taken in addition to the normal 24 credit point semester load (that is students typically undertake a 26 credit point semester when studying Integrated Engineering 2,3 or 4).

> *The Integrated engineering subjects are a good concept on paper but the execution and weighting causes students to lose motivation. The fact that Engg1111/Engg2111/Engg3111 are each only 2cp makes them feel useless and not a thing that the university considers important. As a result, the students don't see it as important either and hence don't make any commitment to work with their group members*

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effectively and learn communication skills. ***(Participant 9, female, 21-25 years old, domestic student, middle year undergraduate, 3+ years in work, no work in a professional job)***

Last but not least, the workload and difficulty level of all of these subjects need to be adjusted accordingly so that students would treat them seriously. Integrated Engg units for 2CP whereas Engineering units for 6 CP, I think that would disincentivise people (as any economics lecturer would say to you) and promote apathy for these softer subjects, and continue to produce engineers who have the brains but not the heart to design their products / services for, not to mention a worse manager/executive/leader in the workplace as they progress in their careers. ***(Participant 10, male, 21 to 25 years old, was international student, employed professional, 3 to 12 months in work, 3 to 12 months in professional job) (note: completed undergraduate degree after the introduction of integrated engineering but before the introduction of PEP).***

*I think particularly with professional competencies, the skills introduced at university are considered more of an add-on than genuine learning necessities in comparison to mathematical fundamentals and technical skills. This is quickly reversed once in a work setting, where I found it was far less likely for employees to want me to work on their assignments unless I had proven a capability to communicate effectively. (****Participant 11, male, 21-25 years old, domestic student, middle year undergraduate, 3 to 12 months in work, 3 to 12 months in a professional job)***

Many students have an expectation that their University engineering studies should focus on technical skills as this is what they believe to be both valuable and most important to employers and will enable them to successfully get a graduate engineering job.

*Throughout my survey, I have noted that I personally believe I experienced greater development of professional skills in more "technical" subjects (eg fluid, soil, structural mechanics), whereas subjects such as "Integrated 1,2,3 (4? haven't done it)" and "PEP" are in place to force this interaction between students, not so much for the student's development, but as a checkbox for the uni to say to employers "yes we put our students in positions to develop professional skills", hence my feelings that these approaches feel disingenuous. Whether or not this is the case, an underlying reason may be that the university does not understand the students' motivations for learning. In an environment filled with academia, where the pursuit of knowledge is its own reward, is the polar opposite of the beliefs expressed by many undergraduates (possibly enforced by a society where our self worth is dictated by what we bring to the table and thus we find the easiest way to do so), where we want our degree and a job as fast as possible and as easy as possible, so subjects like PEP and ENGGX111 do not feel valuable, as we expect to be taught technical skills in a higher education setting. (****Participant 4, male, 21-25 years old, domestic student, middle year undergraduate, 1 to 3 years in work, no work in a professional job)***

In my experience, most of the professional competencies are either inherent or just have to be learnt on the job. Technical competencies are best taught at university so that students can feel prepared for a job's requirements and feel adequately suitable for engineering roles when they go to apply for them. (Eg. just about anyone will apply for a job if it says "good team work" in the job description, but not everyone will feel comfortable applying for a job that mentions "experienced with C++ and Java".) ***(Participant 2, female, 21-25 years old, international student, middle year undergraduate, three + years in work, three to 12 months in a professional job)***

When students are transferring from other universities or receiving advanced credit for other studies they have undertaken, undergraduate program directors often chosen to exempt

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them from Integrated Engineering 1 (the first year six credit point unit). This is interpreted by some students as an indication that the unit is not important or not value by the University.

> *In terms of improvements, I do admire the university's attempt to try to force students to develop professional skills on their own, however, its implementation requires some reworking. As an example, ENGG_111 (Will exempt ENGG1111 as it is a first-year subject) does not feel like a valuable subject (**Participant 4, male, 21-25 years old, domestic student, middle year undergraduate, 1 to 3 years in work, no work in a professional job)***

The following comment from a graduate student seem to suggest a view that professional skills shouldn't be taught by engineering, calling for a more multidisciplinary approach to developing professional skills. The graduate student comments that even calling these core units Integrated Engineering, is sending the wrong message that they are about engineering and technical competencies are not professional skills. This is a particularly interesting perception as the units aim to integrate learning and development of professional skills with the application of the technical knowledge.

> *The Integrated Engg units are a good step in the right direction, but you need to ask the Arts, Commerce and Law lecturers to teach these subjects because when you name it as such, people still think that these subjects are about Engineering and technical competencies, and not soft skills. They will think of it as peripheral to the educational experience and this is not what the intended outcome should be. In every semester, the student must take at least one of this subject to ensure that professional competencies are developed incrementally (as you cannot teach things overnight and certainly to teach that at postgraduate level is a bit too late). Good values are inculcated and indoctrinated over time and that has shaped my personality and my character as I have gone through the degree.*
>
> *In order to effectively teach professional competencies, interdisciplinary degrees that include arts, commerce and law subjects should be offered as these subjects are not maths based, are about people and require writing arguments from a multitude of perspectives and at times with no right and wrong answers. Unfortunately, the STEM way of thinking and the Arts/Commerce/Law way of thinking is almost always mutually conflicting, and some people might end up hating it, but it must be taught, as much as it is a pain in the neck to think in two different ways. **(Participant 10, male, 21 to 25 years old, was international student, employed professional, 3 to 12 months in work, 3 to 12 months in professional job) (note: completed undergraduate degree after the introduction of Integrated Engineering but before the introduction of PEP).***

A number of students also commented on the Covid 19 pandemic, noting that having to interact with students in their class and teams via Zoom was problematic. However, one first-year student saw the pandemic as providing them an opportunity to develop professional skills that will be necessary in the future because of anticipated changes to the way we work.

> *Developing professional skills online has been quite a learning curve. Learning to communicate with people, ensuring each person gets a chance to speak and is on the same page is really challenging. However, I think these skills will be useful heading into the future where it will become easier to collaborate on an international level **(Participant 12, female, under 20 years old, domestic student, first year undergraduate, 3 to 12 months in work, no work in a professional job)***

OUTCOMES

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A number of dominant and often interconnected themes were observed. In this paper we have focused on examining the themes of authenticity and value.

Comments attributed to the authenticity theme ranged from perceptions that professional skills cannot be taught at university and must be learned through workplace practice, to the view that university-based professional skills development is not authentic and/or being taught by academics who have not worked in industry themselves.

It is interesting to note that most participants had definite ideas about how professional skills should be learnt and what skills are required in the workplace even when they had little or no experience in a professional position. Furthermore, there is a belief by many students that problems with lack of professionalism, teamwork, poorly performing team members, motivation and conflicting priorities do not occur in the workplace, and their existence in university student learning and projects contributes to their perception that these activities are not authentic and do not reflect professional practice.

It would obviously be impractical to argue that working in professional practice with other professionals and undertaking the associated activities and consequences would not be meaningful. However many students do not seem to appreciate the opportunity their university studies provide to develop and receive feedback on their professional skills in a low-risk environment. It is interesting that many students appreciate that the technical knowledge they learn at university is regarded as preparation for professional practice and they expect to learn much more from more experienced professionals when they have to apply this technical knowledge in practice. Yet many students do not view that they can develop their professional skills in the same may.

Comments that code the *value* theme range from perceptions that the University doesn't value the teaching of professional skills, often as a consequence of the limited credit points attributed to the Integrated Engineering units. Students also felt the value of the Integrated Engineering units was diminished as they are often given as exemptions to transferring students and hence the University doesn't value them as much as technical units for which they perceive it is harder to obtain credit.

Some students felt the University's commitment to teaching of professional skills was more of an add-on, being poorly focused and structured and hence was not valued by the University. A number of students expressed their concern that the University should focus on developing their technical skills as, in their view, this is what employers wanted and what would enable them to successfully achieve a graduate engineering position. While other students believe that professional competencies are inherent and are learnt through working and everyday life.

Interestingly it was a graduate student who, after three years working professionally, suggested that the program should be expanded and have a wider interdisciplinary focus where arts, commerce and law lecturers should be used to teach important professional skills and competencies as they felt the STEM way of thinking is more technical.

It should be noted that when the Integrated Engineering program was initially introduced at the XXX there was resistance from some staff and students. This resistance was often associated with value, including concerns about the reduction of credit points focused on more highly valued technical content, and a dislike, particularly by students, of the more open-ended, complex and broad problem-based learning the Integrated Engineering units introduced. This required students to use judgement, manage competing demands, uncertainty and complexity. Unlike much of their more technical studies where problems often have a unique correct answer and their learning is “associated with absolutes, moving from the ‘knowable’ to the ‘known’ using predetermined rules, facts and analysis to manage encountered uncertainty” (Willey & Machet 2018, 2019).

While five years into the program this resistance has largely dissipated and student satisfaction with the two credit point units has been steadily increasing, the fact remains that the two credit point Integrated Engineering units are still perceived as being a bolt on, requiring students taking a standard program, to undertake five units in a semester. In response to the concerns, many of which are discussed in this paper, the program has recently been redesigned to consist of three, six credit point units which are now embedded into a student’s normal program. It is hoped that this will increase the perceived value and subsequent commitment to these units by both students and staff.

RECOMMENDATIONS

The student responses suggest that to successfully develop student’s professional skills within university curricula, it is not sufficient to have an integrated, targeted and embedded program. It is clear for success that the intentions and outcomes of such programs, need to be valued, well scaffolded and articulated to both students and staff and seen as an integral part of a university’s culture and beliefs.

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Rural knowledge practices and engineering study: A case study from South Africa

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ABSTRACT

CONTEXT

Rurality is a complex phenomenon that can be understood as both a demographic and social category that intersects with other categories, such as race, gender, and social class. Success on the part of students from rural backgrounds requires that HEIs recognize and value the knowledge practices that these students bring to their experiences of higher education. The term ‘knowledge practices’ refers to the knowledge gained from social, cultural, ecological and epistemological activities.

PURPOSE OR GOAL

This paper seeks to understand the knowledge practices – pertaining specifically to mathematics, science, and language – that a sample of engineering students from rural backgrounds brought with them from their rural contexts. The paper reflects on how these knowledge practices are deployed within engineering teaching and learning.

APPROACH OR METHODOLOGY/METHODS

Data was collected within an interpretive, qualitative, case study design. The case under investigation is a faculty of engineering at an HEI in South Africa. Eight second-year engineering students from rural areas were purposively sampled. These students participated in a three-part data collection process, including the development of ‘digital documentaries’, individual interviews, and a focus group discussion. The qualitative data was coded using Atlas.ti and analysed thematically.

OUTCOMES

The knowledge practices that rural students develop through their upbringing include, for example, practices such as estimation, knowledge pertaining to the natural environment, and communication. However, these knowledge practices are not adequately recognized or employed within their engineering studies, even by the students themselves.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Alternative forms of knowledge remain unrecognized within higher education, such that even many of those who possess such knowledge fail to recognize its value. Identifying ways of recognizing traditional knowledge systems may serve to enrich engineering curricula and enhance rural students’ learning.

KEYWORDS

Engineering education; rurality; knowledge practices.

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Introduction

Higher education has succeeded in attracting greater diversity of students in recent decades, with increasing enrolment on the part of students of colour, women, students with disabilities and students from working-class and rural backgrounds. However, physical access to higher education institutions has not necessarily translated into what Morrow (2009) calls epistemic access. Such access requires that students are enabled to become epistemic contributors (Fricker, 2015), which requires that opportunities are created for students to deploy the skills, knowledges, and experiences they have acquired prior to entry into higher education. Nonetheless, evidence from several studies on rurality in South Africa and elsewhere indicates that the voices, perspectives and practices of university students from rural backgrounds remain ignored (Walker and Mathebula, 2020; Naidoo, Traher, Lucas, Muhuro and Wisker, 2020).

Given this, the present study seeks to investigate the knowledge practices that rural students bring with them to their experience of engineering education, specifically, by answering the following research question: what knowledge practices related to their chosen discipline do engineering students from rural contexts bring with them to higher education? The remainder of this paper is structured such that it begins with more detailed discussion of the issue of rurality in higher education, before positioning knowledge as a social practice. The research design employed is then presented, before the results obtained – pertaining to the mathematical, scientific and literacy-based knowledge practices of a group of engineering students – are discussed.

Rurality and Higher Education

Rurality is a contested and complicated concept (Sauvageot and da Graća, 2007), that has been variously defined in relation to factors such as population density, settlement size, economic factors, and landscape. More importantly for the purposes of this study, rurality is often constructed as ‘backward’ or lacking modernity (White and Corbett, 2014). But, locating rurality on the negative end of an assumed binary, far removed from notions of sophistication, technological advancement, and cosmopolitanism (Cuervo and Wyn, 2012), denies rural populations recognition of their own strengths and values This has implications for the way rurality is treated within higher education.

Walker and Mathebula (2020) show that rural students come from backgrounds with specific values and socio-cultural systems and, as such, their experience of higher education may differ from that of urban students. Their study suggests that there is a gap between the sociocultural practices of rural students and those of higher education institutions. This gap manifests in spatial inequalities of access to higher education (Mgqwashu, 2019), which in turn manifest in several barriers to university enrolment and persistence for students from rural areas. These barriers may (but do not always) include socio-economic status, family and community attributes, personal contexts, educational aspiration and attainment, lack of financial support and academic preparedness.

However, students from rural backgrounds are brought up in a rich cultural world, and they learn skills and knowledge that go unacknowledged within university contexts (Mgqwashu, Timmis, de Wet and Madondo, 2020). According to Cross and Atinde (2015), students from rural backgrounds come to university with well-developed mechanisms and strategies that enable them to cope with challenges. These strategies emerge from their lives in rural communities. As such, exploring the learning of engineering students from rural backgrounds requires exploration of their prior learning and already-developed knowledge practices. This necessitates consideration of knowledge as a social practice.

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Knowing as a Social Practice

This research is based on a practice-theory perspective. One of the leading proponents of practice as a theoretical construct is Schatzki (2001:11), who views practices as “embodied, materially mediated arrays of human activity, centrally organised around shared practical understanding”, which implies that they are purposeful, rule-governed and value-laden. Using this theory enables us to consider the possibilities of knowledge equity, mutual engagement and an ecology of knowledges. In the practice sense, all knowledge is situated as it is contingent upon on the contexts and practices that surround it. Practices are ‘social’ insofar as they are recontextualised – and regulated – in specific contexts (Van Leeuwen, 2008). This means that some social practices, such as those of the family unit, might not be proceduralised or tightly sequenced, when compared to other social practices, such as those of the schooling system, which offer less opportunity for resistance and reconfiguration (Van Leeuwen, 2008).

Moreover, the view that knowledge is a social practice underpins this study and refers to the contention that knowing is inherent in action (Ryle, 1949; Polanyi, 1967). This means that knowledge is implicit in social action and embedded in social practices. This point has been made by several authors, albeit in different terms. In line with a practice-theory perspective, Lave (1988) argues that knowing in practice is continuously enacted through individuals' everyday activities, and Hutchins (1991) suggests that cognition is culturally situated within social activity. To argue, then, that knowledge is a social practice is to contend that knowledge is socially configured in particular contexts. Indeed, as Foucault (1977) argues, socially-constructed knowledge emerges in specific social contexts in ways deemed appropriate to those contexts, where some contexts (such as higher education) have strongly institutionalised procedures for knowledge generation.

It is important to note, however, that this does not mean that knowledge is fixed. Individuals reconstitute knowledge over time and across contexts and, in this way, knowledge shifts as practices shift (Lave, 1988). As individuals develop new practices – and new ways of engaging with the world – knowledge is recontextualised (Chouliaraki and Fairclough, 1999). Such recontextualization requires that existing knowledge is either excluded, included or given greater or lesser prominence (Fairclough, 2003). The notion of recontextualization also allows for recognition that ‘everyday’ concepts and ‘theoretical’ concepts exist alongside one another in what Guile (2010) calls a sphere of reason. Given this, the focus of the present study is on the extent to which the knowledge that students from rural areas bring with them – as emergent from the myriad social activities in which they have engaged during their upbringing – is able to be recontextualised within higher education through processes of inclusion, rather than exclusion.

In line with the view of knowledge as a social practice, different knowledge practices shape the histories and trajectories of students from rural backgrounds as they enter into higher education. In South Africa, as elsewhere in the world, historical inequalities have led to inequalities in access to the processes of knowledge production. This has led to calls to ‘decolonise’ higher education curricula, given that western knowledge has marginalised alternative forms of knowledge (Leibowitz, 2017). This process – which De Sousa Santos (2014) refers to as epistemic injustice – has prompted calls for cognitive justice and the equal recognition of all forms of knowledge (Leibowitz, 2017).

As such, the concern of this paper is with how knowledge is embedded in students from rural backgrounds' everyday activities, and the social and physical contexts in which these activities take place. Doing so is a first step towards understanding how universities can open up – or not – opportunities for this knowledge to be recontextualised. Rural communities engage in unique practices that reflect particular values and sociocultural systems (Cross and Atinde, 2015). The challenge facing rural students is that there is a gap between the practices, values and systems that underpin rural life and those that underpin higher education. There is thus a need to consider how different knowledge practices can be incorporated into higher education classrooms.

Research Design

Because knowledge, as a social practice, is contingent upon the social contexts in which it is generated and deployed, the focus of this study is on the discipline of engineering, specifically. The goal of the research was to uncover the particular knowledge practices that engineering students from rural areas bring with them to their experience of engineering education – and the extent to which these knowledge practices might be deployed in service of learning engineering. The study is interpretive in nature as it attempts to understand engineering students' situated, personal experiences with rural and university-based knowledge practices. In line with an interpretive paradigm, the study adopts a qualitative research design, as it aims for in-depth understanding rather than generalizable findings.

Given the use of qualitative research, the sample selected for this study is small in scale and participants were purposively selected. In total, eight engineering students from rural backgrounds participated in this research project. These participants all reported that they were the first in their families to attend university and that, prior to entry into university, they lived and attended school in rural areas in South Africa. The participants took part in three data collection activities.

First, the participants prepared digital documentaries. Digital documentaries, or digital stories, consist of video and photos with voice-over narration, and are used within research to stimulate self-reflection on the part of participants (Mikhailovich, Pamphilon and Chambers, 2015), and allowed researcher-access to the participants' rural communities in a way that was not invasive and gave the participants the power to decide what – and what not – to share with the researchers. The participants' digital stories were used to capture their 'material culture' and included records of their rural spaces, families, schools, churches. Some also depicted narratives of rural life and livelihoods.

The digital stories were analysed in themselves, but were also used to elicit discussion during the subsequent semi-structured interviews held with the participants. Each participant was interviewed once, for a period of 40 to 60 minutes. The focus of the interviews was on what had been presented in the digital stories, but also on the participants' experiences and trajectories at university. In particular, attention was given to uncovering the participants' knowledge practices brought from their rural backgrounds.

Finally, a focus group was held with five participants (five attended, though all participants were invited). A focus group was held, in addition to individual interviews, given Morgan's (2001) assertion that group interaction can draw out similarities and differences, providing rich information about a range of perspectives and experiences, thus strengthening the triangulation of the research. For the focus groups, participants were asked to bring learning artefacts from their studies and were asked to speak to the artefacts in terms of their personal relevance and practical value. Thereafter, participants were asked to draw a picture, depicting activities and practices that they considered indicative of their rural communities. Participants were then invited to explain and discuss their individual pictures.

The interviews and focus group discussions were audio-taped and transcribed verbatim. Thematic analysis was then undertaken on the data using Atlas.ti. The digital documentaries were collected as part of a larger research project and permission was obtained to use these. In addition, all the participants gave informed consent for their participation in this research. During the research, trustworthiness (Lincoln and Guba, 1985) was enhanced by using multiple data collection methods, as well as member-checking, in that all participants were sent transcripts of their individual interviews as well as of the focus group discussion, and were asked to raise any concerns they had with these transcripts. As is the norm in qualitative research, trustworthiness is also enhanced by providing verbatim extracts from and 'thick description' (Ryle, 1949) of the data collected in the reporting of findings. The use

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of computer-assisted qualitative data analysis software further contributes to the trustworthiness of this research.

Knowledge Practices Related to Mathematics

Mathematics is "a kind of cultural knowledge, which all cultures generate but which need not necessarily look the same from one cultural group to another" (Bishop, 1988: 180). McMurchy-Pilkington (1995) has previously explored the mathematical thinking and reasoning skills that Māori adult learners draw on in their everyday cultural practices and argues that mathematics activities are culturally and socially organized. This is demonstrated in the present study, in which the participants demonstrate awareness of and engagement in a variety of mathematics practices within their rural communities.

Some of them had personal engagements in these practices. For example, the participants indicated that they were taught counting systems and estimation but that the act of counting involved more than simply arriving at a 'total', in that it was tied to intricate knowledge of the livestock being counted. Jabali explains:

> *When you open the gate … you know five cows, five goats out five goats must come back you understand and you sort of like you know your goats because the goats are not like the same white one, black and white.*

According to Matemba and Lilemba (2015), traditional counting systems, including counting of livestock, apply a holistic approach that situates objects within a greater whole. As such, in the rural communities in which the student-participants grew up, counting was not inculcated as a context-free, value-neutral enterprise; instead, it involved broader social values, knowledges and practices. As such, the use of counting reflects the situated nature of (mathematical) practice.

This enables rural communities to use mathematical practices to solve everyday challenges they encounter, especially through the use of estimation. There exists a tension in this regard: at university, particularly in engineering, priority is given to obtaining exact answers to problems whereas in real-world contexts, particularly those characterized by rural livelihoods, estimation is the norm. Jabali, again, explains:

> *The thing is at university, its more or less like a program, somebody already program that these are the steps that you need to take to get to this point. Whereas in the rural areas, it's a program but you are allowed to participate by editing the program. I don't know if that makes sense. There is no fixed structure. Your input can make a lot of change. And you are not limited to whatever that is already been there, you can change. Say maybe, they used to feed the cows that side, you can use the other side. To put fertilizer in the garden we don't measure exact we just estimate. See it's not fixed. You can do what they are doing but with more options to choose from.*

Jabali here recognizes that the ways of solving problems and engaging in social practice are functionally different in his rural home and academic disciplinary contexts.

But Jabali's comments also demonstrate that out-of-school mathematics practices are not legitimated within the university. In his comments, there is a sense of alienation and powerlessness, in that 'somebody' has already 'programmed' what needs to be done, and that people from rural areas can do what 'they' are doing. "In the rural areas", according to Jabali, "you are allowed to participate" – as opposed to higher education where, by implication, participation is limited.

A finding of this research is that the student-participants found it quite difficult to relate what they are learning at university to their rural backgrounds, resulting in a sense of alienation. This lack of connection between knowledge from rural backgrounds and new knowledge in the university needs to be problematized. The comment from Jabali above reflects a deeper social representation that denies status to the mathematical practices of socially and economically marginalized groups. This may have implications for personal self-esteem,

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cultural identity, and construction of mathematical meaning. As Gerger (2014) argues, valuing traditional numeracy practices will make students aware that they already possess significant numeracy skills, strengthening their self-esteem, and increasing motivation for learning.

Knowledge Practices Related to Science

The student-participants had similar difficulty in identifying scientific practices in their rural communities. This was surprising given that rural communities systematically engage in forms of science as they engage in subsistence activities. These activities require sophisticated knowledge of natural processes, plants, animals, and materials. Knowledge practices related to traditional healing and medicine were commonly mentioned by the student-participants. For example, Jane states that:

> *My great grandparents were traditional healers, so they passed the knowledge to my granny. So her knowledge about the traditional medication of how to prepare them, it motivated me a lot in life sciences…because she was the one who nurtured me. I spent a lot of time with her and that's how I got motivated in life sciences because I wanted to know more based on what I have learnt from home.*

Such statements demonstrate how ethnobotanical knowledge is embedded in rural communities' cultural and religious life (Berkes, 2012). According to Lave (1991), people come to understand themselves in relation to their natural environment by organizing their knowledge of flora and fauna to enhance their lives. Although rural students are knowledgeable about these traditional cultural practices, there was little evidence that these were seen as resources within the higher education environment.

A notable exception to this is the role of rural knowledge practices in preparing students for the notion of engineering design. For example, Ken argues that a certain aspect of his rural upbringing prepared him for engineering design:

> *Yes, when I grew up, we used to make cars, small cars using bricks we used to just yah make some small houses there then used the bricks to play there yah that kind of the things so yah we learn how to actually try to if I can say in engineering there is something that we called, we design yah so that kind of a thing you know.*

Similarly, Sef contends that:

> *I used to play with my friends…we used to have everything organized… Yeah so many times we will build this kind of a house for ourselves like for parents, we would have another one for babies. We used card box to build, that kind of inspired me to be a designer (laughs) like I always wanted to plan.*

By and large, however, the students constructed their rural upbringing as a disadvantage. For example, Terry states that:

> *Sometimes they teach about some events you have never heard of, they teach you about casinos… but you have to imagine them. Sometimes they give you examples you do not relate… in rural areas, we are not exposed to a lot of stuff...and they expect us to have experienced such things. So when it come to the examples they give, that's where they kill us.*

In this case, not only are the unique knowledge practices of rural students ignored, but dominant, urban practices are privileged to the detriment of some students in the class. It is perhaps for this reason that, in the focus group session held with the students, Paul, with much agreement from his fellow student-participants, describes his experience as follows:

> *It's like when you go to war, you go with your tools. But when they are useless its automatically that you will struggle. Almost everyone brought everything but in most part it failed because of this environment that we are not familiar with.*

This is indeed tragic as, if given the necessary support and recognition, students from rural backgrounds can and should be able to recontextualize their knowledge practices at university, the possibility of which is highlighted in the above comments by Ken and Sef, pertaining to engineering design. However, this is not possible if these knowledge practices – derived from personal experiences, elders, parents, neighbours, and peers, and constituting the 'lived texts' of students' upbringing – are de-valued in the higher education context.

Knowledge Practices Related to Language and Literacy

The development of mathematical and scientific knowledge is underpinned by language and literacy skills. This is well-argued by Kate, one of the participants in this research:

> *For me science is mostly its derived from Latin...everything seems foreign. Some of the words you can't even translate them into your own language. So that thing of linking what I know from home and what I am learning here it's not that easy. We constantly have to go and research.*

Here, Kate identifies the fact that language presents a significant challenge to rural students, particularly in a multilingual environment such as South Africa. Most rural students are expected to adopt English as a medium of instruction upon entry into higher education. As Jabali describes, their struggle is not because they do not *know* but because they struggle to understand the language:

> *There is little or no interaction between the lecturers in university because of the language of communication, sometimes you don't get the terminology but when things are expressed in your language that's when you understand better, I personally struggle with understanding academic papers we have to study. This causes poor performance.*

A particularly lucid example of how language barriers serve to conceal traditional forms of knowledge – in this case related to science – is provided by Kate:

> *It's the vocabulary or the objects that sometimes they make examples with that I never heard of before. Like in first year when I was doing my introduction to engineering there was this thing that you were to design it's called bio-mass; I was not familiar with those words. So it was kind of too much work for me I had to do research about it only to find that it is something that I know. So sometimes we don't get the concept because we are not familiar with those words.*

However, the data collected for this research shows the wealth of linguistic resources that rural communities draw from; these emerge in a variety of contexts, including homes, church services, children's play, conversations on the street, community gatherings, agricultural work, festivities, and rituals. Literacy learning is intricately tied to social contexts (Barton and Hamilton, 2000), and literacy development in the rural communities of the student-participants corresponded to specific social roles. As Jane shares:

> *And then you just gather as a community you dance those rituals dancing and then you sing if you're a singer and then there were some troops… they play these drums. Yah… and then there will also be other chiefs who also come and then they will also share their stories and then they also give motivations for the youth.*

This richness highlights a need for hybrid literacy practices (Hornberger, 2005) within higher education that provide students with opportunity to deploy their rich linguistic resources and, in so doing, connecting their sociocultural backgrounds to learning at university. Archer's work on symbolic objects and academic literacy in an engineering context (2008, 2009, 2010) is a useful example of how this might be achieved. This work demonstrates that lecturers need to create opportunities for students "to use their cultural knowledge, speech practices, communicative genres, and diverse ways of engaging text" (de la Piedra, 2006: 402) in order to create enabling spaces that enhance learning, especially for students from rural backgrounds.

Conclusion

The generation of knowledge is profoundly situated and relational, involving power and social relations. It is therefore important to understand how universities open up or limit possibilities

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for students from rural contexts in ways that either augment or alleviate inequalities in educational access and achievement. In this paper, a practice-theory perspective allows us to reject the implicit view of engineering knowledge as objective, neutral and value-free. In many cases, as shown in the findings of this research, the values and practices that emerge out of the realities of students from rural backgrounds, often go unrecognized and unutilized in their formal learning. This is problematic, as opportunities should be created to enable these students to recontextualize their knowledge practices at university.

The notion of situatedness of knowledge highlights the importance of shared historical and social resources in sustaining mutual engagement across diverse participants with diverse experiences in diverse contexts. A dialogic approach to pedagogy in engineering education may better acknowledge and legitimize diverse forms of knowledge. Subject content can be presented in a way that reflects the familiar lived experiences of a range of diverse students (including those from rural backgrounds). Indeed, language and literacy are crucial to such endeavors: as Mamdani (2019: 26) argues, “if you want to access a different intellectual tradition, you have to learn the language in which the tradition has been historically forged”. We argue that the corollary of this is also true: that if we want to recognize and give value to rural knowledge practices, we need to recognize and give value to the linguistic traditions and literacy practices through which these too have been forged.

This may involve a shift away from the view of engineering as a hierarchical and singular discipline and towards expansion of disciplinary boundaries and greater epistemological diversity. Creating spaces for a plurality of knowledges may enhance educational access and achievement (De Sousa Santos, 2014). This paper has attempted to understand rural students’ knowledge practices and the extent to which these practices aid students in their learning within engineering education. Unfortunately, it would appear, as was perhaps to be expected, that curricula, teaching and learning and assessment in higher education do not adequately recognize and give value to traditional ways of knowing. The student-participants in this study struggled to identify specific knowledge practices that they drew on in their engineering studies, despite numerous prompts to allow them to do so. This illustrates the extent to which alternative forms of knowledge remain unrecognized in higher education in that even those who possess such knowledge struggle to recognize its value. Nonetheless, there is some evidence that these knowledge practices may assist in engineering education, in particular in the form of estimation and engineering design. How these knowledge practices might be incorporated into the engineering curriculum is beyond the scope of the present paper – but offers rich potential for future research and pedagogical efforts.

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"Nevertheless, she persisted:" Women thrive when they experience the joy of doing engineering in a climate for inclusion

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ABSTRACT

CONTEXT

For the last 40 years, the aggregate number of women receiving bachelor's degrees in engineering in the US has remained stuck at approximately 20%. Research into this "disappointing state of affairs" has established that "the [educational] institutions in which women sought inclusion are themselves gendered, raced and classed" (Borrego, 2011; Riley et al., 2015; Tonso, 2007).

PURPOSE

Our focus is ***women students who thrive*** in undergraduate engineering student project teams. We need to learn more about how they describe becoming an engineer, about how women come to think of themselves as engineers and about how they perform their engineering selves, and how others come to identify them as engineers (Tonso, 2006).

METHODS

We are guided by a feminist, activist, and interpretive lens. Our multi-case study method, i.e., three semi-structured interviews and photovoice, offers two advantages: 1) the knowledge generated by case studies is concrete and context dependent (Case and Light, 2011); 2) case studies are useful in the heuristic identification of new variables and potential hypotheses (George and Bennett, 2005).

ACTUAL OUTCOMES

Our preliminary results suggest these women find joy in their experience of developing and applying engineering expertise to real, tangible, and challenging problems. They find knowing-about and knowing-how exciting, self-rewarding and self-defining. Further, these women work to transform the culture or ways of participating in project teams. This transforming not only facilitates knowing-about and knowing-how; but also it creates an environment in which women can claim their expertise, their identity as engineers, and have those expertise and identities affirmed by others.

CONCLUSIONS

If we aim to transform our gendered, raced, classed institutions, we need to learn more about women who thrive within those institutions. We need to learn more about the joy of doing engineering that these women experience. We also need to learn more about how they create an "integration-and-learning perspective" for themselves (Ely and Thomas, 2001) and a "climate for inclusion" within those project teams (Nishii, 2012), a perspective and climate that fosters the joy of doing engineering.

KEYWORDS

Female, Project Teams, and Undergraduate Engineering Education.

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Introduction

For at least the last 40 years and despite all the well-intentioned efforts, the aggregate number of women receiving bachelor's degrees in engineering in the US has remained stuck at approximately 20% (Beddoes and Borrego, 2011). Sadly, the research that has been done seeking to foster women's increasing participation has used limited rationales, e.g., the pipeline theoretical framework and inadequate theories, including only a few types of participants' roles in only a few types of settings (Beddoes and Borrego, 2011). Such research has been characterized as lacking diversity, e.g., ignoring intersectionality theory, overwhelmingly quantitative, homogeneous, and standardized (Riley et al, 2015). Although it has established that the educational institutions in which women are seeking inclusion are themselves gendered, raced, and classed, the aforementioned research has had little impact on implementing change within those same institutions. Indeed, it may have created a negative discourse regarding engineering education, often associated with deficit thinking (Valencia, 1997); and thereby actually deterred women from viewing engineering as a viable educational and career option.

Our research is distinctive in focus and methodology. Our focus is undergraduate women who are thriving in engineering student project teams and our methodology attends to small numbers in order to learn from small numbers (Pawley, 2013). In order to achieve the goal of more women engineers and to provide a more inclusive and welcoming engineering community, we need to learn more about women's experiences becoming engineers (Tonso, 2007; Tonso, 2014). We need to learn more about why, in our case, women are thriving and how they come to think of themselves as engineers. And, we need to learn more about how women perform their engineering selves, and how others come to identify them as engineers (Tonso, 2006). In this paper, we present the early results of our research. Our aims are two-folded: 1) to facilitate our own reflection on what we are learning and hoping to learn, and 2) to share what we are learning with wide-ranging audiences in order to garner critical review.

Methods

In our approach to learn more, we are guided by a feminist, activist and interpretive lens, one that is grounded in women's experience, gives voice to those women whose experience is sometimes hidden, and encourages emancipatory praxis (Olesen, 1994). Such a perspective is often referred to as standpoint epistemology. According to Sprague (2016), standpoint epistemology argues that all knowledge is constructed from a particular position and that what the knower can see is shaped by the location from which that knower's inquiry begins.

We have adopted a multiple, layered qualitative case study design to learn more about a specific, bounded system – women who are thriving in undergraduate engineering student project teams (Stake, 2005). Engineering student project teams are extracurricular teams that work towards a competition, a service project, or for a client. To date, there is very little research on such teams and what research does exist has not explored gender. Rather the research tends to focus on generalized access (Foor et al., 2013); active, experiential learning (Sirinterlikci and Kerzmann (2011); professionalization of the undergraduate experience (Bland et al, 2016); and the ways project teams can enhance the traditional curriculum (Sulzbach, 2007). In addition, we are investigating these women at three different institutions: a private college of engineering located in the northeast, a state college of engineering located in the Midwest, and a designated MSI state college of engineering in the West. Each institution represents a case, and we expect commonalities and differences in women's experience across these cases. Within each institution, each woman undergraduate student stands as a unit of analysis. Similarly, we expect to observe commonalities and differences across the experiences of these undergraduate women.

Thriving is a term that we choose to describe the experiences of these women undergraduates and our approach has much in common with a relatively new movement: positive psychology and human thriving. Positive psychology represents a "shift from an

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emphasis on pathology toward positive human functioning" (Brown et al., 2017). We too understand our research to represent a shift – one from a disempowering discourse and toward an alternative, more positive discourse of empowerment. Such a different discourse highlights terms often used in reference to "thriving" – development and performance (Lerner, Dowling and Anderson, 2019), motivation (Benson and Scales, 2009) challenge and resilience (Beltmen, Mansfield and Price, 2011, Epel, McEwen and Ickovics, 1998; O'Leary and Ickovics, 1995), and trust and support (Liu and Bern-Klug, 2013). In particular, positive psychology suggests that we look for personal enablers and contextual enablers, factors related to the individual and the environment respectively that encourage thriving (Brown et al., 2017).

We use a critical sampling strategy (Creswell, 2016), i.e., we select participants purposefully using the following criteria: a) undergraduate women who have participated in engineering project teams for 2-3 years and, if possible, are in leadership positions; b) participants who consider themselves to have had positive experiences on project teams (certainly not only positive experiences); and c) participants who are willing to share those experiences. In effect, these criteria serve as our beginning understanding of thriving. We attempt to include women from all three types of project teams: competition, service, and client- serving. We expect a total sample size of 25-35 students.

As a research team, we are keenly aware that the predominate number of women engineers identify as racially white and may benefit from privileges associated with particular sociopolitical spaces. Because we are devoted to diversifying the pathways into engineering, we have and will continue to include participants who may not benefit from such privileges and identify and recruit women of color or women who are minoritized through their nationality, age, language, and social class among others. As we progress with our research, critical sampling will allow us to be cognizant of and responsive to these socially constructed and fluid categories. In addition, we have adopted the integrative model of intersectionality (not yet relevant to the results reported in this paper): one that considers each of a person's subordinate identities to interact holistically, suggesting that people experience these identities as one (Crenshaw, Gotanda, Peller and Thomas, 1995). This perspective will lead us to create a sub-codebook for women of color or other women occupying minoritized spaces separate yet still included within the overall codebook for those who identify as white. We have and will continue to recruit a majority of women of color from at least two of the institutions.

Each participant is asked to agree to a sequence of three interviews: a life history interview, individual learning journey interview, and a photovoice interview. The researchers convene regularly as a team to ensure transparency, consistency, and triangulation in the interview sequence for project quality purposes. Each interview is inductively analyzed using NVivo software for coding and qualitative analysis. The results reported here emerged from that coding and qualitative analysis of preliminary data. Our research approach gives voice to the volunteer participants and adheres to standpoint epistemology. First, case studies and the interviews in sequence focus on the participants lives as they define them. Critical sampling across three different institutions both acknowledges the partiality of any one participant's experience, not only initiating and maintaining a dialogue across difference, but also necessitating that dialogue. The sequence of interviews empowers these women to tell their stories of thriving and claim their identities as engineers. We believe that through claiming their engineering identities, women will feel empowered and powerful. Finally, emancipatory praxis will not result from calling out institutions as "gendered, raced and classed" (Tonso, 2007). Emancipatory praxis is more likely to result when those who suffer bias, can claim to thrive, can claim to be doing engineering, and being engineers in an environment that accepts them as engineers. In what follows, we report the early findings observed mostly at one institution and from the first two types of interview data. PhotoVoice interviews are scheduled to occur in fall, delayed due to COVID circumstances. The photovoice interviews reported here were conducted as preliminary research.

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Results and Discussion

Family, Gender Socialization and School

The women seem to have been members of families in which the parents were involved in their children's lives, but not so involved as to direct those lives. They were generally encouraged to explore new experiences and were supported, both with parental time and resources. The families were gendered in that there were understood male and female roles. As girls, they were aware of those roles. However, the roles did not seem to serve as a prohibition. They were allowed, even encouraged, to assume alternative roles. There were gender differences among siblings, and those differences were both tolerated and celebrated. Finally, failure was not only permitted, but it was also often understood to offer an opportunity for "getting better." Outside of the family, their gender socialization was what one might expect. Again, there were understood male and female roles. However, unlike in the family, assuming alternative roles sometimes came with consequences. Indeed, what seemed most disturbing to these women were the limitations that these gendered roles placed on them, e.g., girls are not interested in understanding how things work; or how those limitations were assumed by others to be true, e.g., girls are not good at math. The women we interviewed experienced both kinds of role limitations. And, while all the women growing up were comfortable in their normative gendered roles, they also bristled, some less and some more, when they experienced those limitations.

School represented an opportunity to explore interests, to learn by doing new things – less in relation to the standard curriculum and more in terms of what might be considered extra-curricular activities, e.g., clubs or competitions. There was always "something to do." And doing these somethings allowed them to explore, to better understand their capabilities and interests, to gain confidence, to develop greater self-efficacy and a sense of belonging in relation to their peers. This seemed quite important for positive identity formation. It was also important that what they explored was challenging and required a commitment. It was sometimes the case that the challenge and required commitment were actually more engaging than the activities themselves. Those engagements that endured often became identity-defining. The women we interviewed seemed "ready" for project teams. They were aware of the potential biases and the consequences, and they were familiar with an extra-curricular commitment. Indeed, they understood that, while challenging, both the experiences and the results of those experiences could be very positive personally.

Gendered Institutional and Project Team Context

In this study, new project team members are generally assigned by existing team members to one of a number of sub-teams. Each sub-team has a team lead. New members understand that they are to follow the directives of that team lead. The structure of the teams and sub-teams is hierarchical and typically based on seniority, but even more so on technical expertise. These two criteria are often related – those with seniority tend to have more technical expertise. However, technical expertise is very highly valued. The women in our interview cohort often reported identifying senior members evidencing expertise as "models." And while senior members may be identified as models, these women experienced little in the way of "top-down" mentorship. Also, they were expected to commit themselves to the work and to the team. If this commitment required sacrifice, e.g., little sleep, no social life, and/or ignoring other academic responsibilities, so be it. Apparent from the required commitment, project teams are very demanding. Self-directed learning or collaborative learning among team members is typical. The culture of the teams is very results- and goal-oriented. Members who cannot deliver those results or fail to meet goals sometimes leave the team. When members do leave, continuing team members are understanding, yet accommodations are rarely made to keep team members involved. Within the teams there is a clear acknowledgement of their interdependence, and an almost palpable fear of "letting others down." That interdependence contributed to the commitment that the women we

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interviewed felt toward the project team. A dedication to realizing results, to developing the necessary skills and expertise, to supporting the efforts of the other team members were recurring topics among the women we interviewed. There are some additional indications in the early data that suggest differences across institutions concerning, for example, how valued technical expertise are relative to the value of social engagement, i.e., “friendship.” That there may be differences only confirms the importance of selecting different institutions with differing ways offering students project team experiences.

Unfortunately, project teams appear just as gendered, racist, and classist as the institutions in which they are housed. All the women interviewees reported direct and/or indirect experiences of gender bias. Instances of direct gender biases tend to be face-threatening challenges of their expertise or of their authority – of their becoming engineers – as team or sub-team leaders. The value placed on expertise and seniority, both clearly related to authority, in project teams suggests that these challenges are formidable. Instances of indirect gender bias tend to dismiss or at least neutralize gender, e.g., “I don’t think of you as a girl.” Also, it is not unusual for these women to have to respond to feminine stereotypes: experiencing pressure to be cooperative rather than competitive and be carefully assertive rather than aggressive.

The project teams, as these women described them, seem to resemble, or at least evince features of other “masculinist contest cultures” or MCCs (Berdahl, Cooper, Glick, Livingston and Williams, 2018) . Berdahl et al (2018) describe such cultures as containing “toxic masculinity.” They identify four specific member features: 1) show no weakness; 2) emphasize success above all else; 3) display strength and endurance; and 4) always compete. While we are not suggesting that project teams are either extreme or even typical examples of MCCs or that the level of toxicity does not vary across teams, e.g., the more “technical teams” tend to be more toxic than the “service” teams; still there is certainly evidence of MCCs. That the teams are results- and goal-oriented does not in itself suggest masculinist contest culture, except when that orientation leads to face-threatening challenges of team members. Nor do displays of strength or endurance suggest MCCs, except when those displays require draconian sacrifices in other areas of team members’ lives.

We are not far along enough in our research to suggest with confidence how perceptions of gender may be complicated by race and class. Because we are focused on women who thrive in project teams, we are also unclear if women who left project teams, did so because of gender, race or class biases (although it is not unreasonable to assume that some women did leave because of those biases). However, it is the case that the women project team members that we interviewed strongly resisted, even openly defied instances of gender bias. They were unwilling to allow experiences of gender bias to compromise their membership and leadership within project teams. Of course, that resistance or defiance also came with consequences, often those women were “masculinized.” This masculinization itself suggests what is often true of MCCs – that power and the ability to wield power is associated with manhood.

Women project team members seemed most likely to experience gender bias when they assumed leadership roles on the teams. The leadership models these women identified for themselves often were not the ones that they had experienced or were currently present in team leadership. In other words, while these women were/are not aware of MCCs, many were/are aware that the project teams that they were participating in displayed features typical of MCCs. Consequently, they reported wanting to change the ways that leadership was enacted. They reported learning what needed to change from what they understood to be the problematic behaviour of prior leadership. The changes that they wanted to make, and had some success making, when they assumed leadership positions were to facilitate new member growth and development, to encourage mentorship by creating more feedback opportunities for team and sub-team members, to develop training protocols, to delegate more responsibility and accountability among members, to foster reflective and supportive responses to mistakes and failures, and to emphasize communality. We believe that these women, women who are thriving, wanted to create what might fairly be characterized as an alternative culture, an “integration and learning culture” (Ely and Thomas, 2001) or a “climate for inclusion” (Nishii, 2012). Indeed, some clearly wanted and hoped to offer a style of leadership that could become a much-needed alternative to those features of a masculinist contest culture already present in project teams.

While our research team was clear-eyed about what we might discover about undergraduate student project teams, we were still hopeful that we might learn of a culture unlike the academic engineering educational culture described by Tonso (2007). We were hopeful because of the increasing numbers of women members. We were hopeful because those women were assuming leadership roles at least equal to that of men. We were hopeful because of their whole-hearted enthusiasm for project teams. Consequently, we asked ourselves and our interviewees – “Given their experience(s) of indirect and direct gender bias, why did they persist? Our research has not yet matured enough for solid answers, but the women we have interviewed so far have offered us two possible answers, both of which constitute ***two experiences of agency***: 1) the “joy of doing engineering” (Goldberg and Summerville, 2014) and 2) the genuine satisfaction that can be derived from participating in, even helping to create a “climate for inclusion” (Nishii, 2012).

Joy of doing engineering

Perhaps, the single most important experience these women have while participating in project teams is the joy of doing engineering. According to Goldberg and Sommerville (2014), joy is the first pillar of engineering educational transformation. They note that that joy is a result of overcoming complexity, seeing theory applied to real-life, and learning together. Our early results suggest that these women are thriving because they experience joy in developing and applying engineering expertise, in developing “declarative knowledge” and “procedural knowledge” (Bereiter and Scardamalia, 1993) or, as the philosopher Gilbert Ryle (1949) refers to them, *knowing-about* and *knowing-how* to respond to real, tangible, and challenging problems. They reported knowing-about and knowing-how as exciting, self-rewarding and self-defining

Based on their descriptions of themselves and others in their project teams, we believe that this joy emerges in three phases: the apprentice phase, the artisan phase, and the expert phase. All three phases involve both knowing-about and knowing-how but at different levels of performance. The first phase begins when they are introduced to knowing-about as novice team most directly as sub-team members. They begin to learn relevant knowledge or knowing-about for the purpose of developing procedural knowledge or knowing-how to address a particular problem, or realize a particular aim. The artisan or second phase begins when they start to see problems from more than a single perspective, alternative pathways to realizing a certain aim. Knowing-how in this phase facilitates a more advanced, more specialized knowing-about. It is during this second phase primarily that they begin to understand themselves not only as engineers, but also as certain kinds of engineers. It is during this second phase that they begin to recognize and affirm specific disciplinary interests. Finally, in the third or expert phase, they begin to self-monitor their application, to change strategies, when necessary, to make “educated guesses.” It is in this third phase that they begin to internalize discipline-specific norms and thereby routinize the use of discipline-specific tools. Knowing-about and knowing-how are fused, each supporting the continued growth of the other. It is in this phase that they can facilitate the learning and doing for others through mentorship.

These three phases align somewhat roughly but still in ways discernable with the components of expertise articulated by Bereiter and Scardamalia (1993). They maintain that expertise is not a “thing” but rather a developmental process. Expertise is not the possession of an individual, rather the result of situated social action and interaction. Expertise involves constant and progressive problem-solving encouraging the development of “active wisdom” or cultivating new ways to both frame and solve increasingly complex problems. And finally,

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expertise is not itself a goal. Rather expertise, as a developmental process that involves others in constant and progressive problem-solving, serves goals apart from or outside of itself.

Experiencing the joy of doing engineering are personal and contextual enablers of thriving. The stories these women tell culminates with them claiming their identity as engineers. We believe these women's stories suggest an important pathway toward a genuine engineering educational transformation. The joy of doing engineering constitutes the first of the two experiences of agency.

A Climate for Inclusion

In a seminal article on diversity perspectives among groups in the workplace, Ely and Thomas (2001) identified one especially effective perspective, the "integration-and-learning perspective," that seemed to yield "sustainable performance gains attributable to diversity." According to this perspective, the different experiences, skill sets, and insights developed by members of various cultural identity groups can and do serve to change "the way people do and experience work – in a manner that makes diversity a resource for learning" (Ely and Thomas, 2001). Two of the outcomes of an integration-and-learning perspective are: 1) that participants place "a high value on process" and 2) that they share a "deep commitment to educating and learning from each other" (Ely and Thomas, 2001) .

Building on their work, Lisa Nishii (2012) introduced the construct "climate for inclusion," and investigated possible features and benefits for gender-diverse groups in the workplace. She identified three important features of an inclusive culture: 1) fairly implemented practices or the equitable distribution of resources both material and personal; 2) the integration of differences or encouraging complex perceptions of others and acknowledging ever-present variability; and 3) democratic decision-making or challenging dominant points of view and understanding those challenges as "value-enhancing propositions" (Nishii, 2012) . The two most relevant benefits were that within a climate for inclusion, relationship and task conflict in gender-diverse groups was significantly reduced. Even more importantly, the negative association between relationship conflict and work satisfaction (the more conflict, the less satisfaction) seemed to disappear. These two benefits suggest that within a climate for inclusion conflict is not understood as confrontation, but rather more like educating and learning from each other and part of the process. Further, when understood in this way, relationship conflict did not impact work satisfaction.

The project teams that the women initially joined, based their own descriptions, did not very often promote an integration-and-learning perspective, nor did they facilitate a climate for inclusion. And, even if the project teams were not full-blown MCCs, they at least exhibited features of MCCs. However, learning from the problematic behaviour of past leadership, these women, when they became leaders, changed project team culture to some extent. The above reported changes – including facilitating new member growth and development, encouraging mentorship by creating more feedback opportunities for team and sub-team members, developing training protocols, delegating more responsibility and accountability among members, fostering reflective and supportive responses to mistakes and failures, and emphasizing communality – all could be listed as practices suggestive of an integration-and-learning perspective and of a climate for inclusion.

Working to facilitate an integration-and-learning perspective and a climate for inclusion serve, like the joy of doing engineering, as personal and contextual enablers for thriving and the second experience of agency. The stories these women tell reveals them as engineers within a community of engineers, recognized by each other as engineers, empowering each other to become better engineers. We believe these women's stories suggest something important about that environment and how that environment might foster the joy of doing engineering. Again, if our aim is a genuine transformation of engineering education to something more inclusive, then encouraging the integration-and-learning perspective and a climate for inclusion might offer us a pathway.

Conclusions

Our distinctive focus and methodology allow us to identify the situated instances of all the terms highlighted in positive psychology and human thriving: development and performance, motivation, challenge and resilience, trust and support. It allows us to locate these abstractions in the particulars of these women engineers' experience. It allows us to see and understand these women as they see and understand themselves. However, it also allows us to get to know, at least a little, some very amazing women. And it suggests that if we are truly interested in transformation, then the pathway forward is to make doing engineering and being an engineer more joyful and to encourage both project teams and undergraduate engineering education to adopt an integration-and-learning perspective within the context of a climate for inclusion.

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Global Learning at Home: Understanding Students' Experiences in Global Virtual Team Projects

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ABSTRACT

CONTEXT

As the engineering workforce becomes more globalized, engineering students must develop the skills needed to work on engineering projects across cultural boundaries. Global virtual team projects are one way to develop these skills without requiring students to travel abroad. This format has the potential to improve access to intercultural learning for engineering students who are not able to study abroad or participate in extracurricular activities. Prior research on global virtual team projects has focused on a limited set of learning outcomes, rather than understanding students' experiences holistically, and has primarily used quantitative survey approaches (e.g., Zaugg et al., 2013).

PURPOSE

The purpose of this study was to gain a holistic perspective of students' experiences in a global virtual team project to explore what and how they learned through the experience.

METHODS

We used a mixed-methods approach to collect data from 65 students participating in global virtual team projects. Students from the United States, Mexico, Ecuador, and Germany formed 7 project teams that worked together for one semester. We collected pre-and post-course individual student reflections describing their goals, challenges, and learning as part of the global virtual teams. We also collected pre/post assessments using the Intercultural Development Inventory (IDI) instrument. Our team iteratively coded the student reflections to identify themes emerging from the reflections. After initial coding, we re-coded each reflection using a holistic coding scheme based on the themes (Saldaña, 2013).

FINDINGS

We identified 7 themes in the students' reflections and found that students shifted their focus from intercultural themes at the start of the semester to team dynamics, professional development, and technical topics by the end of the semester. The pre and post IDI results indicate that students who had received prior intercultural training demonstrated growth in their IDI scores whereas students who did not have prior training experienced a small decline. Further, the students who had received intercultural training were more likely to discuss intercultural knowledge in their reflections compared to the other students.

CONCLUSIONS

Our results suggest that although global virtual teams can provide opportunities for intercultural learning, such learning is more likely to occur when emphasized and supported through intercultural training. However, by taking a holistic view of learning, we highlight a range of other learning outcomes including teamwork and working in a virtual environment.

KEYWORDS

Global virtual teams, qualitative data analysis, intercultural development

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Introduction

Research on engineering work has suggested that engineers need to be able to work effectively with diverse groups of people. For example, coordinating the technical work of team members has been identified as a significant part of engineering jobs (Trevelyan, 2007). It is also important that engineers consider the impact of their work on society, requiring an understanding of both social and technical aspects of engineering problems (Bijker, 1997; Trevelyan, 2007). Additionally, engineers from different cultures define problems in different ways, suggesting that engineers should be socially, technically as well as culturally competent to operate in a global engineering industry setting (Downey et al., 2006). Similarly, Ravesteijn et al., (2006) observed that communication competence was needed to secure social consensus for innovation in engineering practice. Given the cross-cultural nature of engineering work, engineering students must have opportunities to develop the skills necessary to be successful in these global environments. The purpose of this project was to gain a holistic perspective of students' experiences in a global virtual team project to understand what and how they learned through the experience.

Literature Review

Although global learning has not historically been emphasized in engineering programs, there has been increasing awareness that these skills are important to include in engineering education (Grandin & Hirleman, 2009). In the U.S. context, there has been growth in the number of engineering students studying abroad (Jesiek, 2018), but this opportunity is not accessible for all students for personal and financial reasons. It is important, therefore, that global skill development be integrated into engineering coursework so that more students can benefit (Downey et al., 2006). Several approaches have been suggested for courses that incorporate global engineering content, including taking a humanities perspective (Downey et al., 2006), using case studies (Rectanus, 2013), incorporating a cultural simulation (Davis et al., 2019), and global virtual team projects (Alves, 2018; Zaugg et al., 2012). This final option has been a popular choice within engineering specifically because so many engineering courses already include team projects, so less adaption is required on the part of instructors.

Prior research on global virtual team projects has suggested that these experiences can contribute to engineering students' development of intercultural skills. For example, one study compared students who had studied abroad with those who participated in a course with global virtual teams, finding that although the study abroad students saw higher gains in intercultural competence, there were some areas where the students in the course scored just as high or better (Ball et al., 2012; Zaugg et al., 2013). Other studies have identified similar outcomes from global virtual team projects, including understanding cultural differences (Miranda et al., 2017), awareness of diversity (Reid & Garson, 2017), and intercultural maturity (Alves, 2018). However, research on global virtual team projects has also identified challenges students face while working on such projects, including personality conflicts, digital literacy issues, prejudices and stereotypes, failure to develop relationships, and lack of cultural awareness (Alves, 2018; Liu et al., 2015; Reid & Garson, 2017; Whitman et al., 2005). As part of their project on global virtual teams, Zaugg et al., (2012) identified several best practices to help overcome these challenges, such as requiring student teams create a code of conduct, helping students develop their communication skills before engaging in virtual teams, and having students reflect upon their experiences.

Few studies of these earlier studies have explored students' experiences while they are participating in global virtual teams to understand how opportunities for both learning and conflict may arise in this environment. Prior studies have used surveys, questionnaires, interviews, and reflections to understand the development of competencies in students but without much emphasis on student perspectives (Alves, 2018; Ball et al., 2012; Duus & Cooray, 2014; Liu et al., 2015; Miranda et al., 2017; Whitman et al., 2005). In contrast, our

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study aimed to uncover student perceptions of their experiences in global virtual teams in a holistic manner by analyzing student reflections at the start and end of the semester.

Background

The Global Engineering Alliance for Research and Education (GEARE) is a comprehensive study and work abroad program from the College of Engineering at Purdue University available to students in all engineering disciplines. The multi-year program involves intercultural training sessions, domestic professional experiences (industry or research internships), and international experiences including one semester of study abroad and a work experience in the same country. The program also requires a global design project (GDP) that may be conducted at an international location or remotely. In response to the COVID-19 pandemic, all GDPs have been conducted remotely in collaboration with GEARE partner universities. In the GDPs, students work in a multidisciplinary team of students from both Purdue and a global partner university to tackle real-world problems related to engineering, transportation, energy, and sustainability in a global context.

Starting in Fall 2021, intercultural learning sessions were incorporated into the GDP course at three points during the semester (early, middle, and end). Before these sessions, students submitted individual reflections (discussed in the Methods section). During the intercultural learning sessions, one of the instructors led group discussions building on the reflection topics and asking students to respond to each other's ideas. The topics of these discussions included reflection on the students' experiences with their project teams, looking specifically at their teamwork, intercultural awareness, and any mediation needed to work together. The goal of these sessions was to provide a space in which we guided the students to consider more critically how they worked together and their own goals for the projects.

Methods

Participants

In Spring 2021, 69 students participated in the GDP course from four countries: Ecuador, Germany, Mexico, and United States. All students had a background in engineering, although their specialties differed. All the students from the United States had completed a prior semester-long intercultural competency introduction course, and during Spring 2021 were also taking the GEARE program's second semester-long intercultural seminar. The students from the other countries did not have previous intercultural training. This project was approved by the Purdue University Institutional Review Board, and 65 of 69 students (94.2%) in the GDP course agreed to participate in this study.

Data Collection

We collected both quantitative and qualitative data for this project. The quantitative part consisted of a pre-and post-test of the Intercultural Development Inventory (IDI; Hammer et al., 2003). Students took the IDI assessment at the beginning and end of the course. The IDI assesses intercultural competency, locating individuals on the intercultural continuum (ranging from denial to adaptation). Additionally, we collected students' reflections on cross-cultural teamwork at the start and end of the semester. We provided a prompt for each reflection in both English and Spanish, and participants were encouraged to respond in the language in which they felt most comfortable. The prompt for the end of semester reflection is shown below:

- *Tell the story about one specific experience on the team project that has been significant for your learning. This could be something that went well, was challenging, or helped you develop a different perspective. Explain what happened, how you responded, and what you learned from the experience (e.g., knowledge, skills, behaviours, perspectives).*

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- *In addition to the learning mentioned as a part of the first question, what other knowledge, skills, behaviours or perspectives have you learned related to working on a team project, working on a cross-cultural team, and/or working in a virtual environment?*
- *What areas for growth can you identify that you want to continue working on in your:*
    - *Next group project?*
    - *Next cross-cultural experience?*
- *Lastly, think about your team as a whole. What did the team do well? What areas for improvement might you identify if the team was going to work on another project together? (which is typical in many work settings)*

The start of semester prompt was similar but asked about students' prior intercultural experiences, prior team projects, and expectations for the semester. Most students wrote between 1-2 pages for each reflection.

Data Analysis

We analysed the students' reflections in two stages. We first thematically coded a subset of reflections to identify common themes. Our research team of five authors reviewed the same subset of reflections through several iterations of analysis and group discussion to develop the final set of themes. In the second stage of analysis, the research team used holistic coding to score each reflection based on these themes (Saldaña, 2013). We began by coding a subset of reflections as a group to ensure a consistent coding approach. Two researchers then scored each reflection and met to discuss and reach an agreement. Our scoring approach assessed the depth with which a reflection discussed each theme, where a 0 indicated no mention of a theme, a 1 indicated a surface-level mention, and a 2 indicated a detailed description or a story related to a theme. This scoring process was applied to both the pre- and post-course reflections, which were pooled separately.

Limitations

One limitation of this project is the format of the course, where students were divided across seven projects with different engineering goals and professors. Thus, students had more variation in experiences than in a typical course. A second limitation is that the post-course reflection was assigned at the end of the semester when students also faced significant amounts of work, such as exams. This may have resulted in less time and thought spent on the reflections. Finally, all students faced different situations related to the COVID-19 pandemic, which impacted their ability to engage with this project and the related reflections.

Results

IDI Results

A total of 47 students completed both a pre-course IDI and a post- course IDI. The results from the tests showed that the entire group grew an average of 4 points (see Table 1).

Table 1: Results from the Pre- and Post-Course IDI Surveys

	Pre-Course IDI	Post-Course IDI	Change
IC Training	92.00	101.73	9.73
No IC Training	83.58	81.90	-1.68
All Students	87.71	91.34	3.61

The students who had received intercultural training (IC training) in a prior semester as part of the GEARE program ("IC training" group in Table 1) had higher average scores in the pre-

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course assessment and saw more significant growth between the pre- and post-test. Two separate paired *t*-tests were conducted to compare the effect of GDP on the groups with and without the IC training. The results show a significant increase between the pre-course and post-course IDI surveys for the group with IC training ($p < 0.01$) but no statistically significant difference for the group without IC training. We also compared the scores of the two groups using *t*-tests and identified no significant difference in pre-course scores, but the IC training group's scores were significantly higher in the post-course survey ($p < 0.01$).

Reflection Results

In the first stage of our analysis, we used thematic coding to identify common themes in the student journals and identified seven themes using this approach. These themes along with their definitions and example quotations from student reflections are shown in Table 2. This process addressed the first goal of our project, which was to gain a holistic perspective of what and how students learned through global virtual team projects. The themes we identified revealed that such projects provide a range of learning opportunities for students across technical, professional, and intercultural topics.

Table 2: Themes Identified in Student Reflections

Themes	Definition	Sample Quotes
Technical	The reflection mentions technical goals, developing a product, or creating a deliverable.	*"I remember in a specific moment when I was working with [instructor] on relating the lift distribution analysis of the 3-D elevator to the proper sizing of the glider elevator based on our selected NACA 0024 profile, and [instructor] had ideas that I had not considered when I felt stumped like I hit a wall."*
Team Dynamics	The reflection provides specific examples of challenges, benefits, or processes that teams face.	*"I personally believe that the previous issue was a failure on the part of [teammate] and I to properly make sure everyone in the team felt included, which I think is one of the unique issues that can arise with remote work."*
Professional Development	The reflection describes specific skills, knowledge, or growth the student gained or would like to gain (including language skills, but not technical or intercultural skills).	*"This was challenging because I felt unprepared, since we didn't really have a 'backup plan.' Although the whole experience was pretty stressful, it taught me a few valuable lessons about how to assign different responsibilities and to prepare properly for a group presentation."*

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Social	The reflection mentions wanting to connect with or get to know teammates in a personal sense.	*"I wish I would have spent more time getting to know my team members personally, and asked more questions about what their university experience is like, what classes they take, etc. I do think this is harder virtually, because it's not very common to make small talk in a Zoom class."*
Intercultural Knowledge	The reflection mentions specific cultural differences (i.e., *facts* about cultures).	*"I remember our team met for one of our weekly meetings and we ended up having a very insightful conversation about the various social movements (specifically regarding women) in each of our countries."*
Intercultural Mindset	The reflection mentions respect, openness, or cultural awareness (i.e., positive *attitudes* towards other cultures).	*"Some method should be implemented to make sure that everyone is understanding what needs to get done and feels free to express their thoughts without feeling insecure. I do not know the best way to go about doing this, but I think starting with patience and trying to listen is a good way to start."*
Intercultural Behavior	The reflection mentions adapting, being flexible, adjusting to others' preferences, or wanting to learn new approaches from other cultures (i.e., past or future *actions*).	*"Communication-wise, it's the first time I've worked this closely with someone from another country, with a different cultural background. It was definitely a learning experience trying to be careful how I word things, and trying to avoid using too much slang in my texts. There was also the different type of English that both of us had to adapt to."*

In the second stage of our analysis, we scored each reflection on a scale of 0-2 for each of the seven themes identified above. We used heat map visualizations to compare the scoring results between the pre- and post-course reflections (Tables 3 and 4). These tables show the percentage of reflections that received each score for each theme, where 0 indicated no mention of a theme, 1 indicated a surface-level mention, and 2 indicated a detailed description or a story. This process addressed the second goal of our project, which was to explore how students' experiences shifted over the course of the semester.

These heat maps summarize our main observations in comparing the pre- and post-course reflections. The biggest shift was that at the start of the semester, students were more likely to discuss the intercultural themes than at the end (especially *Intercultural Mindset*). Instead, the post-course reflections focused primarily on topics related to the *Technical*, *Team*

Dynamics, and especially *Professional Development* themes. Some students seemed to be aware that this shift had occurred, mentioning that they wished they had spent more time learning about the cultures of their teammates and getting to know them as individuals.

Table 3: Pre-course reflection heat map

Score	Themes						
	Tech	Team Dyn	Prof Dev	Social	Int. Know.	Int. Mind.	Int. Beh.
0	42.86	7.14	14.29	67.86	30.36	17.86	69.64
1	33.93	30.36	53.57	28.57	39.29	66.07	19.64
2	23.21	62.50	32.14	3.57	30.36	16.07	10.71

Table 4: Post-course reflection heat map

Score	Themes						
	Tech	Team Dyn	Prof Dev	Social	Int. Know.	Int. Mind.	Int. Beh.
0	41.07	5.36	16.07	55.36	35.71	42.86	62.50
1	21.43	10.71	33.93	39.29	41.07	39.29	30.36
2	37.50	83.93	50.00	5.36	23.21	17.86	7.14

We also compared these results between the IC training and no IC training groups (from Table 1) but did not see many notable differences in their responses on the reflections. The students with prior IC training were more likely to discuss *Intercultural Knowledge* in both the pre-and post-course reflections, which may be the result of their prior training. Their focus on *Intercultural Knowledge* development may have supported their improved scores on the IDI. The no IC training group was slightly more likely to discuss *Professional Development* in the pre-course reflections, mainly focusing on improving language skills through the course. The overall trends between pre- and post-course were similar between the two groups.

Discussion & Implications

In this study, we used a mixed-methods approach to explore students' experiences and outcomes during a global virtual team project course. In analyzing the pre- and post-course IDI scores, we found that the students in the course had improved their IDI scores on average, but that students who had prior intercultural courses and training saw more notable growth than those who did not. We gained a more holistic view of student learning by analyzing students' reflections at the start and end of the semester, identifying seven main themes that students discussed in their experiences of the course: technical topics, team dynamics, professional development, social interactions, intercultural knowledge, intercultural mindset, and intercultural behavior. Over the semester, there was a shift in the reflections towards the technical, team dynamics, and professional development topics, resulting in less emphasis on the three intercultural themes in the post-course reflections.

Taken together, our results suggest that although global virtual teams can provide opportunities for intercultural learning, such learning is more likely to occur when emphasized and supported through intercultural training. The IDI results we report here align with similar findings from the study abroad literature, where students who have more pre-travel support and ongoing cultural mentoring during their time abroad experience greater increases in IDI scores (Engle & Engle, 2012; Vande Berg et al., 2009). Although we sought to incorporate intercultural learning in the course via the intercultural learning sessions, these remained a much smaller component of the course than the engineering projects. The students' reflections revealed that they tended to focus on the technical and team learning outcomes of the course, despite their interest (expressed in both pre-and post-course reflections) in the

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intercultural learning component. Students have been found to adapt their learning approaches and priorities based on their perceptions of an assigned task (Marton & Säljö, 1976), which may have influenced students' increasing focus on the technical projects over the semester (as the projects comprised the majority of their final grade).

Although the reflections had less emphasis on intercultural learning than we had hoped, the students thoughtfully reflected on several other important learning outcomes. In particular, students described *Team Dynamics* that they dealt with through the semester and how they handled these situations. This finding aligns with prior work on global virtual teams, which has suggested that there are unique teamwork skills required in virtual environments that can make such projects more complex to manage than those where students are co-located (Liu et al., 2015). Students also emphasized other *Professional Development* outcomes, including topics such as public speaking, project management, and time management. Students reflected that these skills were necessary to work effectively in a virtual environment, and anticipated that this would be a part of their future work experiences. Similar findings have been reported for marketing students in global virtual team projects (Duus & Cooray, 2014).

In the era of COVID-19, there has been a rush to develop global virtual team projects as traditional travel-based opportunities for intercultural learning have been unavailable. Although this approach may be useful for improving access to intercultural learning for engineering students, our findings indicate that simply placing students in a global virtual team environment may not result in intercultural learning. We suggest that if intercultural learning is a desired learning outcome for a global virtual team project course, it is important to emphasize this part of the course equally with the other course content. For example, it may help to include more intercultural training than we did in this study and emphasize intercultural learning more in course assessments. Although the students in our study were interested in getting to know their teammates and learning about their cultures, this does not happen organically in global virtual teams, so instructors will need to build opportunities for such connections and learning to occur. Lastly, based on our experience in this project, we recommend the use of reflections as both an instructional and assessment approach, as they allowed us to gain a more holistic perspective on students' learning outcomes.

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Professional Shame as a Socio-Psychological Mechanism for Marginalization in Engineering Education

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BACKGROUND

Previous work has identified the reality of structural constraints placed on engineering students from underrepresented gender, racial, or ethnic backgrounds, a process known as minoritization. Students from minoritized and marginalized backgrounds are often expected to overcome additional obstacles in order to be successful in engineering or to claim identity as an engineer. Such a cultural backdrop contributes to the experience of *professional shame,* which has not yet been characterized in the lived experiences of engineering students who identify with minoritized backgrounds.

PURPOSE

We contend that professional shame is a major factor in both creating and perpetuating cycles of marginalization that inhibit students from forming a professional identity as an engineer or succeeding in their academic program. Anchored in theoretical foundations of psychology and sociology, we define professional shame as a painful emotional experience that occurs when individuals perceive themselves to be wholly inadequate in relation to identity-relevant standards within a professional domain. In this paper, we examine the lived experiences of professional shame in undergraduate engineering students in the United States who identify with racial, gender, or ethnic backgrounds that are minoritized within the structural constraints of their engineering programs.

METHODS

To answer our research question: How do students from minoritized gender, racial or ethnic backgrounds experience professional shame within the context of engineering education? We conducted an interpretative methodological analysis (IPA). Specifically, we conducted semi-structured interviews with junior engineering majors (n = 7) from two predominantly white institutions (PWIs) who self-identified as being from a minoritized gender, racial, or ethnic background. We found IPA to be especially effective in answering our research question while affirming the nuances of the diversity found in our participants' gender, racial and ethnic backgrounds. We carefully analyzed the interview transcripts, generating descriptive, linguistic, and contextual comments. These comments informed multiple emergent themes for each participant, which were subsequently integrated into robust themes that characterized the psychological experiences shared by all participants.

SUMMARY OF FINDINGS

Our findings are summarized in four robust, psychological themes. First, minoritized identities were salient in moments of professional shame. Second, in response to professional shame, students sought out confirmation of belonging within the engineering space. Third, their perception of engineering as an exceptionally difficult major that required exceptional smartness intensified the shame experience. And, finally, participants experienced a tension between wanting to adhere to engineering stereotypes and wanting to diverge from or alter engineering stereotypes.

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SIGNIFICANCE AND IMPLICATIONS

Through examining participants' experiences of shame and subsequent struggle to belong and claim identity as an engineer, we seek to address efforts in bolstering diversity, equity, and inclusion that may be hindered by the permeation of professional shame in the experience of minoritized students. We see these findings as critical in giving insight on how minoritization occurs and so that equity can become a systemic objective for everyone in the engineering community rather than the burden only on the shoulders of those who are marginalized by the community.

KEYWORDS Emotion, shame, identity, marginalization, interpretative phenomenological analysis

Introduction & Background

In this paper, we are specifically examining the experience of professional shame in the context of engineering education for students who are minoritized in their departments. Based in our understandings from sociopsychological literature, we define shame as powerful emotional experience that occurs in an individual when they perceive to have failed to meet identity-relevant, socially constructed expectations in a professional setting (Gilbert, 2003; Huff et al., 2020; 2021; H. Lewis, 1971; M. Lewis, 1995; Tangney & Dearing, 2002). From previous literature about marginalization in engineering, we know that this socio-cultural phenomenon impacts the individual student in a myriad of ways that provide barriers for minoritized students (Foor et al., 2007, Faulkner, 2007; Hererra & Hurtado, 2011, Russell & Artwater, 2005). Like most experiences for students from underrepresented backgrounds, professional shame is tied to this experience as a student *minoritized* in their department, that is, or constrained as subordinated or underrepresented on the basis of gender, racial or ethnic backgrounds (Varraco & Newman 2016). Deep shame, especially exemplified in the cases of our participants who hold identities as a student who is minoritized in their department, can be found in felt failure to match the *idea* of an engineer—even when that idea is completely unrelated to competency in the engineering field. In conducting this research, we seek to understand these emotional experiences so that we may improve both individual and cultural strategies for advancing systemic equity and emotional well-being within engineering programs.

Research Question and Methods

To understand the lived experiences of shame for minoritized students within the context of engineering education, we asked the research question: How students from underrepresented racial or ethnic backgrounds experience shame?

Recognizing that professional shame is both a deeply individual phenomenon while also being influenced by broader patterns within the experience of holding a minoritized identity, we used interpretive phenomenological analysis (IPA). IPA allows the study of personal experiences of phenomena in ways that maintain the nuances of individual experiences while allowing investigators to present the findings in a cohesive manner (Smith et. al 2009). Emerging literature demonstrates that underrepresentation, although being quite diverse in its manifestation for different groups, is often the mark of deeper patterns of marginalization at play. (Faulkner, 2000; Faulkner, 2007; Jorgenson, 2002). The participants of this study belonged to social categories who were minoritized in relation race or gender in engineering education. This study was approved by the institutional review boards of the investigators' universities.

Data Collection

Participants were recruited using a sampling survey sent out through the engineering departments of two predominantly white institutions which recorded responses about their racial and gender identities and surface level experiences of failure which helped the investigators gauge their willingness to speak on the subject of the interview. Each participant was given a $35 Amazon gift card for their participation in the study. In relation to the gender, racial, and ethnic identifications of the participants, we interviewed two participants who identified as White women, three participants who identified as men from a racially minoritized background, and two participants who identified as women from a racially minoritized background. In order to ascertain the participant's experience of shame as an engineering student with an underrepresented background, we followed a non-standardized interview approach in which the participant guided the researcher through their experiences of failure within the department and then probed the emotional experience of such failure experiences. Our approach to interviewing the participants is extensively detailed elsewhere (Huff et al., 2020; 2021).

Data Analysis

Consistent with the process of IPA, we analyzed the interviews with attention the participants' experiences of shame within the specific context it took place. The transcripts were prepared for analysis by sending the interview recordings to a professional service and transcribed a second time by the investigators with special attention to nuances in the way the participant spoke. From there, the interviews were analyzed with three lenses that gave insight to how the participant understood their experience on their own terms (descriptive), the language the participant chose to use (linguistic) and connections to socio-psychological concepts (conceptual). From these comments, emerging themes, which highlighted major insights or patterns from the interviews, were developed. Each participant had their own set of emerging themes from the interview. Emerging themes from each participant were taken from the interview, with reference to the specific quotes from which they were drawn and organized into 3-5 overarching themes. Quotes related to the individual participant's overarching themes were then organized into themes regarding the patterns found in the group. It is from these themes that our findings are drawn.

Findings

In order to present the experiences of these seven participants in a way that is understandable while preserving the nuances of the individuals, we have chosen to delineate the findings from this study in four themes. First is an exploration of how salience of the participants' marginalized identities fostered a sense of unique pressure to succeed. Second, in recognition of the experiences of the first theme, we see a pattern of searching for confirmation belonging in the engineering space. Third is an exploration of how the definition of engineers as exceptional impacted our participants' ability to identify themselves as part of the engineering group. Fourth and finally is discussion of the complex relationship the participants had with the stereotypical expectations of being an engineer and their individual need for belonging.

Theme 1: Salience of Minoritized Identities

Participants experienced heightened awareness of their minoritized identities by feeling categorized by those around them. Such categorization added complex layers to how they understood themselves within engineering and, consequently, how they would experience professional shame. For example, Nicole described her identity categorization as a woman among her male peers and a resulting desire to prove her place:

> *When I started in engineering, some boys did not know how to talk to me in the class. I was like, "Guys." I told them, I said, "Treat me like a boy because we cannot have a conversation." Because they would look at me, they're like, "Hey." Then they'd run away. I'm like, "Human, I'm a human. It's fine, really" … But I was like taken aback by it, like, "This is why women shouldn't do engineering." (mockingly) I was like, "Look, I have a brain. I can do whatever I choose to do" (Nicole).*

In Nicole's case, the salience of her minoritized identity created a complex weight on her performance:

Honestly, I just felt more pressure on myself, like well I'm standing for all girls in engineering. Since there's only two of us, I have to do better. And I definitely did put more pressure on myself. I mean, I still do. I feel like a responsibility to represent - to try and represent women in engineering as well as I can, which is not a bad thing. I don't think- It can be, and I definitely put a lot of pressure on myself for that (Nicole).

For Rebecca, identity salience developed an into understanding that the responsibility to positively represent one's own identity group is an opportunity. She says, "Most engineers are guys. That's like the stereotype so I like being a girl. I think I can bring an interesting perspective to engineering. So I enjoy that." Here, identity categorization lead to a sense of pride in being able to positively stand for their identity group. Mano's case provided another strong example of this thought process as she describes herself within the engineering space:

And there's not a lot of like natives in general, um, in the STEM field at all. So I think it's really cool that us natives, we can actually be a number. I mean, we can start growing our number. Um, and especially me being a native woman, I mean being a woman is already a minority and me being a native woman is already a minority within a minority. So it already kinda makes me a little exclusive. So it, and I, of course I want to, um, have other women to come into it, but I'm also open to like just everybody in general (Mano).

From this perspective, success does not only belong to the Mano herself, but to all Native women in STEM. The sense of pride demonstrated in the above quote is foundational in positioning the self in the engineering educational space. It is from this position, meeting the salience of an underrepresented identity with pressure to perform and/or pride, that our participants experience shame. In both perceived success and failures which contribute to shame, the experiences of their identity being made salient in the educational space were relevant in how participants applied the meaning of external events to their sense of self.

Theme 2: Searching for confirmation of belonging in the engineering space

For our participants, the experience of failure brought on shame characterized by a global, that is, holistic, negative self-evaluation. Consequently, they sought affirming messages regarding their overall value as an engineer through belonging within the engineering group. Leona discussed her experience of looking around to see if she was failing with others or alone:

And during that class it's like there's people who are doing the work and they're speeding through it. And then there was like me and my friends, we were just like, I don't know how to do this. And we tried to get her to help us and it didn't help at all. And I felt like I just wasn't a part the major because of that separation. The people who are doing well, they just ignored all of us. They just wouldn't want to help. And the professor tried to make groups for people to talk to each other, the people who are doing well, she would pair two of those people with people who weren't doing so great. And that made me feel even worse because those people just didn't talk to both of us (Leona).

Here, the isolating nature of failure compounds the shame experience and expands the implication upon the global self. As failure led to shame, Leona looked to see if her experience was unique and personal or perhaps part of the educational experience. Our participants also provided examples of moments where the distress of shame was relieved through messages that restored belonging. Here, Steven experienced failure but rather than hiding, sees that others had also failed:

I feel like, I don't know, if everyone else fails it, it makes it feel like it wasn't more of your fault. It maybe might have been too difficult or there's a lot of times where professors put something on a test that they never taught in a lecture. So because of that they take away so many points, and so everyone could relate to it. And so when you do talk to others and you're like, "Oh you got a 40." And I was like, "Oh, yeah, I got a 45." I was like, "Dang." This is funny. It's funny, we laugh about it, but a lot of times we understand that it's not hurtful. And then that makes it more relieving because most of the times when ... Because when you take a test or a quiz, it's literally all you. It's you, and the paper, and the material that's on the paper, and the

> *pencil of course, and calculator. But when you realize that everyone else is doing the same thing, you're thinking, okay, maybe it wasn't your fault (Steven).*

Steven saw failure with others as part of the learning experience that could be repaired. In his mind, knowing that others are struggling too removed the sole weight of failure from himself. Without the element of assigning blame for failure to the self, shame became action-focused and the path forward can become action-focused as well. Willingness to bring failure into the community space was key to repairing the direct consequences of failure – bad grades. For example, Steven, who received strong positive messages regarding of belonging place in the engineering space, emphasizes the importance of belonging in coping with shame. Distress of the shame experience was either resolved or fueled by belonging and the understanding of failure as part of the educational experience or, as a signal of their overall worthiness to be an engineer.

Theme 3: Exceptionality shapes identification as part of the group

The participant's perception of how they related to standards within the major was heavily influenced by engineering stereotypes- characterized by the perception of difficulty and need to be exceptional to succeed held by both those going through the major and those observing from the outside. Jack describes his perception of engineering:

> *I think that engineering students have a pretty difficult coursework and course load, more than some other majors. And I think that sets us apart, kind of, in a way when people hear my "Oh yeah, I'm an electrical engineer. Oh yeah, I'm a mechanical engineer," they're like, "Oh, that's difficult. Good luck to you." Things like that. It's just a different staple or stigma around it (Jack).*

Like Jack, many participants discussed how engineering is "set apart" from other disciplines by those within and outside of the major. The perception of a high standard for success produces an idea of exceptionality in order to reach it. For our participants, the high standard interacted with their minoritized backgrounds as lack of previous experiences or connections within the field seemed enlarge the gap between themselves and being an engineer. Leona discussed how her background created a separation within her peer group:

> *But I feel like students who don't realize what they have, a lot of students that I've spoken to have parents that are engineers and I'm just like, this is crazy. Three out of five people I talk to have family members who are engineers and they are allowed to talk to those family members about different things or they grew up hearing terms and things about engineering of that nature. And they don't really realize that other people don't know much about that. So I feel like those types of students set the expectation that other students should already know what they know and faculty members it's the same thing, they hold that above student's heads (Leona).*

Leona felt that the knowledge and experiences that other students had gained was "[held] above student's heads". Mano tied an experience of lacking experience similar to Leona's to belonging when she said "I just felt, as I said, it felt like I just didn't belong cause if it was already this one person and then how many other people have already had experience"? Leona and Mano demonstrated how the interaction of the standard of exceptionality and feeling behind white male peers damaged two critical elements of commitment to the major-feeling as though they could succeed and feeling that they belonged in the space. Difference in initial knowledge and experience created a divide in the engineering education space. However, that divide is maintained by the lofty idea of engineers as having some intangible "it" factor coupled with the lack of experiences that level the amount of resources available to minoritized students. For our participants, the difficulty of engineering, both in concept and reality, shaped the dynamic of the engineering group and their ability to feel they belonged.

Theme 4: Tension between wanting to be seen as part of the engineering group while also separating the self from the stereotype

The participants' need to find belonging within the intricate concept of engineering identity presented in an interesting and seemingly contradictory desire to both be seen as part of the engineering group engineer and distance themselves from it. Jack discussed his relationship to the stereotypical engineer when he said

> *Okay. So I would say that there are good aspects of the stereotype, and there are also just in my opinion negative aspects. I would say that the stereotype of being smart and studious, and staying rigorous with my classwork that's something I would want to lure to because I think that's a good thing. And I think that's something that can help me. But the stereotype of not being extroverted, or being shy that's what I'd want to stay away from (Jack).*

Jack simultaneously wanted to be some parts of the engineering stereotype like being smart and studious while differentiating himself from the idea of engineers as introverted. He elaborates on his relationship with adherence to the stereotype when he says "I would say because it's been ingrained in me, I want to live up to it. I do think that there are aspects of it that could change" (Jack). Here, regardless of a desire to change the stereotype, there is still an overarching need to adhere what is expected of an engineer. The wording "live up to" is indicative of the felt pressure of meeting expectations even in recognition of a flawed standard. Jack' desire to live up to the standard despite its flaws is indicative of a larger desire to be what is expected in order to belong in the engineering space.

Nicole also takes pride in differentiating herself as she relayed an interaction with a peer who said "'When I think of an engineer, I think of an introvert who has no life and um is quiet and nerdy and only does math all day' They were like, 'That's not you at all.' I was like, "No, I like to have friends and I like to do other things besides math'". In fact, many of our participants mentioned extracurricular activities in the interview with specific mention to how that participation separates them from the stereotype of an engineer and some members of their peer group. Despite a desire to belong in the group, our participants sought to distinguish themselves in some aspects from the group to avoid becoming a caricatured representation of an engineer.

Discussion

Following an understanding of the findings within this study, we now present connections between the lived experience of the participants and theoretical frameworks. This discussion will be organized around two major points. First, we explore the impact of connections, made by the student or the surrounding culture, between the participant's minoritized identity and their experience of shame. Second, we argue that the stereotype of what an engineer looks like, which is centered largely around the White male experience, is specifically salient in the shame experience of minoritized students.

Connection of Shame to Identity as a Minoritized Student

Shame is characterized by a negative emotion tied to the global self rather than the action that caused the failure. For our participants who hold minoritized identities, that connection to the self specifically connected shame and their inclusion in the department. Thus, within these student's experiences, shame transformed an experience of not meeting educational standards to a questioning if they, or minoritized students overall, can be engineers. This process delineates a phenomenon seen in existing literature where students who are minoritized in their departments show lower measures of self-efficacy, identity commitment and other measures of success (Wu et al., 2020). Our findings shed light on what numbers show- students are who are minoritized in their departments aren't just simply more effected by academic failure, the shame experience plays a key role in making failure a distinct experience from that of white male peers.

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Our participants described this distinctiveness on their own terms while describing their internal reactions to moments of shame. Holding a minoritized identity brought feelings of being marked as different and, with it, a feeling of being watched by others who were wishing to. Like Nicole, many participants felt a responsibility to represent their entire group well which, when met with failure, translates to a fear that personal failure has a larger impact outside of the self. Desiring acceptance within engineering education for themselves and others like them often took the form of advocacy, which in some instances lent itself to strong resilience in grit within their studies. However, that same noble notion also quickly turned into a mechanism for amplifying shame.

Fighting to Assert Belonging in Engineering

Knowing how shame manifests for students with minoritized identities, we can understand how belonging plays a critical role in coping with shame for our participants. The ties between shame and minoritized identity means that failure accents messages that seem to invalidate belonging. Assertions of privilege highlighted the sense of “otherness” felt through the salience of minoritized identity and reinforced the shameful notion that failure to do or be what is expected is indicative of overall worthiness to be an engineer.

Our participants presented many accounts of receiving the message that their backgrounds and experiences were different from and perhaps inadequate in comparison to the expectation. These messages contributed to the feeling of not feeling like they belong within engineering education. When examining measures of belonging for minoritized students in engineering education, literature strongly reinforces the idea of previous background experience and familial capital being instrumental to engineering success (Barber, 2015; Cheryan et al., 2013; Eliot & Turns, 2011; Johnson, 2012; Malone, & Barabino, 2009; McGee, & Martin, 2011; McGee, 2016). Background and prior experiences were frequently noted as a mechanism for identity related shame in our participants.

If internal and external messaging communicates the message that grades not only determine personal standing as an engineer but the standing of an entire group of people, failure is much heavier. Across participants, various definitions of the self as a “people-pleaser”, someone who cares for others or some other definition of the self in terms of other’s approval were consistent. In fact, the felt requirement for minoritized students to achieve the in the eyes of peers in order to prove that they have the right to claim belonging within STEM spaces is emerging through diverse methodologies as a sort of “prove them wrong” syndrome (Eglash et al., 2013; McGee & Martin, 2011; Moore et al., 2003). This claim gives insight to the ways that our participants reacted to the experience of not belonging in engineering culture in seemingly contradictory ways, even in the same participants.

Implications and Future Work

From understanding phenomenological experiences of shame that contribute to the larger patterns seen within engineering education, we can draw some conclusions about what coping with shame looks like on both an individual and community level. Fundamentally, our participants have demonstrated that pressure to perform increases salience of minoritized identity and, much like literature describing identity threats, these pressures produce negative consequences for both academic performance and identity formation. For example, Nicole was constantly aware that her performance was meaningful to other women students and, when she failed, that meaning was a mechanism for withdrawal, low motivation and lack of identity commitment.

Since professional shame is so heavily connected to minoritized identity for these students, cultural change is required for healthy coping to be accessible. The harms of self-focused shame can be mitigated by reframing failure as action-focused. When failure is about the action and not the self, guilt leads to repair and persistence. Minoritized students have

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neither the responsibility nor the ability to counteract identity-related shame messages on their own. The notion that a student, just by being who they are, without any actions, does not belong and is not capable of being an engineer is a major barrier to persistence for minoritized students. Repair must come from messages that oppose identity-related shame directly. Although it may be tempting to examine cases like Mano's and her desire to be an advocate and positive representation for other minoritized students as the heroes in the story of progress, the depth of our findings show exactly why minoritized students should not and cannot shoulder that burden. Rather than celebrating the student who persevere through a marginalizing system, the system itself must be made equitable.

Since cultures of well-being must be nurtured to create engineering education as a space of equity and inclusion, our future work is oriented to address moments of professional shame that are both experienced and propagated by engineering faculty.

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It takes one to know one: Co-awareness as mechanism of identifying gendered marginalization

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CONTEXT

One common practice for team formation is to not isolate students from underrepresented groups; in other words, female students should not be isolated on a team. However, it has been found that women on teams with only one female student had significantly higher team satisfaction than women on teams with two or more female students. This finding also extended to the male team members, who were also more satisfied with their teams when the teams included one isolated woman rather than two or more women. This finding suggests that the common team formation strategy of pairing women on teams may lead to a more dissatisfying experience for the female students that we are attempting to support.

PURPOSE OR GOAL

The research question driving this work was: "what is contributing to dissatisfaction of female students who are paired on teams?"

APPROACH OR METHODOLOGY/METHODS

We conducted a qualitative research study to answer this question, holding fifteen semi-structured interviews with female engineering students, in which they were prompted to reflect on their team experience during a project-based first-year engineering course. Interview transcripts were axially coded for themes related to satisfaction as well as to perceived effects of gender on experiences. Both domain experts and female student researchers contributed to coding.

ACTUAL OR ANTICIPATED OUTCOMES

In this research paper, we focus specifically on one phenomenon that arose from the data: *co-awareness*. Female students discussed how the presence of another woman on their team led them to attribute characteristics of their team experience to their gender, rather than assuming it was more individual or personal. That is, a solo woman on a team may find herself relegated to particular project tasks and may believe something unique about her preparation or skills makes that situation appropriate. In contrast, two or more women see similarities across their experiences and realize that gender is affecting their possibilities in the engineering team context.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This work illuminates how co-awareness can contribute to female student dissatisfaction on teams, but also to female student development as they work through gender dynamics that occur on student teams. We conclude that the satisfaction evidenced on engineering teams containing an isolated woman is not a reason to advocate for isolating women on first year engineering teams. In fact, we believe that pairing women allowed them to better recognize common forms of gender-based marginalization on teams, and to push back against unfair treatment.

KEYWORDS

Gender, teamwork, women in engineering

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Introduction

Team-based learning is a common pedagogical tool used in engineering education, both as a method for delivering content (e.g., students study physics in study groups; students design and build something in response to a PBL scenario) as well as a way to address teamwork as a learning goal in itself (Lamm et al., 2014). However, the benefits of team-based learning are not equally distributed; researchers have highlighted multiple ways that teamwork can lead to negative experiences for some students (Cooper et al., 2018; Eddy et al., 2015) often based on a student's identity. Thus, team formation, scaffolding, and support is important to ensure that students all have equitable experiences.

Consistent with a widely cited paper on supporting undergraduate engineering teams (Oakley et al., 2004), many engineering instructors have avoided "stranding" historically marginalized engineering students on teams (e.g., avoiding having only one woman on a team, or only one student of racial/ethnic minority). An analysis of students' team satisfaction (Fowler, 2016) found, however, that women who were isolated on teams (i.e., who were the only woman on a team) had higher team satisfaction than women who were grouped with other women. The same analysis found that this sense of team satisfaction extended to all the team members, though the women's responses were more extreme (that is, men on teams with a solo woman were happier than men on teams with two or more women, but these differences were smaller than the differences between solo and grouped women).

In an attempt to understand these puzzling results and also to evaluate popular team formation choices, we embarked on a qualitative study to ask students about team satisfaction and gender following a first-year engineering team project.

Methods

The study presented here is a qualitative study, focused on collecting and analyzing female engineering students' perspectives on their experiences in a team-based, first-year design project course.

Participants and Setting

All of the participants in this study were enrolled in a large, public, Midwestern university in the United States of America. The participants were all sophomore students at the time of the interview but were reflecting on their experiences as a first-year student in the prior academic year. The participants all took a mandatory introductory engineering course, centered around a team-based, open-ended design project. The course content is equally divided between technical communication content (both written and verbal) and technical content. There are several sections of this course offered, so the specific project or technical content of the course was not consistent for each student. Examples of technical content are an electrical engineering-based section with a project focused on building and coding for a solar-powered device that tracks the sun in the sky; a computer science-based section that tasks students with creating a computer game for children with disabilities; or a biomedical engineering section that involves students researching and proposing a novel medical device. Teams were typically assigned by the instructor, and not self-selected by students.

Participants of this study included fourteen female engineering students who self-selected into the study, after receiving a broad recruitment email to all female students within the sophomore cohort across the entire college. In this paper, we refer to all participants with randomly-assigned pseudonyms (S1, S2, S3, through S14). In Table 1, we summarize the participants, noting the technical focus of the project and gender makeup of their team within their first-year design course experience.

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Table 1. Summary of study participants.

Student	Technical Content of Course	Gender Makeup of Team	
		Number of Women	***Number of Men***
S1	Researching orthopedic implants & medical devices	3	2
S2	Building a renewable wind energy system	2	2
S3	Making recommendations to businesses to improve efficiency & customer experience	3	2
S4	Designing a diagnostic test or biomedical device	3	2
S5	Building a solar tracking device	1	2
S6	Researching orthopedic implants & medical devices	3	2
S7	Designing atmospheric sensing instruments on a weather balloon	1	3
S8	Developing a computer game for children with Autism Spectrum Disorder	2	2
S9	Researching orthopedic implants & medical devices	3	1
S10	Researching orthopedic implants & medical devices	3	2
S11	Designing a diagnostic test or biomedical device	3	2
S12	Design a device using transistors	2	2
S13	Researching orthopedic implants & medical devices	2	2
S14	Design an object to solve a problem on campus	3	2

Data Collection

Data was collected via semi-structured interviews, so there was a set interview protocol, but interviewers also allowed the participants to drive the conversation in different directions as needed. The interview protocol involved three phases, with increasing pointed discussion about gender dynamics within teams:

1. *General discussion about team project*: Students were first asked to generally discuss their experience in their first-year design course. They were asked to describe their course project, team members, and the tasks that each team member did as part of the project. They were also asked if there were any elements of the experience that they wish they had done differently: if there were tasks that they did but did not want to, or tasks that they wish they took on but did not.
2. *Gender dynamics within their team*: Next, students were asked questions about how gender might have impacted their experience. They were asked if they thought their experience in the project or with their team may have been different if they were a man. They were also asked generally how they thought the gender makeup of their team might have influenced their time in the project. If they were on a team where they were not the only woman, they were asked to reflect on other group experiences

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where they were the only woman and consider how that differed from their experience in this class.

3. *Hypothesizing why solo women are more satisfied in teams:* In the final phase of the interview, the interviewee was shown the results of the team satisfaction study (Fowler, 2016), which demonstrated that women who were alone on a team were more satisfied with their team compared to women on teams with at least one other woman. The interviewees were first asked to speculate why this might occur and encouraged to reflect on their own team experiences with this new lens. Finally, they were presented with some findings from a focus group where students postulated why women were more satisfied alone on the team, and interviewees were asked to agree or disagree with the scenarios and explain why.

Data Analysis

After the interviews, the audio was transcribed by an external company and names of interview participants were removed. The interviews were then analyzed using thematic analysis (Braun & Clarke, 2006, 2012) to identify general themes without a specific framework.

The interviews were coded by two high school student researchers and two engineering education researchers (the authors of this paper). After individual coding, the four would discuss their identified themes and put together an initial codebook. After several rounds of iterating on the codebook, through individual coding and then group discussion, the resultant codebook was assembled (Hirshfield & Fowler, 2019).

Results and Discussion

The final codebook (Hirshfield & Fowler, 2019) includes themes that broadly describe female students' experiences in first-year engineering design project team course, organized into three categories: Treatment, or external factors impacting women in team projects; Feelings, or internal emotions that women have while in team projects; and Behaviors, or the actions that women take in response to these Treatments or Feelings (Table 2).

Table 2. Themes describing a female engineering student's experience in a team project.

Category	Theme	Definition
Treatment	Male-coded institutional culture	Overarching engineering culture that traditionally caters towards males
	Male-coded course structure	Course pedagogy or structure that is catered towards stereotypically male topics or qualities
	Ignorance	Others are oblivious to difficulties that women face in engineering disciplines
	Exclusion	Others prevent women from participating or engaging fully, either knowingly or unknowingly
	Patronization	Others make women feel inferior
Feelings	Representing their gender	Feeling pressure to prove themselves or speak on behalf of all women
	Competitive with other women	Women feel that they need to establish superiority over the other woman/women on their team
	Friendly with other women	Feeling a kinship specifically with other women on the team
	Co-awareness	**Realizing gendered behavior that is occurring in a team after confiding in and discussing with female teammate(s)**
	Regret	Feeling disappointed for doing or (more often) not doing something in the project
	Self-doubt	Lacking confidence

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Behavior	Making excuses		Defending the behavior of a team member (typically male), often due to a friendship with that person
	Asserting herself		Standing up for herself
	Taking on tasks	Stereotypical tasks	Taking on a role that is traditionally and stereotypically assigned to women (i.e. notetaker, secretary, scheduler, writer, etc.)
		Unfavorable tasks	A team member assigns a woman to do a specific task, despite her not wanting to take on that role
		To pick up slack	Taking on a task due to lack of effort or action from other team members
	Not taking on tasks	To improve team performance	Refraining from taking on certain project tasks for fear of negatively impacting the team
		Due to lack of experience	Not doing a project work because she perceives that she has less experience than the other group members

Examples of each of these themes, and further discussion on the development of this codebook, is discussed in prior work (Hirshfield & Fowler, 2020; Hirshfield & Fowler, 2019). In this paper, we focus specifically on one theme: a Feeling that we are calling “co-awareness,” which we define as a female team member *realizing gendered behavior that is occurring in a team after confiding in and discussing with female teammate(s)*.

Initially, the main research question driving this work was, “why are women who are alone on teams more satisfied with their teams than women on teams of two or more women?” However, the codebook we developed ended up describing female students’ experiences most generally, identifying any type of external factor (Treatments), emotion (Feelings), and Behavior that women experience during their team-based engineering project courses, regardless of the gender makeup of their team. Yet, one theme that does address our initial research question, specifically, is co-awareness, which is a concept that may explain why women may be less satisfied in their team when they have at least one other woman with them. It is important to note that several limitations (a small dataset, with only two women who were isolated on their team, in one institutional context) keep us from making the claim that co-awareness, specifically, is the sole reason for why women are happier alone on teams; rather, in this work, we are presenting it as one potential rationale, with supporting examples from the interviews conducted in this work.

Experiences of Isolated Women on Teams

Only two of the female students interviewed (students S5 and S7) were the sole woman on their team in the first-year engineering design course (further illuminating that avoiding isolation is a common team formation strategy, at least at our university). Both students described similar experiences with their teams: they reported high satisfaction with their team and the project experience, consistent with the statistical findings that motivated this study (Fowler, 2016) in which female students who are isolated on a team report statistically higher team satisfaction. Both interviewees discussed how they spent very little time on technical tasks because the male students were more experienced (coded as “not taking on tasks due to lack of experience”), although it was unclear if that was due to a lack of confidence compared to the male students due to a perception that they were less prepared or an actual inequity in experience. Both women also discussed that they were friendly and close with their male groupmates, while simultaneously describing problematic gendered team behaviors (the inequity in task distribution for both of them, and experiences with male teammates being patronizing for student S7) that these team members exhibited. They did not seem to blame their male team members for these behaviors or even view them as problematic. For example, student S7 outright described how her male teammates were patronizing to her at the beginning of the project, but she didn't necessarily seem affected by that in a negative way:

> *I think at the beginning, maybe there was a little bit of patronizing tones every once in a while, but I don't think it was super conscious of them, I don't know, that I guess it normally would be. But I don't think that they were ever saying things with the mindset that I was somehow holding them back or like less good or the weak link of the team or anything like that. I don't think they ever did anything on purpose to upset me.*

Experiences of Paired Women on Teams

Contrastingly, female interviewees who were one of two or more women on their teams almost all reported several more negative aspects of their experience. (Of course, twelve out of fourteen interviewees were part of this group; so simply because of numbers, we were bound to see a wider range of experiences.) Several of the interviewees identified experiences with co-awareness during phase 1 of the interview, before even being prompted to discuss gender dynamics of their team during phases 2 or 3 of the interview. One student, S2, discussed how the male members of her team would consistently take control of the project and "wouldn't let us [the female team members] touch any of the equipment" but then would "expect us to write up the report for them." S2 described how she and her other female teammate experienced the concept we are calling co-awareness:

> *We were both noticing it separately and we could tell that we were both getting annoyed by it, so I don't know who brought it up first, but we brought it up aside from the group and we talked about it, and realized the extent to which it was happening. Then we confronted the guys with it.*

When first describing team dynamics during phase 1 of the interview, Student S6 identified experiencing co-awareness with one of her female teammates, noting that they were "closest on the team" and they would discuss "concerns about what was the team dynamic… throughout the whole experience" but she did not necessarily mention that the "concerns" might be related to gendered During phase 3 of the interview, when the interviewees were asked about what specifically might contribute to less team satisfaction when women are paired on a team, S6 attributed it to this type of close relationship with another woman on a team:

> *So, I feel like whereas maybe in a team with one woman, she's not necessarily gonna have that other person to go through it, she's going through it on her own. It's just gonna happen how it happens. Whereas, if there's two women, if someone's not performing there's more of a like gang up and then you don't feel so bad marking them down in a survey or something like that. And it's talked about more, I feel like it's more of a voiced opinion between the team.*

While student S8's team in her first-year engineering project class had two women and two men, she also reflected on other team experiences in which she was the only woman on the team. Comparatively, she said she preferred having another women on her team to experience co-awareness, saying "it's definitely nice to have somebody who you could just be like, 'oh, did you hear how he just mansplained me?'"

When student S10 described her experience, she mentioned specifically that she did not necessarily realize how gender impacted her team dynamics while she was on her team. However, she realized it later, while in a seminar class where other women discussed experiences similar to her own. S10's experience perfectly describes co-awareness, in that several women had experienced gender-based discriminatory behavior (being "assigned" tasks that are stereotypically feminine like taking notes, writing, or organizing) but they did not realize it might be gender-based while they were on the team. But later, when they reflected together as a group of women, they did:

Freshman year, we had to take a seminar class where a lot of the times we would come and just talk about different experiences that we had in our entering classes and stuff. And I would definitely say that a lot of the people would recount their experiences where they were given the secretarial role. And then maybe they didn't realize it, but then maybe on reflection they're like, "Oh yeah. It was." But then when they're a couple of them, they did realize kind of ... not necessarily off the bat, but you go away from them being like "Wait. What role did we just get?" I think you have more people to reflect with then if there were more people on the team.

One final example of co-awareness was presented by student S13, who noted that it can be easier to not only notice gender-based discrimination on teams when there is another female team member (co-awareness), but also to confront others to fight against it. She describes how it can be more approachable to advocate for others rather than ourselves:

I'm definitely, in general, more defensive of my views if I see them happening outside of myself. Whereas ... I don't know, this could be a very individual, personal thing. But if someone says something sexist about one of my female friends, I'm like, "No. Shut it down, stop." But I might not be ... I guess that's a bad example 'cause I'm pretty good at catching sexist things in general. But if it was something towards me more specifically, I might not catch it or be as defensive. That might just be like how I view myself and how I'm more critical of myself, so I'm expecting more negative feedback… it would be nice if there was someone to advocate for me and be like, "Hey", and verify and validate what I'm feeling. "That's not cool." So I would want to be that person for someone else.

Conclusion

In this work, we present the concept we are calling "co-awareness," or realizing gendered behavior that is occurring in a team after confiding in and discussing with female teammate(s). In the interviews we conducted, we see evidence of female students being more aware of gender-based patterns when they were not isolated on a team. That is, while a female student might not observe or name gender-based discrimination when she is the only woman on a team (as we saw with students S5 and S7), they may more readily notice and recognize gendered patterns more when there is another female student on the team, as described by the other interviewees. Some interviewees described pushing back or confronting teammates with the unfairness of gendered expectations. Others did not, but they certainly developed some critical consciousness regarding their work as female engineering students and as prospective female engineers. While this study is limited in its small number of participants and singular context, we argue that this concept of "co-awareness" may be a contributor to female students' team dissatisfaction when they are on teams with other female students.

However, this does not mean that we suggest women be isolated on teams. While the women who are isolated on teams may be more satisfied with their teams, we do not maintain that this means they had a better experience overall. Women still may be having inequitable experiences on teams when they are isolated – for example, as we saw with students S5 and S7, they may be having inequitable access to project tasks or being patronized by their male team members – and simply not realizing that they are being mistreated because they do not have a fellow female team member with whom to experience co-awareness. In fact, we maintain that co-awareness is an important mechanism to how female engineering students can explore and establish their identity in a male-dominated field, which is likely a more important outcome than having a high team satisfaction score. By pairing women on teams to encourage co-awareness and using other means to embolden all of our students to recognize and confront gender-based discrimination, we can develop culturally-proficient, critically-conscious engineers.

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With regards to future work in this space, we would like to explore this concept further with a wider set of participants across a broader set of contexts, to determine if this is, in fact, a primary reason why women may experience less satisfaction with their teams when they are not isolated.

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A Self-Reflection on Lab Mentoring Practices for a Diverse Lab Group

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ABSTRACT

CONTEXT

Mentoring in research environments can serve as a tool for building resilience and supporting those belonging to groups marginalized by race, gender, international status, and first-generation status (Alvarez et al., 2016; Patton, 2009). Mentorship experiences of students and professors who are approachable, respectful, and available correspond to higher student self-efficacy and motivation (Komarraju et al., 2010), and mentoring undergraduates in research has similarly shown increased academic and motivational outcomes (Ahn, 2014). This paper examines mentoring practices within an engineering education lab group composed of students from multiple countries, ethnicities, and educational backgrounds.

PURPOSE OR GOAL

Using the collective mentoring experiences of members of our lab group, this paper examines the following questions:
1. What are the key mentoring values of this specific lab group?
2. How do these values impact our lab group's mentoring practices and the difficulties surrounding our lab group's mentoring practices?

APPROACH

We employ collaborative autoethnography, a form of autoethnography that involves "engaging in the study of self, collectively; it is a process and product of an ensemble performance, not a solo act" (Chang et al., 2012). In the discussion section this paper will specifically compare these findings with existing mentoring approaches as defined in Pfund et al. (2016).

OUTCOMES

Our lab group mentoring practices are characterized by three core values: collaboration, growth through exploration, and care and belongingness. Each of these values is defined and described within this specific diverse lab group. Collaboration for the lab group extended far beyond apprenticeship and was better characterized as a web of collaborative mentoring relationships characterized by growing each person's expertise and contribution while also allowing for the development of formal and informal mentoring experiences. Growth through exploration encourages and supports students to actively engage in new research practices. Care and belongingness provide the foundation that the rest of the mentoring experiences are built on, allowing students to feel safe enough to grow and contribute. Each of these values also created specific difficulties and challenges including availability constraints, time management, communication issues, and concern regarding ability to contribute. When comparing these values to Pfund et al. (2016), these mentoring values best reflect interpersonal and psychosocial mentoring practices. These practices encouraged the building of other research related and professional skills associated with other types of mentoring practices (Pfund et al., 2016). However, core values of the lab group were most connected with interpersonal and psychosocial mentoring practices. These findings agree with literature that psychosocial mentoring practices that build care and belongingness are particularly beneficial to marginalized students (Alvarez et al., 2016).

KEYWORDS

Mentoring, Diversity

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Introduction

Mentoring in a research environments can serve as a tool for building resilience and supporting those belonging to groups marginalized by race, gender, international status, and first generation status (Alvarez et al., 2016; Patton, 2009). Experiences between students and professors who are approachable, respectful, and available lead to higher self-efficacy and motivation (Komarraju et al., 2010), and mentoring undergraduates in research has similarly shown increased academic and motivational outcomes (Ahn, 2014). While the benefits of mentoring are clear, many universities do not have clear avenues for fostering these mentoring relationships for marginalized populations (Alvarez et al., 2016). Thus, this paper focuses on understanding the mentoring relationships developed in a single lab group with a team of students that spans several marginalized groups. Several frameworks have been created to analyse the roles, processes, and stages of mentoring (Dominguez & Hager, 2013). The roles of mentors have been described as allies, ambassadors, and master-teachers for their mentees (Lechuga, 2011). Several frameworks have set out to describe successful mentorship (Cho et al., 2011). These frameworks often describe mentees as simply in a receiving role that can eventually grow into the role of a peer while some frameworks emphasize the importance of peer-to-peer mentoring and collaboration such as communities of practice and through action learning (Dominguez & Hager, 2013). While mentoring is often described as one on one relationships, research environments often have informal mentoring or systems of mentoring implemented within a lab group structure (Ahn, 2014). This paper will contribute to the conversation around mentoring practices by describing the mentorship in practice for a diverse lab group where mentoring relationships can face additional barriers due to cultural and communication differences. and connect these findings with prior literature.

Method

This study will use collaborative autoethnography to examine the processes associated with mentoring for a diverse lab group. Autoethnography is a study of self, a study of the researcher's own group by examining the structures and experience taken for granted within the group (Eriksson, 2010). The focus of an autoethnography is applying methodological tools and research literature to analyse experience in a way that describes an unfamiliar environment for the reader (Ellis et al., 2010). Specifically, this paper will employ collaborative autoethnography, a form of autoethnography that involves "engaging in the study of self, collectively; it is a process and product of an ensemble performance, not a solo act." (Chang et al., 2012). This paper will compile and analyse the experiences of the undergraduates and graduates in a lab group focusing on the experiences each have in regard to mentoring. Experiences were gathered anonymously through reflection and then compiled into themes by various authors and confirmed by the entire lab group. As much as possible, exact wording from reflections were used both in framing each theme and in the examples given for each theme. Examples are meant to reflect the average experience within the lab group and are thus not attributed. This close collaboration helped shape the interpretation of the mentorship experience and individual reflections.

Context

This lab group is situated in a large midwestern research university in the Engineering Education department. Although the lab is mostly composed of international students, there is a wide spectrum of diversity in the lab group across ethnicities, genders, and first-generation status. At the time of the initial theme generation: There were 6 graduates or post-doctoral students and 5 undergraduates. There were 6 males and 5 females. Race/ethnicity lab demographics were 4 Caucasian, 2 African American, and 5 international students (Latin American, South Asian, and African). These numbers vary with semester changes, graduations, visiting scholars, and new hiring.

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Mentorship in the lab group is generally done through formal and informal pathways. Graduates and undergraduates meet with the head professor regularly. Undergraduates meet with the graduate students for their respective projects. Informal groups have formed on various topics and informal mentoring relationships have formed as needed. Lab practices are reflected upon and re-evaluated each semester by all in the lab group and throughout the semester as smaller adjustments are needed.

Results

This lab group came to a consensus description of good mentoring within the lab group as a process involving availability, transparency, and openness in a comfortable and safe environment conducted both formally and informally built through conscientious listening, a friendly relationship, help breaking down problems, and mutual sharing of experiences and knowledge. This definition reflects several of the practices of the lab summarized by three themes developed from the shared experiences of members of the lab group: collaboration, growth through exploration, and care and belongingness.

Collaboration: "The Mentoring Web"

Our analysis shows that the collaboration model in the lab enables mentor-mentee relationships to happen formally and informally between multiple members of the lab. This collaboration model is described as a "mentoring web" by one member of the lab which is also emphasized by other members in terms of how this collaboration occurs across several projects. We also identified a strong sense of collaboration beyond research projects, which can be identified in moments outside of the lab hour or even during outside guest visits. While visiting other lab groups and hosting students from other labs, collaboration was one of the key differences noticed in how our group approaches mentoring. As one member of the lab said:

> *"A person does not just come into our lab. They are welcomed and connected. Coming into the group originally as an undergraduate student, I watched the connections grow. It was not just the graduate student I was assigned to who taught me the basics of research. It was the graduate students who gave feedback as I presented and were willing to teach me various components of research. It was our professor who was willing to give feedback not only on our immediate work but on our life plans and willing to place us in the areas that intersected with our goals."*

Further, our data analysis shows that mentoring in this lab goes beyond one time but instead happens with the goal of creating long-term, collaborative, mutually respectful relationships. We have an open and collaborative environment that allows us to support each other in all sorts and different types of projects/activities/tasks in our lab helping us to share our honest opinion and feedback. On the other hand, we also identified that this extensive collaboration is also time-consuming. As one member said, "the mentoring and collaboration style in our lab requires probably more time than a more "traditional" style, and time is a resource we have little of". Therefore, we identified that members of the lab need an appropriate environment that allows time flexibility in order to sustain a collaborative environment that can take many shapes.

This collaborative environment also calls attention to how members build and share interests in specific topics across different projects. This aspect of sharing interest and knowledge across different projects is highlighted by one of the members. Collaborative groups and

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mentoring forms around shared interests and goals, but each lab member is also contributing to each of the projects in smaller or larger ways.

> *"Every person in our lab can talk about almost all of the projects. Even though we have not been in the minutia of each project, we are there giving feedback from the beginning to the end of each project. We are there offering our skills, our critiques, and our support. Once during a methods class, I could come up with an example of each type of research method from our lab's workday after day. The professor finally asked, "How many projects do you have?" Yet, this is so far from how projects are assigned in our lab group. Yes, we have "our" projects, but we are expected to contribute to and learn from all the projects in the lab. Undergraduates are no less than graduate students in the expectation that they are listening, learning, and contributing."*

The goal of collaboration draws heavily on communities of practice mentoring style as described by Dominguez & Hagar (2013). This form of mentoring focuses on the benefits that each individual is bringing to the group. It allows for the flexibility of individuals moving in and out of the mentor and mentee roles as each individual offers their expertise (Dominguez & Hager, 2013). This is best demonstrated in the way we navigate between the roles of mentor and mentee. Serving as a mentor or mentee is usually precipitated by need and demonstrated competency and very rarely by seniority. Traditionally, graduate students further along in their studies mentor newer graduate students and undergraduates. However, our lab group created much more flexibility where learning had no connection with seniority. Older graduate students, newer graduate students, and undergraduates are equally likely and willing to learn new skills or teach new skills to the rest of the group.

Overall, collaboration also grows interpersonal relationships while building research skills. These are two key components of Pfund, et. al.'s (2016) effective mentoring attributes. The research component involves building new skills and is what is traditionally thought of as mentoring. The interpersonal component involves building relationships that can help support communication (Pfund et al., 2016).

Growth through Exploration

As new members come in with very little research experience starting off, they are guided in exploring what it means to go through a research process from various mentors. Our analysis revealed that members of the lab often participated in multiple research projects during their earlier stages in the lab, but at the same time, they often reported a collaborative environment where each member relied on each other to succeed in their professional growth. In some cases, doctoral students served as mentors to help undergraduate students to conduct research tasks, as one noted:

> *"My first systematized literature review was a very novel experience for me. I needed plenty of directions about how to frame a research question, how to choose a topic of interest, and how to report my findings. I really appreciated being mentored throughout the process by two doctoral students in our lab."*

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While our analysis revealed an intense collaboration across multiple members in the lab that supported growth, we also identified that a couple aspects should be taken into account as part of the mentoring practices in the lab. First, we identified that members have different research interests, and it needs to be considered before approaching lab members considering their research background and expertise on a specific research method or theory. Second, students with a very specific research might be biased towards a particular research method. These two factors are important to be considered because as students grow through exploration, they need to recognize the different lab expertises and research interests in order to fully take advantage of the different projects. Our lab group often goes beyond simply guiding but actively encouraging exploration, questions, and curiosity considering that students have a good understanding of their research environment in order to receive informed mentorship and encouragement. Part of this encouragement comes from creating a safe environment where such exploration can happen. As one member noted:

"Research is a complex endeavour and learning that while living in a new culture and environment away from home was challenging. Most of my memory, I have of being mentored has been to comfortably and confidently pursue education and feel safe."

Growth through exploration is related to mentoring through action learning. In our lab, a number of factors contribute to this process, such as research diversity, trustworthiness to share ideas, and freedom of choices. Growth through exploration focuses on the mentor as a guide or facilitator as the mentee actively engages in the work (Dominguez & Hager, 2013). Within the Pfund et. al. (2016) framework, this corresponds to both research and psychosocial components of mentoring where mentees receive support that helps build their identity as a researcher and self-efficacy. Growth through exploration is intimately connected with the next theme of care and belongingness as mentees must feel safe enough to explore and fail as they engage in research.

Care and Belongingness

The words "open", "willing", "understanding," and "intentional" describe the mentoring that happens in this group. Whether it be from the professor to graduate students or graduate students to undergraduates, these four descriptors perfectly capture the natural mentor-mentee relationships that have formed.

"As a newbie I felt welcome, and everyone was willing to pitch in and show me the ropes. I would describe that as great mentoring since I never felt like I did not belong or did not know what to do."

This care and belongingness come out through the inclusion of everyone in the lab group in activities, feedback, and opportunities for growth. Meetings are not just for complete work, but instead are filled with the struggles each student is working through in research and in life. Through this outlet, there is time for support and new mentoring relationships to spring from those who have previously had the same struggles.

"One experience in particular stood out for me. I was new as an undergraduate and going to my first lab meeting. I was listening and trying

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to understand all the new terms floating in the air. Our professor turned to me after one of the presentations was done and asked for me to give feedback. What feedback did I have to give? In my mind, I was new to all of this and could not offer much. Yet, everyone contributes, everyone's thoughts are useful, and everyone belongs. Later, I was still afraid of looking right in these meetings and only presented my best work. One week when I was scheduled to present, everything was far from done. The feedback I got wasn't criticism, but instead was assistance helping me move the project forward and giving me a new perspective."

While many mentoring frameworks do not necessarily name care and belongingness as key concepts (Dominguez & Hager, 2013), they are the groundwork that many of these mentoring relationships are built upon. Care and belongingness are emphasized as key components for mentoring relationships to benefit marginalized students (Alvarez et al., 2016). Still, we call attention to a couple aspects of care of belongingness that should be taken into account in similar settings. Our data revealed that members should clearly define their boundaries in terms of criticisms when giving feedback. In addition, cultural perceptions should be highlighted and considered when giving and receiving feedback. By having a clear perception of level of criticism and cultural perceptions, we can clearly connect care and belonging to the words often described in our data, such as "open", "willing", "understanding," and "intentional".

Challenges

Examining the perception of mentoring within the lab group by lab members has identified strong themes of collaboration, growth, and belongingness. These themes prove through positive interactions fostered by the mentor-mentee relationships that mentoring benefits the lab group as it navigates through research. However, mentoring as described by the lab group has its challenges as well, presented in various forms such as availability constraints and time management, communication issues and concern regarding ability to contribute. The following delves into how each of these concepts have affected the lab group.

While growth through exploration and care and belongingness are key lab group values, they are not always easy in practice as was noted by the lab group.

"In the mentor-mentee relationship, mentees feel ashamed of letting their mentors down especially when they are learning a complex skill for the first time. The many times they fail before they get it is fine for them, but the moment they get whatever the mentor was trying to model, they want the mentor to walk away, look away, so they can figure the rest out themselves...I think it's because they don't want to let their mentor down...now that they have gotten it the first time."

Mentees can feel like they need to prove themselves leading them to be afraid of failing or afraid of asking questions. While the lab culture focuses on working against these issues, shame or fear or failure can still prevent students from fully feeling supported in these areas.

A key issue of mentoring is creating time for the mentoring to occur and managing time within mentoring projects. In our lab group, various projects are being worked on simultaneously by members. Thus, time management created particular challenges for mentoring and maintaining mentor-mentee relationships within the group.

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"Availability is certainly one of the issues that I've run into where mentoring in our lab is concerned."

Members noted that time is a resource not held in abundance, and that on rare occasions deadlines would not be met by individuals in a mentor-mentee relationship. This leads to several issues including issues meeting deadlines and generally having less time to complete work.

"Time is a big one - the mentoring and collaboration style in our lab requires probably more time than a more "traditional" style, and time is a resource we have little of."

Time and support were also given as key to the development of effective mentoring in Cho, et. al.'s (2011) findings. Strong and effective communication may help address this issue. Communication itself was established to be a challenge for mentoring aspects of the lab group. However, cultural barriers in the lab group tend to create opportunities for miscommunications. Specifically, intent and delivery can be compromised due to the perception of feedback between the mentor and mentee figure.

"I think we have had to negotiate a style of communication between mentor and mentee. I suppose there's a part of that that is cultural. Sometimes, as a mentor, I suggest some things to my mentee when they should be more strongly communicated as imperative. At such times, I find the mentee coming back to say they didn't know what I was suggesting was a paramount factor."

Cultural responsiveness is one of the key components of effective mentoring and communication that actively acknowledges biases and diversity of viewpoints is key within mentoring (Pfund et al., 2016). Our lab group often meets this challenge through seeking a deeper understanding of each other and celebration of one another's cultural differences as a key part of the growth and belongings in order to foster connection with each other. This focus best combats the imposter syndrome and negative preconception installed in oneself as a new member and mentee.

"A challenge that I initially faced while being mentored was getting over a fear of asking a lot of questions. It took some time to be able to ask for multiple clarifications on something because I felt like it would make me look bad/not good at this if I did ask that much."

While these challenges do continue to impact the lab group, lab group practices are continuously evaluated to better implement the vision of our group and help to improve the mentoring environment. Recent improvements and changes have included evaluating onboarding into lab procedures to make the transition into being a lab member easier for new graduate students and undergraduates.

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Conclusion

Overall, this lab group employs a mix of communities of practice and active learning within its formal and informal mentoring behaviours. This practice leads to three areas of emphasis: collaboration, growth through exploration, and care and belongingness. Collaboration emphasizes each person's expertise and contribution while also allowing for the development of formal and informal mentoring experiences. Growth through exploration encourages and supports students to actively engage in new research practices. Care and belongingness provide the foundation that the rest of the mentoring experiences are built on as students feel safe enough to grow and contribute. Our findings also describe how mentoring practices can happen in research environments with a diverse group of students and how this mentoring process can help students to thrive and grow.

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Female International Students in Engineering: A Qualitative Review

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ABSTRACT

CONTEXT

When international students relocate overseas to pursue higher education, they undergo transitions in social culture, educational approaches and professional practice. These transitions shape various aspects of their identity (e.g., personal, professional), engineering identity being one of them. Engineering identity is a complex, contested construct that informs how engineering is perceived, how education curricula are developed, and which student it attracts. Due to stereotypes about engineering, white middle-class males continue to dominate the profession. However, there is a need for a more diverse engineering workforce that better represents the society. With female international students' varied journeys and intersectional identities, a closer look at this population will shed light on ways to attract and retain diverse individuals within engineering.

PURPOSE OR GOAL

As a first step in a larger study about understanding the identities and experiences of female international students, in this paper we ask the following research question: What research has been conducted on female international students in engineering?

APPROACH OR METHODOLOGY/METHODS

As a starting point, the following keywords (and their synonyms) are searched on Scopus and targeted journals: 'international student', 'wom*n', 'engineer*'. After the abstracts are screened based on their relevance to the research question, the remaining abstracts are analysed to determine an appropriate scope for this review, and the inclusion and exclusion criteria are refined. References from the included papers are screened and analysed using the same process.

ACTUAL OR ANTICIPATED OUTCOMES

Based on the search strategy as well as inclusion and exclusion criteria, 6 papers were identified as relevant to the research question, and the findings were qualitatively analysed based on two categories: university and family/society. Discussion on university focussed on female international students' interactions in the social and academic context, while discussion on family/society focussed on the impact of societal perceptions of engineering and gender roles on female international students.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The paucity of relevant literature from the initial search strategy suggest that female international students in engineering are understudied. The findings suggest that this population's experience has been underrepresented in both the literature on international students and women in engineering. We conclude with a call for more studies to investigate more nuanced accounts and narratives of female international students in engineering to better inform pedagogical approaches and interventions.

KEYWORDS

International Student, Literature Review, Gender

Introduction

When international students relocate overseas to pursue higher education, they undergo transitions in social culture, educational approaches and professional practice. While the onus is usually on international students to adapt to these transitions, their economic, social, and cultural contributions to their host countries have prompted further research to attract international students (Department of Education and Training, 2016). Topics that are well covered in the literature of international students include their experiences with adjustment (Burns, 1991), with some focussing on the acculturation process (Dervin, 2011). Several scholars have also studied (perceived) differences in educational approaches (Chalmers and Volet, 1997), and more recently there has been a rise in literature discussing strategies to support international students (Ryan, 2005). While there is a wide spectrum of research on international students, many of them are heavily practice-based, which limits the applicability of findings in a different context (e.g., a different host country with different demographic of international students).

Within engineering, women account for only 17% of university enrolment, the lowest across STEM education in Australia (Australia Academy of Science, 2019). Extensive research on women in engineering has been undertaken to tackle the issue of under-representation and address the barriers to participation. However, several quantitative studies have shown that there is little to no gender difference among international students' enrolment in engineering compared to domestic students (Miner, 2019), and that gender gaps in mathematics are not present in all nations (Else-Quest et al., 2017). These findings suggest that there is a need to take a closer look at women from abroad who choose to study engineering. Furthermore, as international students, they face multiple layers of marginality as racial/ethnic minority and foreigners whose first language may not be English (Lim et al., 2021).

As a first step in a larger study about understanding the identities and experiences of female international students, in this paper we ask the following research question: *What research has been conducted on female international students in engineering?*

Method

Search Strategy

To better understand the range of literature on female international students in engineering, we searched for the following sets of terms on Scopus without applying a date range:

Term 1: wom*n OR female OR gender

Term 2: international student OR overseas student OR foreign student

Term 3: engineer* OR STEM

From the 52 results, only 4 of them were directly relevant to all three sets of search terms. Many of the results covered two aspects (e.g., international students doing engineering but lack a gender lens, women in engineering but not international students), which do not answer the research question.

To enhance the relevance of the literature, we extended the search to include targeted peer-reviewed journals, for example:

- Searching for Term 1 & Term 2 in the Journal of Engineering Education, European Journal of Engineering Education and Australasian Journal of Engineering Education
- Searching for Term 1 & Term 3 in the Journal of International Students and Journal of Studies in International Education

While the intention was to search for literature that included studies of international students of diverse nationalities and women in engineering in different countries, we found that the

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different framing of this population in different contexts, as well as the focus on literature published in English made it hard to achieve. However, we recommend doing so as part of a future study.

Inclusion and Exclusion Criteria

In the process of screening the literature, we applied the following criteria to refine the scope of the paper:

- Excluding literature that focusses only on race, as students from underrepresented racial/ethnic background who were brought up in the country where the institution is based have significantly different experiences to international students who travel to the host country and adapt to potentially unfamiliar cultures and approaches
- Excluding literature on professionals in the workplace, as the purpose of this review is to better inform pedagogical approaches rather than workplace practice
- Excluding students who are engaged in short-term study abroad programs, as they are often not in an unfamiliar context for long enough to undergo significant transitions in identity

Findings and Discussion

The purpose of this study is to develop a preliminary understanding on an underrepresented population. We conducted a qualitative review, which is “a method for comparing the findings from qualitative studies, where accumulated knowledge resulting from this process may lead to the development of … an overarching ‘narrative’,” with the goal of broadening understanding of a particular phenomenon (Grant and Booth, 2009).

Table 1 summarises the literature that was analysed. Details on each study’s target population are noted under Context. However, as each study framed the cultural contact of their participants differently, we have only noted the cultural contact in instances where it applies to the entire study. This is done to prevent stereotyping a particular culture based on a participant’s statement, considering that most studies are drawn from international students of diverse nationalities and are based on theoretical frameworks that are not centred on cultural models.

Table 1: Overview of Relevant Literature

Author	Title	Source	Context	Research Question(s)
Anderson-Rowland et al. (2007)	Encouragers and discouragers for domestic and international women in doctoral programs in engineering and computer science	Proceedings of American Society for Engineering Education 2007 Conference	Doctoral students; international women	How does being a woman play a role in your progress through the doctoral program? What types of things happen in your days that encourage you to keep going in your program? What types of things happen in your days that discourage you from continuing in your program?

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Dutta (2015)	Sustaining the pipeline: experiences of international female engineers in US graduate programs	Journal of Engineering Education	Graduate students; US institution; international female	What are the discursive practices in which international female engineers engage when faced with gendered constructions, policies, procedures, and organizing processes in engineering graduate programs of study?
Dutta (2016)	Negotiations of cultural identities by Indian women engineering students in US engineering programs	Journal of Intercultural Communication Research	Graduate students; US institution; Indian international students	How do Indian women engineering students negotiate their cultural identities in US engineering programmes?
Dutta (2017)	Cultural barriers and familial resources for negotiation of engineering careers among young women: relational dialectics theory in an Asian perspective	Journal of Family Communication	Graduate students; US institution; Asian	What, if any, competing discourses inform the choice of gendered careers such as engineering in Asian familial narratives from the perspective of women engineers? How do these narratives resist the dominant discursive assumptions about young women's engineering careers?
Gupta (2012)	Women undergraduates in engineering education in India: A study of growing participation	Gender, Technology and Development	Undergraduate students; Indian institution	Not explicitly stated – the paper argues against the simplistic notions of the masculine image of science and engineering, and suggests that a culture-specific picture would include the intersection of "market forces, dynamically developing social changes, gender, and technology"

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Lim et al. (2021)	Walking on gender tightrope with multiple marginalities: Asian international female students in STEM graduate programs	Journal of International Students	Graduate students; US institution; Asian female international student (AFIS)	How do AFISs envision the role of gender and foreign nationality in their STEM program experiences? How do AFISs cope with or counteract the challenges derived from their embodied marginalities, gender, and foreign nationality inevitably complicated with their race/ethnicity?

University

Based on the literature summarised in Table 1, participants' experiences in the university setting are often studied as they spend a considerable amount of time there. Generally, participants from both Dutta's (2016) and Lim's (2021) studies initially had a positive outlook on their host country (United States), which is perceived to be more gender equitable compared to their home countries. However, several participants from Dutta's (2016) study found themselves more marginalised and less valued by men classmates in the US compared to men classmates (where they did their undergraduate degrees) in India, while participants from Lim's (2021) study gradually learnt about their marginal status as an Asian international female student (AFIS).

The findings from the above literature are categorised into several sections: *interactions in social context, interactions in academic context, coping strategies and support mechanisms*. Academic context refers to settings such as classrooms and labs where formal learning and research takes place, while social context more fluidly describes other environments both in and out of the university where education is not the core activity, or is conducted informally.

Interactions in social context

Participants from Dutta's (2015) study expressed that they found it harder as an international women student to connect with their peers within the engineering program. As it was easier for international men students to find peers with shared interests, they would meet each other outside of class and know each other better. While some of the participants were friends with men, it did not feel as comfortable as being friends with women due to underlying social norms on relationships with the opposite gender (Dutta, 2016).

The tension in relationships with the opposite gender extends to teaching staff as well, where participants felt that they had nothing in common with the teaching staff apart from their studies (Dutta, 2015), and found that men supervisors tend to be friendlier with men in the program (Anderson-Rowland, 2007). These experiences resulted in women feeling socially disconnected with academics and consequently, disengaged with the program especially if they already had a hard time understanding lectures as international students.

Interactions in academic context

A participant from Dutta's (2016) study found it hard to vocalise her thoughts and participate in classroom discussions. She felt that many classmates saw her as incapable because she is a woman from abroad, which highlights the role of this participant's intersectional identity in her academic experiences. This was consistent with the experiences of several other participants in the lab, where they did not feel included and that their contributions were

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needed (Dutta, 2015). While the participants in Anderson-Rowland's (2007) study hesitate to get help with manual work in the lab, they shared that men of certain cultures expected women to clean up after them in the lab and do menial tasks. However, participants from Dutta's (2015) study also reported on positive experiences, such as the willingness of peers to take time answering questions from women in labs and understanding that international students may require more time to adapt.

Apart from their interactions with peers, participants from Dutta's (2016) study reported on experiences where men teaching staff questioned their abilities and long-term interest in pursuing an engineering profession. Some of them assumed that upon degree completion, participants will embark on a career in software engineering/information technology, or get married and stop working, hence using it as a justification to not take them seriously and prioritise men for conference opportunities (Dutta, 2016). This account emphasises how an academic's assumption on an international woman student's interests can be a detriment to their engineering career, and how they play a role in further exacerbating the perception that women engineering students are not 'cut out' for engineering (Dutta, 2016). However, one participant mentioned that her professor believed in her and took extra time to mentor her, which gave her the confidence to stay in engineering (Dutta, 2016).

Participants' roles in the academic context are not limited to those as a student being taught or supervised, but also as an academic in tutor or Teaching Assistant (TA) roles. A participant in Lim's (2021) study, who is a TA that is still developing her English language proficiency, shared her experiences with implicit microaggression and explicit disrespect by noncompliant undergraduate students. Not only do these participants face marginalisation by their peers as mentioned previously, undergraduate students refuse to acknowledge their expertise despite them being employed as a TA.

Reflecting on their program's effort to increase women's enrolment and retention by giving them an advantage, participants from Lim's (2021) study felt less confident about their competence. They often wonder if their acceptance to the program was intended as a push for more international students to generate more revenue for the higher education institution, or because they were women. Participants from both Dutta's (2015) and Lim's (2021) studies were cognizant that inclusion is sometimes used as departmental agenda to portray diversity. One participant spoke about how women in her cohort were nominated for their reports due to the higher probability of them getting an award. While the nomination is encouraging, the participant did not see it as recognition (Dutta, 2015). Participants from Lim's (2021) study also shared this sentiment on how their perceived advantage could obscure the merit and qualification for an award. This would lead to their hard work getting overlooked (Lim, 2021) and the need for women to prove they were as good (Anderson-Rowland, 2007).

Coping strategies and support mechanisms

In response to the experiences faced by participants across these studies, participants cited varied coping strategies and support mechanisms. One participant in Dutta's (2015) study selectively worked with other international women students. Other participants further elaborated on the importance of support from groups like the Women in Engineering Society (Dutta, 2015) and their respective ethnic community or common cultural institution (Lim, 2021). These support mechanisms were backed by participants in Anderson-Rowland's (2007) study, who found associating with a group of students from their home countries encouraging. Overall, there is a consensus that knowing others with similar experiences (whether it is a fellow woman in a male-dominated degree program or a senior student with a shared cultural background) helps to derive strength that they can overcome current challenges. A participant from Lim's (2021) study further explained how seeing that there are people that "look and talk different" makes her feel comfortable, alluding to the importance of a diverse environment in creating a safe space for students.

Apart from getting support through communities mentioned above, participants from Lim's (2021) study also raised the need for academic support in the form of mentoring. Due to the

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lack of international women faculty members, mentoring in their program is often limited to peer mentoring as faculty members with immigrant or transnational backgrounds are more willing to work with international women students. Participants from Dutta's (2015) study found networking to be a great way to boost self-efficacy, suggesting a possibility in using networking as a mechanism to address the challenge raised by Lim's (2021) participants on low international women faculty member numbers. In the absence of staff availability, Anderson-Rowland (2007) concluded that an encouraging advisor will act as an encourager for these participants.

Family/Society

Based on the literature summarised in Table 1, family plays a key role in determining participants' choice of degree and career. In the context of this paper, 'family' and 'society' are used interchangeably as "cultural discourses, which produce and reproduce gendered career expectations, pervade familial understanding of careers" (Dutta, 2017). The findings are categorised into several sections: *factors contributing to the desirability of engineering, perceptions on engineering and gender fit, support and negotiation to pursue engineering*.

Factors contributing to the desirability of engineering

In Gupta's (2012) study on women engineering undergraduates in India, they found that 68% of respondents chose engineering due to its job prospects, with only 27% citing interest as a reason for doing engineering. This finding was consistent with several participants' statements in Dutta's (2017) study, where having an engineering career is their parents' preferred choice (for both sons and daughters) due to its prestige, and their belief that engineering will ultimately lead to social mobility and respect in society. The qualitative data from Dutta's (2017) study complements Balakrishnan's (2014) quantitative survey, where Japanese and Malaysian women engineering students reported strong encouragement by their parents and family members to pursue a career in engineering. Participants from Dutta's (2017) study also spoke about their parents' encouragement for daughters to study math/science as a subject in school to appear smarter. These findings contrast the challenges faced in Western contexts, where girls report significantly lower interest and confidence levels in math/science (Else-Quest et al, 2010).

These considerations are overlaid with marriage prospects in contexts where families play a huge role in finding and selecting a spouse for their children. On the one hand, having a higher education qualification increases a bride's value in the marriage market (Gupta, 2012). On top of its perceived prestige, engineering is also favoured for its 'friendly' image in the Indian context, which "makes it easier to fix a daughter's marriage" (Gupta, 2012). However, since a match in educational and professional qualifications is a key criteria when finding a suitable spouse, there are additional concerns for women who study engineering overseas, as it will be hard to find a spouse that matches the participants' overseas qualification as an engineer.

Perceptions on engineering and gender fit

The above concerns add to many reasons engineering is discouraged for women, which are typically associated with families' perceptions on engineering. They include the below perceptions on engineering:

- Engineering involves hard work like "hauling machines and picking up big boulders" which women will not have the energy for (Dutta, 2017)
- Engineering is unsafe as it involves being on sites like bridges and tunnels (Dutta, 2017)
- Engineers have to work in the field for days "in the middle of nowhere" where amenities are lacking (Dutta, 2017)
- As an engineer, they will be the only woman among men, which is frowned upon in cultures where women should not be around men without supervision (Dutta, 2017)

One participant shared her father's concern on engineering as he favoured career options that provides "comfort, safety and stability" (Dutta, 2017), which is associated with computer-related subjects and careers that tend to be office-based and does not require physical strength (Gupta, 2012). These preferences extend to families' decision for their daughters' education as well, with one participant sharing her parents' and relatives' desire for her to go to a nearby college rather than study interstate (Dutta, 2017), and another participant's experience with her parents disapproving her decision to live alone in an unfamiliar area despite being accepted to a prestigious institution.

Support and negotiation to pursue engineering

Where participants receive support to study engineering, it usually comes from their parents (Dutta, 2016). In most cases, these parents are not bothered by gender expectations imposed by the society they are part of, such as their relatives' suggestion for women to study subjects with more women like Medicine or English, or their grandparents' concerns on engineering interfering with their marriage (Dutta, 2017). In many cases, parents prioritised what their daughters want despite being unfamiliar with engineering (Dutta, 2017). In some cases, parents actively endorsed engineering for their daughters by bringing them to engineering talks and training them to understand the mechanics of objects around them. One participant's mother, who did engineering herself, would share stories from her past experience in engineering, which helped the participant develop confidence to overcome the challenges faced in engineering school (Dutta, 2017).

In these cases, what is notably absent in the participants' families' considerations on engineering is a woman's ability to do well in science/math, which tends to be one of the primary concerns in the Western context despite studies that show no gender differences on mathematics achievement (Else-Quest et al., 2010). One participant in Dutta's (2017) study shared that her father believes that she would be good at anything she puts her mind to, including engineering. It is also worth noting that most parents and relatives prioritise education equally for both sons and daughters to the extent of investing in private education (Gupta, 2012).

It is important to recognise that all of the above points are not standalone factors of why women are encouraged or discouraged by their family to pursue engineering. A common thread that was found across many participants in Dutta's (2016) study, who were primarily of Asian descent, was the juxtaposition of their personal concerns on career and family concerns on marriage. Some participants were expected to meet potential matches set up by their parents on top of their hectic study/work schedules (Dutta, 2016), while others reported having their academic/career achievements overlooked due to the notion that women's lives are only deemed as a success when they get married and have children (Dutta, 2017). Many participants constantly walk a fine line between building an engineering career and fulfilling parental obligation, and some participants land on 'negotiated deals' – for example, they are allowed to study engineering only if they are set on working in IT (deemed as a safer and more stable career choice) and getting married upon graduation (Dutta, 2017). While there are cases where parents are supportive of participants pursuing a career in engineering, they encourage participants to get married upon graduation in consideration of their old grandparents (Dutta, 2017).

Conclusion and Future Research

In this study, we provided a preliminary overview of the research on female international students in engineering, specifically through the lens of their interactions within the university and with their family/society. While most of the participants are based in US institutions, we found that including family/society in the larger picture of this research shed light on several culturally-informed blind spots in most of the literature on women in engineering as well as quantitative studies which treated female international students as a homogenous population, collapsing the diversity to simple binaries of domestic versus international, or

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male versus female. We conclude with a call for more studies to investigate more nuanced accounts and narratives of female international students in engineering to better inform pedagogical approaches and interventions.

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Entrepreneurially-Minded Program Assessment During Emergency Situations: Using Photovoice to Understand Customer (Engineering Student) Needs

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STRUCTURED ABSTRACT

CONTEXT: Innovation, design, and entrepreneurship are economic drivers promoting competition and growth throughout the world, many of which would not exist without well-established continuous improvement and new product development processes. Continuous improvement and new product development processes, such as the lean start-up methodology and design thinking, are well known and thriving in the business world due to the vast amount of empirically-grounded research. Unfortunately, educational institutions and researchers, alike, are lagging when it comes to these processes. Although the quantity of new and transformative degree offerings has increased substantially over the past several decades, limited research has been conducted to document key procedures associated with continuous improvement and the creation of new programs. This problem is only exacerbated when considering the role of innovation during emergency situations.

PURPOSE OR GOAL: The purpose of this study is to show one approach (using photovoice) to understand how student voices can be incorporated into the continuous improvement and new program development process, specifically during emergency situations. In contrast to traditional passive data collection methods, such as a survey or focus groups, photovoice is an active data collection method where students engage in the information sharing and interpretation process at a deeper level. Using photovoice, researchers and practitioners, alike, can gain greater insights into the who, what, and how of educational effectiveness. The guiding research question is as follows: *What are the factors which can influence the discovery, evaluation, and exploitation of continuous improvement and new program development during emergency situations?*

APPROACH OR METHODOLOGY/METHODS: This approach uses participatory research, wherein students act as researchers and actively participate in the data collection and analysis process. Under the umbrella of participatory research, the study uses photovoice for collecting qualitative data. The study was implemented in a software engineering course at a university located in the United Kingdom. Students responded to the photovoice prompts by supplying both picture and narrative. The prompts target student perceptions (positive and negative) with respect to blended learning perceptions, technology integration, and career preparedness. The qualitative data was analyzed for themes using NVivo.

ACTUAL OR ANTICIPATED OUTCOMES: Analysis of the qualitative data led the researchers to identify three core themes related to the blended learning approach implemented as a result of the COVID-19 pandemic: (1) Institution – macro level, (2) Instruction – mezzo level, and (3) Student – micro level.

CONCLUSIONS: The study concludes with recommendations for various higher education benefactors of the user generated data including administration, faculty, marketing, recruitment, advisors, and the students, themselves. It is intended for the overall recommendations to have a direct impact on improving the student experience.

KEYWORDS: Entrepreneurial mindset, program assessment, emergency situations

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1. Introduction

Innovation and entrepreneurship are economic drivers promoting quality of life and sustainability throughout the world (Usai, Orlando, & Mazzoleni, 2020), much of which would not exist without well-established continuous improvement and new product development frameworks. Some of these frameworks include design thinking (Brown, 2009), business model and value proposition canvas (Osterwalder & Pigneur, 2010; Osterwalder, Pigneur, Bernarda, & Smith, 2014), and lean startup methodology (Nirwan & Dhewanto, 2015). Moreover, these frameworks have proven successful in the business world as evidenced through a vast amount of empirically-grounded research (Di Russo, 2016; Roth, Globocnik, Rau, & Neyer, 2020). Unfortunately, educational institutions and researchers, alike, are lagging when it comes to the effective implementation of these frameworks. Although the quantity of updated and new degree offerings has increased substantially over the past several decades (Jacob, 2015), limited research has been conducted to document key procedures and models associated with continuous improvement and the creation of new programs. This problem is only exacerbated when considering the role of innovation during emergency situations.

The purpose of this study is to show one approach (using photovoice) to how students can be incorporated into the continuous improvement and new program development process, in particular during emergency situations. In contrast to traditional passive data collection methods, such as a survey or focus groups, photovoice is an active data collection method where students engage in the information sharing and interpretation process at a deeper level (Wang & Burris, 1997). Using photovoice, researchers and practitioners, alike, can gain greater insights into the who, what, and how of educational effectiveness. This approach is considered entrepreneurially-minded as it relates to the definition of entrepreneurial mindset - "*inclination to discover, evaluate, and exploit opportunities*" (Bosman & Fernhaber, 2018). As such, the intention is to take action via participatory action research (as an entrepreneurially-minded assessment approach). The guiding research question is: *What are the factors which can influence the discovery, evaluation, and exploitation of continuous improvement and new program development during emergency situations?*

2. Literature Review

COVID-19 was declared a pandemic by the World Health Organization (WHO) on 11th March 2020 (Spinelli & Pellino, 2020) and dubbed the greatest challenge that education systems have ever faced (Daniel, 2020), as institutions around the world (Senel & Senel, 2021) had to stop face-to-face learning and adapt to online/virtual learning. This led to a paradigm shift within the higher education landscape, as it provided institutions with an opportunity (some might say forced) to rethink their pedagogic approaches to deliver and assess online learning. One example of assessment can be through applying entrepreneurially-minded participatory action research and photovoice assessments.

Photovoice is a *participatory action research* strategy, which is an ethnographic and experiential technique which brings together photography and images, narrative and critical dialogue, and reflection to uncover social issues and promote change (Sutton-Brown, 2014). According to Wang and Burris (1997), photovoice has three core goals: (1) empower participants to reflect upon and document strengths and weaknesses, (2) promote discourse through narrative, and (3) inform decision makers for the purpose of taking action. Photovoice has been applied in a variety of environments and social settings including veteran experiences in higher education (Tomar & Stoffel, 2014), healthcare (Ahari, Habibzadeh, Yousefi, Amani, & Abdi, 2012), food insecurity (Shannon, Borron, Kurtz, & Weaver, 2021), and refugee camps (Green & Kloos, 2009) as a form of needs assessment to promote problem identification and social transformation.

In summary, photovoice has been applied within education settings and emergency situations, separately. Yet, limited research shows the effective use of photovoice applied with education and during emergency situations together. The purpose of this study aims to shed light on this

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phenomenon by conducting an entrepreneurially-minded program assessment during the COVID-19 pandemic using photovoice to better understand customer (i.e. software engineering students) needs.

3. Methods

3.1 Participants

The study focuses on the learning experience of Degree Apprenticeship software engineering students (participants) enrolled in an industry-based degree program offered in the United Kingdom. The participants are classified as part time students as they spend only two days with the university and the remaining three days they are with their respective employers during term time. The questionnaire was shared with a group of 23 participants which returned a response rate of 39%. Demographic data on the study participants indicated that the views were more skewed towards female learner perspective (66.6%) with male learner perspective (33.3%) underrepresented.

3.2 Study Design and Data Collection Protocol

The study design for this research follows a similar approach to previous photovoice research (Kotla, Bosman, & Keller, 2021), which is a qualitative approach that explores the data as it gives a unique depth of understanding to the research questions explored. The participants were required to provide three pictures that best describes their response to each question. In addition, each picture was supplemented by a short narrative (3-5 sentences) to explain the choice of image. The questions are as follows:

1. Blended Learning Experience: What are three things you liked **least** about the blended learning mode? What are three things you liked **most** about the blended learning mode?
2. Learning Management System: What were the three biggest factors **negatively** impacting your use of the learning management system? What were the three biggest factors **positively** impacting your use of the learning management system?
3. Work-Based Module: What were the three most **memorable** aspects of the module assessment that helped you in developing skills that would be transferrable within your workplace context.

3.3 Data Analysis

Thematic analysis was used to analyze the photovoice data. According to Braun and Clark (2006), a thematic analysis is a foundational qualitative method for discovering patterns within the data, which should be conducted using a step-by-step process. All three researchers first individually became thoroughly familiar with the data to generate initial codes, where the NVivo 12 qualitative analysis software was used to code the data. Then all three researchers came together to review their findings and come to agreement. Upon completion of coding, themes were generated. As a final step, the lead author revised the themes and wrote the report. Quotes were drawn from the data to allow readers to judge credibility, accuracy, and fairness (Corden & Sainsbury, 2006).

4. Results and Discussion

Analysis of the qualitative data led the researchers to identify three core themes related to the blended learning approach implemented as a result of the COVID-19 pandemic: (1) Institution – macro level, (2) Instruction – mezzo level, and (3) Student – micro level.

4.1 Macro Level (Institution): Technology

The institutional macro level theme primarily addressed the use of technology, viewed somewhat outside the control of the individual student and instructor. Here, three subthemes emerged.

Learning Management System (LMS) Access: Participants acknowledged challenges with LMS access, speed, and reliability. Example quotes are provided here:

- *I felt as though the [Learning Management System] was slow and crashed more frequently due to the number of users on the system. This meant that it took longer to do work than necessary.*
- *When using [Learning Management System] and studying the site will always timeout and say that the session has expired and the user must log in again, it would be nice if the time before the session expires was longer, because it should be expected that those studying might not interact with the [Learning Management System] page for a while.*

LMS User Experience (UX) Design: Participants recognized both negatives and positives associated with the LMS UX design. From a negative perspective, participants perceived difficulties in finding resources. Example quotes are provided here:

- *Each model was structured into layers, and whilst this was a good way to separate content, it made each page long and it took a long time to find what I was looking for. If I then clicked on a link (for example to see my quiz results) and wanted to go back, I would need to scroll down the long page again to find where I was.*
- *I don't like how the [Learning Management System] has the date in red, even if you have already submitted something, because it gives me the impression that I have missed the deadline/ not submitted something.*

From a positive perspective, once the resources were found and identified, participants agreed that having resources to look back on was a good thing. Example quotes are provided here:

- *There are student forums where I could ask questions, as well as if I encountered any issues.*
- *The fact that a lot of lectures are recorded so I can rewatch them in my own time is a positive factor as it allows me to be flexible with my revision and note taking.*

Internet Access: Participants established that their home or personal internet access had the potential to be troublesome, which in some cases only exacerbated issues associated with the other two sub-themes. Example quotes are provided here:

- *Sometimes my Wi-Fi is not always the best, seeing as everyone in my household uses it at one time it can be quite difficult to work with, especially when I am completing quiz's in a time frame, I can concur in technicality difficulties.*
- *The [Learning Management System] crashes a lot sometimes and with slow internet it doesn't help. Sometimes it acts up when you need it the most so I downloaded what I needed and rarely accessed it after.*

4.2 Mezzo Level (Instructor): Curriculum Design

The instructional mezzo level theme mainly addressed the curriculum design and pedagogical structure of the course, viewed as the principal area where instructors can make direct and immediate changes to improve the course content and delivery. Here, two subthemes emerged.

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Delivery and Pedagogical Approach: Participants recognized beneficial outcomes associated with the course delivery and pedagogical approach. Example quotes are provided here:

- *One of the lecturers did a whiteboard exercise, where all students can put their ideas on one page. This made the lectures much more interactive and interesting.*
- *The Tutorial sessions made up for the blended learning approach because any questions to do with the content for that week can be discussed in the Tutorial. I like the way the Tutorials are formatted as they support the independent learning done before the lesson.*

Authentic Learning and Transferable Skills: Participants identified constructive outcomes related to authentic learning (e.g., real-world domain-related skill development) and transferable skills (e.g., skills perceived to be beneficial across domains and learning environments). Example authentic learning quotes are provided here:

- *The lecture's where we had to create diagrams really helped to improve my skills, which is beneficial at work as I am a BA.*
- *Design patterns are mentioned often at work so useful to have an understanding of what they are.*

Example transferable skills quotes are provided here:

- *I'm glad we were able to present as we rarely get to practice this work skill at university, and this skill is so vital for work environments.*
- *This module has allowed me to work in a group and learn skills, such as delegation. Going forward, this will definitely allow me to understand how to work and handle colleagues in projects where collaboration is vital.*

4.3 Micro Level (Individual): Student Adaptability

The individual student micro level theme largely highlighted student adaptability, within the control of the participants. Here, four subthemes emerged.

Health and Wellbeing: Participants recognized both pros and cons connected to personal healthy and wellbeing (including both physical and mental health considerations). From a pro viewpoint, participants discovered the silver lining and new habit development implemented as a result of blended learning. Example quotes are provided here:

- *Blended learning helped counteract the negatives health effects of travelling I had previously experienced (such as fainting and panic attacks due to the trains).*
- *Due to having more time on my hands by not having to travel into university, I have found more time to cook and bake, here you can see a picture of a cheesecake I made in the first lockdown and since then I have enjoyed making my meals at home, so in my lunch breaks for university I can spend time cooking which I also find therapeutic.*

From a con viewpoint, participants revealed the challenges with implementing new personal habits as a result of blended learning. Example quotes are provided here:

- *Blended learning made me feel isolated and lonely as I wasn't experiencing the social aspect of university.*
- *My desk space is very limited which makes it hard to make written notes and feel comfortable. I do not have a proper chair either, I sit on a stool which makes it very uncomfortable.*

Efficiency: Participants detected efficiency related consequences with respect to time saving and money savings. Example time saving quotes are provided here:

- *Due to not having to waste time travelling to the campus, I found I had extra time to complete my work.*

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- *I enjoy that because I am home all the time, I can spend time with my cat and my dog. During my breaks or in the mornings before work, I enjoy taking my dog for a walk to get some exercise as well as running which I now have more time to do.*

Example money savings quotes are provided here:

- *Saving time also leads to saving money as less travel and food costs.*
- *Once blended learning was introduced, I saved money on travelling to and from university. In addition to this, I saved on spending money for lunch during university days.*

Procrastination and Time Management: Participants admitted challenges with procrastination and time management as a result of working from home during the COVID-19 pandemic. Example quotes are provided here:

- *Staring at the laptop all the time isn't so good, especially when having weird timetables (starting at 9am and then finishing at 6pm). I can get lazy as well sitting in bed all day.*
- *When I come onto campus I feel like I have routine and structure in my day, whereas when I am at home I could be more inclined to work from my bed, which is not very practical.*

Acknowledged Implementation of Best Practices for Moving Forward: Participants acknowledged ownership, empowerment, and recommendations for overcoming many of the previously mentioned challenges. Example quotes are provided here:

- *To influence my behavior going forward I attend morning meetings with my teams at work and this gives more of a collaborative structure to my mornings.*
- *I have been recently using the do not disturb mode which has helped massively and I will put my phone in another room resist the temptation to go on it.*
- *I have now started to write out my day plan and a to do list and get satisfaction when things are ticked off therefore applying some sort of routine to my day.*

4.5 Summary and Discussion

In summary, the qualitative analysis of photovoice data resulted in three core themes (Figure 1) related to the blended learning approach implemented in response to the COVID-19 pandemic: (1) Institution – macro level, (2) Instruction – mezzo level, and (3) Student – micro level.

The institutional macro level theme primarily addressed the use of technology. Although this theme and subthemes are commonly considered outside the control of instructors, instructors have the opportunity and responsibility to at least share the LMS issues and UX challenges with the computer (IT) help desk department (in this case, the Information Technology Services and future students (so they can be prepared and respond accordingly). The subthemes identified are not uncommon within the higher education setting and can be categorized under "system factors" which account for infrastructure system quality and organization service quality (Radwan, Senousy, & Din, 2014). However, although Radwan, Senousy, and Din (2014) suggest the evaluation of LMSs in general to be "costly, time consuming, and needs an effort", the current student showcases how the use of photovoice can obtain relatively quick feedback with limited costs, time, and effort.

The instructional mezzo level theme mainly addressed the curriculum design and pedagogical structure of the course. This theme and subthemes are considered within the direct and immediate control of instructors, and thus, are "low hanging fruit" for instructors to make course improvements. Moreover, these subthemes align well with instructional best practices identified in the literature which suggests content skill development is just as important as transferable skill development (Chase, S. Rao, Lakmala, & Varma-Nelson, 2020). As a result of this study, the instructors intend to make the following changes: (1) implement more active learning via tutorials, (2) consider creating content using media (e.g., audio- or video-based) so participants can download if internet or LMS is a barrier to access, (3) provide opportunities to reinforce learning through instructor-led group discussions, (4) be more explicit about labeling and calling out transferable skills, and (5) offer additional opportunities for group work, especially online.

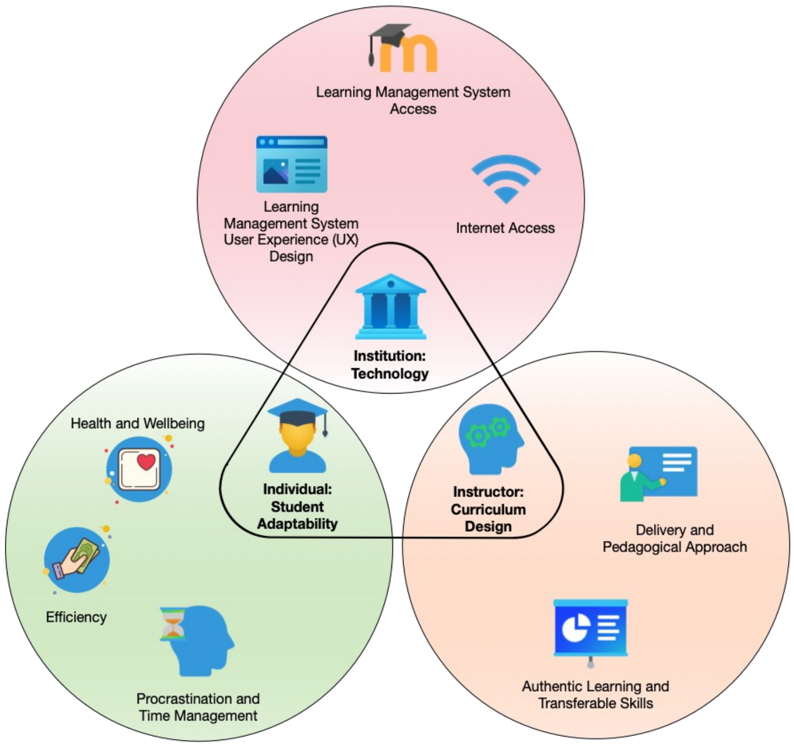

Figure 1: Summary of Themes

The individual student micro level theme largely highlighted student adaptability. This theme and subthemes are considered within the primary control of the students, yet can be influenced by the institution and instructor. For example, the literature on metacognition and self-regulated learning suggests instructors can encourage students to gain self-regulated learning skills through reflective metacognitive assignments (Cunningham, Matusovich, Hunter, McCord, & Ieee, 2015). As a result of this study, the instructors intend to make the following changes to encourage and promote student adaptability and resilience: (1) share printout of student recommended best practices from previous semester with students entering the new semester, (2) setup the place and time for students to connect with each other informally to ask questions, get answers, and build their networks, and (3) implement a rotating student advocate role whereby a designated student will provide anonymous feedback throughout the semester on behalf of their peers.

Since the COVID-19 pandemic started, some other publications have come out to document best practices and lessons learned within the engineering classroom (Asgari et al., 2021; Jamalpur, Chythanya, & Kumar, 2021; Kapilan, Vidhya, & Gao, 2021; Liu, Vijay, Tommasini, & Wiznia, 2021; Piyatamrong, Derrick, & Nyamapfene, 2021). Piyatamrong, Derrick, and Nyamapfene (2021) found students were frustrated with the lack of socializing, perceived low accountability, and were disappointed with the limited opportunities to practice hands-on skills. Liu, Vijay, Tommasini, and Wiznia (2021) founded the discussion sessions promoted instructor-student interactions and the perception of support; yet, commented on the increase in course budget to accommodate the greater integration of technologies (e.g., simulation, computer-aided design, and finite element analysis) and shipping out prototype kits to promote a virtual classroom. Asgari, Trajkovic, Rahmani, Zhang, Lo, and Sciortino (2021) recognized

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the benefit of Zoom break-out rooms and students downloading/using phone scanning apps to share work. The authors went on to recommend the use of syllabus templates for online teaching and the development of a university-wide repository for sharing best practices.

5. Conclusion

The purpose of this study was to demonstrate how an approach using photovoice was incorporated into the continuous improvement and new program development process during emergency situations, namely the COVID-19 pandemic. In contrast to traditional quantitative data collection methods, such as an end-of-semester survey, photovoice is an active data collection method where students engage in the information sharing and interpretation process at a deeper level. Although the primary purpose of this study was for instructors to assess and evaluate course delivery during an emergency situation (e.g., the COVID-19 pandemic), the debrief aspect of the photovoice assignments also allowed student participants to reflect on what went well and what didn't go so well. In this way, students received an immediate effect and potential for making changes going forward simply by reflecting and writing down future intentions. In response to the guiding research question, *What are the factors which can influence the discovery, evaluation, and exploitation of continuous improvement and new program development during emergency situations?*, three core themes and eight subthemes emerged from the qualitative data collection and analysis process, as visually summarized in Figure 1. From a practical perspective, photovoice-based course evaluations have the potential to provide instructors with rich student feedback which can be enhanced by focusing on the institutional macro level, instructional mezzo level, and individual student micro level.

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Exploring mathematical mindset in question design: Boaler's taxonomy applied to university mathematics

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ABSTRACT

CONTEXT

Dropout from engineering studies at tertiary level remains a persistent global problem. The social psychology theory of mindset explains how behaviour necessary for successful engagement with challenging academic content can be derailed by beliefs about intelligence as fixed-at-birth rather than growth mindset beliefs that intelligence can always be further developed. Given the complexity of research involving humans and the early stage of mindset research in tertiary settings, it is not surprising that the results of a recent systematic literature review on growth mindset interventions in engineering education did not identify a leading intervention. However, the review suggested that growth mindset interventions should address the broader education context and not only individual students.

PURPOSE OR GOAL

Of all subjects, mathematics is one where fixed mindset beliefs are more frequently seen in the general population. High performing students may be at risk from the negative effects of a fixed mindset when they encounter new challenges at university. This research explores the potential of creating growth or fixed mindsets through the words used in mathematics questions. Examples from mathematics assessment tasks will be analysed to see how they align with mindset principles described in a taxonomy by Boaler (2015).

APPROACH OR METHODOLOGY/METHODS

A modified version of the Delphi Technique was used to reach consensus on the applicability of Boaler's taxonomy to undergraduate mathematics courses. Questions from past assessments from first-year mathematics courses were compiled, based on their potential to match the categories in Boaler's taxonomy. In six meetings over three months, all three authors discussed and classified the selected questions into the categories from Boaler's taxonomy. Where questions did not fit, modifications were brainstormed to see if modified questions could align with one or more categories from the taxonomy.

ACTUAL OR ANTICIPATED OUTCOMES

Examples matching all categories of Boaler's taxonomy are presented and contrasted with non-examples on the same mathematics topics.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Boaler's taxonomy can guide the design of mathematics questions so that they can also reinforce growth mindset beliefs. Utilising Boaler's taxonomy in addition to the well-established Bloom's taxonomy to guide question setting may increase the possibility of promoting growth mindset. Multiple directions for future research are described.

KEYWORDS

Growth mindsets, intervention, beliefs, assessment, taxonomy, question setting.

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Mindset Theory

Dropout from engineering studies at tertiary level remains a persistent global problem (Bengesai & Pocock, 2021). The social psychology theory of mindset (Dweck, 2006; Dweck & Leggett, 1988) explains how behaviour necessary for successful engagement with challenging academic content can be derailed by beliefs about intelligence. The extremes of the spectrum of such beliefs are the 'fixed mindset' belief that intelligence is predominantly fixed at birth and the 'growth mindset' belief that intelligence can always be further developed. Context can affect whether we are closer to one end of the mindset spectrum or the other (Levinthal et al., 2021; Walton & Cohen, 2011). The belief that one is born with a 'math brain' is common (Jonsson et al., 2012) and can be detrimental to students' performance (Rattan et al., 2012). Growth mindsets are typically associated with greater tenacity and success in problem solving (Pierrakos, 2017). Therefore, engineering students may be more successful in their studies if they can be nudged towards the growth mindset end of the mindset spectrum.

In the everyday experiences of engineering students, mindset beliefs are likely to operate more on a subconscious level than a conscious one. Given the complexity of any research involving humans and the early stage of mindset research in tertiary settings, it is not surprising that the results of a recent systematic literature review on growth mindset interventions in engineering education did not identify a leading intervention (Campbell et al., 2021). However, the review suggested that growth mindset interventions should address the broader educational context and not only individual students.

A crucial area that captures students' attention is assessment. The statement by Biggs (1999, 141) remains valid over two decades later: "What and how students learn depends to a major extent on how they think they will be assessed." Those who set assessments may benefit from research on how the words used in assessment tasks may be subtly promoting fixed or growth mindset beliefs. A supportive learning environment should send the message that students can succeed in the academic challenges they encounter.

Mathematics is a subject in which fixed mindset beliefs are more frequently seen (Jonsson et al., 2012) and mathematics educators are likely to encourage ideas about giftedness (Leslie et al., 2015). High performing students may be at risk from the negative effects of a fixed mindset when they encounter new challenges at university. These include avoiding academically challenging work (Mueller & Dweck, 1998), viewing assessment feedback or criticism as a personal attack or an insult (Dweck, 1999), becoming less confident when they put more effort into a task (Miele & Molden, 2010), and being more interested in getting good marks than learning (Dweck, 2000). Furthermore, approximately half of engineering students drop out from engineering studies (Boles & Whelan, 2017) and most dropout occurs in the first year of studies (Lukic et al., 2004). Interventions to develop growth mindsets in engineering students would therefore be well placed in mathematics modules.

This research explores the potential for developing growth or fixed mindsets through the words and approaches used in mathematics questions. It is the first stage in a larger project that will later include feedback from students on reframed questions. The focus of this paper is to establish a framework for designing mathematics assessment questions that align with growth mindset principles.

Boaler's Mathematical Mindset Taxonomy

Boaler (2015) has provided recommendations for writing mathematical problems to encourage growth mindset. These recommendations can be summarised as follows, and we will refer to them as Boaler's taxonomy:

A. Open up the task so that there are multiple methods, pathways, and representations.
B. Include inquiry opportunities.
C. Ask the problem before teaching the method.
D. Add a visual component and ask students how they see the mathematics.

E. Extend the task to make it lower floor and higher ceiling.
F. Ask students to convince and reason; be skeptical.

Boaler's work has focused on school-level mathematics. In this work we explore the practicality of using Boaler's taxonomy in undergraduate mathematics. In line with the guidance that Bloom's taxonomy (Bloom et al., 1956; Krathwohl, 2002) gives to educators when setting assessment tasks, we anticipate that Boaler's taxonomy may help to guide the development of questions that extend the development of students' growth mindsets in addition to developing their mathematical abilities.

Research question

The research question explored in this paper is, to what extent can Boaler's taxonomy be used to guide the writing of university mathematics questions?

Methodology

The Delphi Technique is described by Green (2014, p.6) as "a communication structure aimed at producing a detailed critical examination and discussion." The technique has been used in education research and involves spaced cycles of deliberations by a panel of experts on a problem until reaching consensus or reaching an agreed-upon endpoint. A modified version of the Delphi Technique was used to reach consensus on the applicability of Boaler's taxonomy to undergraduate mathematics courses. The first and second authors compiled 41 questions, 30 from past assessments from first-year mathematics courses they had convened from 2012 to 2020, and 11 from the prescribed textbook for engineering mathematics at our university (Stewart et al., 2016). Questions were chosen for their potential to match the categories in Boaler's taxonomy. In six meetings over three months, all three authors discussed and classified the selected questions into the categories from Boaler's taxonomy. Where questions did not fit, modifications were brainstormed to see if modified questions could align with one or more categories from the taxonomy.

Our backgrounds position us as an expert panel for judging and creating mathematics questions to fit Boaler's taxonomy. The authors have 22, 10 and 8 years of experience teaching and convening first-year mathematics courses. The first author has a PhD on growth mindsets and the second author is working towards a PhD on growth mindsets.

Findings and Discussion

Here we present examples from engineering mathematics assessment questions under each of Boaler's six recommendations.

Open up the task so that there are multiple methods, pathways, and representations

One of Boaler's recommendations is to open up tasks to encourage students to think about different methods and pathways. In the example below, instead of asking, *"Find the fifth roots of* $1 + i$*,"* students are asked to give a visual representation of the solutions.

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1. Plot (roughly) all the fifth roots of $1 + i$ on the complex plane below.

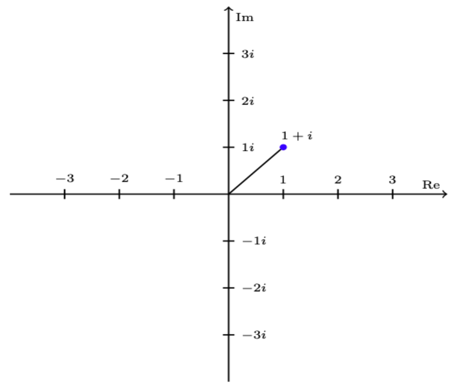

Figure 1: The complex number 1+i plotted on an Argand diagram

This leaves multiple pathways open as the student can perform the calculation through a graphical understanding of roots or using the algebraic methods of finding roots and then plotting them.

Include inquiry opportunities

An example of an inquiry-based approach to assessments is requiring students to do a mathematical investigation. Jaworski (1986) describes mathematical investigations as "contextualised problem-solving tasks through which students can speculate, test ideas and argue with others to defend their solutions." (as cited in Diezmann et al., 2001, p.170). An example of a mathematical investigation problem is outlined below.

2. The Sierpinski triangle is created recursively by removing the middle fourth of each existing triangle as shown below. Let $n = 0$ denote the first (solid) triangle and assume it has sides of length 2 units.
   (a) Show that the first triangle has $Area = \frac{\sqrt{3}}{4}\, side^2$.
   (b) What is the area of the second shape from the left? What is the total length of all the edges of the shape?
   (c) What is the limit of the perimeter and area of the shape as $n \to \infty$?

Figure 2: The Sierpinski triangle

A traditional way of asking this question would be to give the general formula for the area and the perimeter of the nth triangle and ask the student to compute the limit of the area function as $n \to \infty$ as in the example below:

Evaluate the following limits, if they exist.

(a) $\lim_{n\to\infty} \frac{\sqrt{3}}{4}\left(\frac{3}{4}\right)^n$ (b) $\lim_{n\to\infty} 6\left(\frac{3}{2}\right)^n$

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Ask the problem before teaching the method

Posing problems for students before introducing the method offers students an opportunity for learning and using intuition (Boaler, 2015). The approach of giving a problem before instruction on how to solve it was shown in a review by Chen and Kalyuga (2020) to be effective for learning the conceptual knowledge of principles underlying procedures, whereas instruction-before-problem was effective for learning procedural knowledge. In this example, a problem about approximating the area under a curve can be asked before the students are taught about Riemann sums and definite integrals.

3. The area under between the graph of $f(x) = 4 - x^2$ and the x-axis between $x = 0$ and $x = 2$ can be estimated using rectangles of equal width as shown in the figure below:

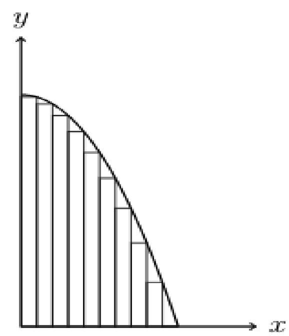

Figure 3: Rectangle of equal width estimating the area under the curve

(a) Let n be the number of rectangles, and let Δx be the width of each rectangle, and x_i be the right end-point of each rectangle. Show that the total area of n rectangles is given by

$R_n = \sum_{i=1}^{n} f(x_i)\Delta x \; = \sum_{i=1}^{n}\left(4 - \frac{4i^2}{n^2}\right)\frac{2}{n}$.

(b) How can you improve the estimation? How can you find the exact area A between f(x) and the x-axis on [0,2]? Find A using the identity $\sum_{i=1}^{n} i^2 = \frac{n(n+1)(2n+1)}{6}$.

A traditional version of this question could be:

> The Riemann sum for the area under the graph of $f(x) = 4 - x^2$ is $R_n = \sum_{i=1}^{n} f(x_i)\Delta x \; = \sum_{i=1}^{n}\left(4 - \frac{4i^2}{n^2}\right)\frac{2}{n}$, find the area by taking the limit as $n \to \infty$.

This would usually be asked after the students have been taught about Riemann sums.

Add a visual component and ask students how they see the mathematics

The importance of visual representations for teaching and learning of mathematics has been highlighted in several studies (Barmby et al., 2013). Adding a visual component enables students to gain insights into abstract mathematical ideas (Duval, 1999, as cited in Barmby et al., 2013).

In the example below, students are required to understand the relationship between graphs of functions and their derivatives.

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4. The figure below shows the graphs of a function f and its first two derivatives, f′ and f″. Which is which?

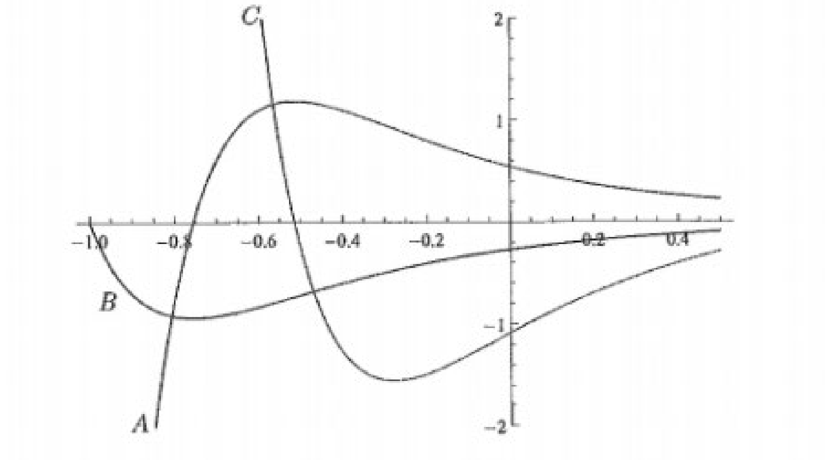

Figure 4: The graphs of f, f', and f''

A traditional version of such a question on the same topic that does not include a visual component would be:

> Given $A(x) = x^3 - 4$, $B(x) = x^5 - 2x^2$, and $C(x) = 5x^4 - 4x$, if one of them is f, another is f' and the other is f'', match A, B and C to f,f',and f''.

Extend the task to make it lower floor and higher ceiling

Low threshold and high ceiling (LTHC) or low floor and high ceiling tasks, as described by Boaler (2015), are tasks that have multiple entry points such that students of all levels can access them. For instance, instead of asking the students to solve the inequality: $|2x - 1| - |x + 3| \geq 8$, the task can be extended as in the example below. This gives the students who may struggle with the inequality an entry point.

> 5. The function f is defined by $f(x) = |2x - 1| - |x + 3|$.
>
> (a) Write f as a piecewise defined function.
> (b) Draw the graph of f.
> (c) Find the set of all x which satisfies the inequality $f(x) \geq 8$.

Ask students to convince and reason; be skeptical

Many researchers have emphasized the importance of promoting reasoning and understanding in tasks (Mueller et al., 2014). Correctly worked examples are an effective method for initial acquisitions of procedural knowledge (Adams et al., 2014). However, Große and Renkl (2007), in their study involving university students, suggested that introducing errors in the learning process can encourage students to reflect on what they know and help them create clear and more complete explanations of the solutions. In the example below, students are presented with an erroneous example, and asked to spot and explain the errors. This gives students an opportunity to offer reasons and critique the argument provided.

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6. In the following argument about the function $f(x) = ln(3x^2)$, explain which step is wrong, and what is wrong with it:

Let f(a)=f(b), so $ln(3a^2) = ln(3b^2)$. (1)

Then, using logarithmic laws, we get $ln\,3 + 2ln\,a = ln\,3 + 2ln\,b$, (2)

It follows that $ln\,a = ln\,b$, (3)

So finally, $a = b$ and f is a one-to-one function. (4)

Conclusions and Recommendations for Future Research

In conclusion, each category of Boaler's taxonomy was found to be applicable to university-level mathematics questions. Growth mindsets benefit engineering students by encouraging behaviour needed throughout engineering studies, such as willingness to tackle challenging tasks in which the outcome is not certain and using mistakes and feedback to improve. Mathematics is a core part of engineering, typically taken in the first year of engineering studies when dropout is high. Assessment captures students' attention and designing assessment is a key focus for lecturers. This research has established that mathematics assessments can be designed to align with growth mindset principles.

This finding encourages a number of directions for further research on how growth mindset may be developed through changes to the wording used in mathematics questions. Utilising Boaler's taxonomy in addition to the well-established Bloom's taxonomy to guide question setting may increase the possibility of promoting growth mindset. Future investigations can test the extent to which questions matching the categories in Boaler's taxonomy can help to promote growth mindset in university mathematics students, and if all the categories in Bloom's taxonomy are equally suited to enhancement with Boaler's taxonomy. Future research can also explore how the use of the taxonomy may shift lecturers towards the growth side of the mindset spectrum and help to raise awareness of mindset beliefs that may be conveyed to students in subtle ways.

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PREDICTING STUDENT PERFORMANCE IN ENGINEERING COURSES: A RISK MODEL ANALYSIS

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Abstract

CONTEXT

Improving student academic success in higher education courses is a central objective for educational institutions. Hence, student academic failure and dropout rates are of significant concern. Recent studies link academic success to student self-efficacy, academic performance, social environment, demographics, and performance expectations of students. One of the strategies to evaluate academic success is through risk analysis: a set of methods to analyze, understand, and predict student outcomes before enrolling in specific majors or challenging college courses.

PURPOSE OR GOAL

Contributing to the goal of academic prediction, the purpose of this research is to develop a simple methodology to estimate fragility curves for students entering an engineering course. A fragility function describes the probability of succeeding in a course, given the students' GPA. The implementation of the proposed methodology facilitates the generation of models and decision-making according to the estimation of the probability of a student surpassing or not a specific grade for a course.

APPROACH OR METHODOLOGY/METHODS

The data used to generate fragility functions comes from a database of engineering courses collected over several years at a particular university. The data includes Course Grade of interest (CG) after taking a class, and the Grade Point Average (GPA) of the students before taking it. The methodology estimates the probability of surpassing a specific performance level in a course implementing the idea of fragility functions used in the earthquake engineering field but adapted to engineering education. For example, the data can be organized to developed cumulative distribution functions to represent the probability of surpassing or failing a specific course given the students' GPA.

ACTUAL OR ANTICIPATED OUTCOMES

The resulting fragility curves have the potential to achieve two goals: (i) assessing the population at risk for a course to take actions for improving student success rates, and (ii) assessing a course difficulty based on the fragility function parameters. A practical case in which fragility curves are helpful is to compare the difficulty of two or more engineering courses, detecting subjects in which students tend to have more challenges to succeed.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

In the literature, there are research studies that have focused on predicting student failure or dropping out in the first academic year or models to predict academic performance in the last semester of the program; however, this research focused on predicting academic success in any course of the program, provided that the GPA information is available. The procedure used to generate fragility curves used in seismic engineering is applicable to generate risk curves that estimate the probability of academic success in engineering courses.

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Keywords

Fragility functions, academic success, engineering education, risk assessment, retention.

Introduction

Improving student academic success in higher education has been an important objective for academic institutions over the years. Student academic failure and dropout rates in engineering are a significant concern in several countries, including Colombia (Casillas, Robbins, Allen, Kuo, Hanson, & Schmeiser, 2012; Lucio, Hunt, & Bornovalova, 2012; Vieira, Aguas, Goldstein, Purzer & Magana, 2016). In Colombia, engineering dropout rates are more than 50%. Students drop engineering programs for several reasons, but academic performance is one of the main predictors at all educational levels (Casillas et al., 2012). Past academic performance and student demographics are some of the main predictors of academic success (Shahiri, Husain, Rashid, 2015; Alyahyan & Düştegör, 2020). Predicting student failure becomes relevant for institutions to develop procedures to support engineering students and avoid student dropout (Knight, Carlson & Sullivan, 2007).

Several approaches have been used to predict student success/failure rates. For instance, Lucio and colleagues (2012) used the receiver operating characteristic (ROC) curves to identify the optimum number of risk factors. Vandamme and colleagues (2007) implemented mathematical techniques (decision tree; neural networks and linear discriminant analysis) to predict the probability of failing or dropping out in their first academic year. Educational data mining (EDM) methods have also been used to predict students' performance. EDM methods extract relevant information from a large educational database to predict or analyze students' performance (Angeline, 2013; Shahiri et al., 2015). Risk analysis is another important process that has been used to analyze, understand, or predict students' outcomes before enrolling in specific majors or particularly difficult college courses (Bernacki et al. 2020; Alipio, 2020; Esmat & Pitts, 2020; Wilson & low, 2014; Dekker et al., 2009; Ohland et al., 2011; Marbouti et al., 2016; Belfield & Crosta, 2012). The importance of predicting student risk failure lies in the possibility of improving the teaching-learning process (Shahiri et al., 2015; Alyahyan & Düştegör, 2020), allowing teachers to make informed instructional decisions. This process may also minimize student repeating attempts at courses and improve completion rates through timely actions (Esmat & Pitts, 2020).

While all these different methods may help predict student failure or academic success in undergraduate programs, our approach will focus on predicting student success in individual courses. We argue that institutions may benefit from lower student dropout rates by improving the course-specific success rate at the program level. This study proposes a model to predict student success in specific undergraduate courses using their past grade point average (GPA). The model is based on fragility functions used in the earthquake engineering field to estimate the chance of structural damage given the ground-motion intensity. This approach also allows comparing two different courses and may help higher education institutions to make informed decisions to support student learning.

Theoretical Framework

In earthquake engineering, fragility functions are useful to describe the effect of earthquakes in a building. Given a particular building, a fragility function helps to estimate the probability of exceeding a specific limit state of an engineering demand parameter (EDP) as a function of ground motion intensity measure (IM). For example, the limit state of an EDP could be an acceleration threshold at the roof of a building which can vary according to different values of IM. Note, this is only a statistical data organization procedure that may be expanded to other fields. In this sense, this paper adapts this organization procedure to engineering courses when generating fragility functions to estimate the chance of obtaining a certain course grade

(CG) as a function of the grade point average (GPA) of the students before taking such course (**Figure 1**).

Earthquake engineering		**Engineering courses**
Intensity Measure (IM)	→	Grade Point Average (GPA)
Engineering Demand Parameter (EDP)	→	Course Grade (CG)

Figure 1: Equivalence of concepts from earthquake engineering to engineering courses

Baker (2015) presents two methods to obtain the data for estimating fragility curves, both fulfilling the need of finding correlating pairs of a cause and a consequence. Fragility curves are defined as a cumulative distribution function (CDF), which depends on the statistical distribution of the data treated. Typically, the lognormal distribution is used to elaborate these functions, as is shown in Equation (1)

$$\boldsymbol{P(CG > cg|GPA = x) = \Phi\left(\frac{\ln\left(\frac{x}{\theta}\right)}{\beta}\right)} \tag{1}$$

where $P(CG > cg|GPA = x)$ is the probability of obtaining a course grade greater than *cg*, given a test value of $GPA = x$; and Φ() is the standard normal cumulative distribution function. According to Baker (2015), logistic regression is also used to describe fragility functions. These are special cases of generalized linear models (GLMs) and will be the preferred option used in this paper. All GLMs have three components: the random component, the systematic component, and the link function. According to Agresti (2012):

- **Random component:** identifies the response variable *Y* (i.e., a consequence) and chooses a probability distribution for it. When the *Y* observations are binary, as is the case of success or failure, then a binomial distribution must be assumed for *Y*.
- **System component:** specifies the independent (predictor or explanatory) variable(s) (i.e., the cause). These variables get in as predictors and the linear combination of them is known as a linear predictor.
$$\beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k$$
- **Link function:** Specifies a function of the expected value of *Y*, this is, $E(Y) = \mu$. When μ takes values between 0 and 1, then is appropriate to use a logit link function, this is, $g(\mu) = \log[\mu/(1-\mu)\ ]$. When a GLM has a logit link function, then is called a logistic regression model, which is the case for this study.

The distribution of *Y* is represented by the probability $P(Y = 1) = \pi$ of success, $P(Y = 0) = 1 - \pi$, and $E(Y) = \pi$. The binomial distribution of *Y* follows Equation (2).

$$\boldsymbol{P(y) = \binom{n}{y}\pi(x)^{y}(1-\pi(x))^{n-y}} \tag{2}$$

where *n = 1* when we work with binary observations, and $\pi(x)$ represents the conditional mean of *Y* given the independent variable *x* according to Equation (3)**.** The corresponding logistic regression function is presented in Equation (4), which implies that $\pi(x)$ increase or decease as an *s*-shaped function of the independent variable *x*.

$$\boldsymbol{\pi(x) = \frac{e^{\beta_0+\beta_1 x}}{1+e^{\beta_0+\beta_1 x}}} \tag{3}$$

$$\boldsymbol{logit[\pi(x)] = \log\left(\frac{\pi(x)}{1-\pi(x)}\right) = \beta_0 + \beta_1 x} \tag{4}$$

In this Logistic regression, or logit model, the parameter β_1 indicates if the curve increase ($\beta_1 > 0$) or decrease ($\beta_1 < 0$), and its magnitude defines how fast increase or decrease, that is, the slope. When $\pi(x) = 0.5$, *x* corresponds to the median effective level (*EL₅₀*) which represents the probability for success equals to 50% and can be calculated as $x = -\beta_0/\beta_1$.

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According to Hosmer (2013), there are two significant reasons for selecting the logistic distribution. The first one is that logistic regression is an extremely flexible and easily used function, mathematical speaking. The second one is that model parameters provide "*the basis for clinically meaningful estimates of effect*".

The maximum likelihood method is used to estimate the parameters of the function for this model (Equation (5)):

$$\boldsymbol{l}(\boldsymbol{\beta}) = \prod_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{n}} \boldsymbol{\pi}(\boldsymbol{x_i})^{y_i} * (\mathbf{1} - \boldsymbol{\pi}(\boldsymbol{x_i}))^{1-y_i} \tag{5}$$

where $\beta = (\beta_0, \beta_1)$. Taking advantage of the logarithm's properties, then Equation (5) can be transformed to Equation (6).

$$\boldsymbol{L}(\boldsymbol{\beta}) = \ln[\boldsymbol{l}(\boldsymbol{\beta})] = \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{n}} \{\boldsymbol{y_i} \ln[\boldsymbol{\pi}(\boldsymbol{x_i})] + (\mathbf{1} - \boldsymbol{y_i}) \ln[\mathbf{1} - \boldsymbol{\pi}(\boldsymbol{x_i})]\} \tag{6}$$

Procedures for Estimating the Fragility Curves

In this section, we present the steps to estimate the risk of failure given the GPA of the student before taking a specific course. To explain the procedure, we use the data from a mid-sized private university in Colombia. The sample course is Calculus II which has 6,709 data points collected between 2008 and 2017. In the next section, the courses Physics I and Statistics are included to compare the three courses.

1. **Collect GPA versus CG pairs for the concerned course**
   Collect (GPA, CG) pairs, where the GPA is that of the students before taking the course of interest. Additional metadata may be included depending on the purpose of the fragility curve. For example, if the idea is to compare the evolution of a course, a third parameter can be the period in which the course was taken (e.g., semester, year). On the other hand, if the purpose is to compare the success in different educational institutions, it will be important to separate the information according to its origin. Note that the use of only one input variable (i.e., GPA) is a limitation of this methodology.
   The scatter plot in **Figure 2** helps visualize the data distribution. For the case study presented here, good-standing students at the college of engineering must have a GPA ≥ 3.3; hence the X-axis range starts there. The course grade scale goes from 0 to 5, and the minimum approving course grade is 3.0.

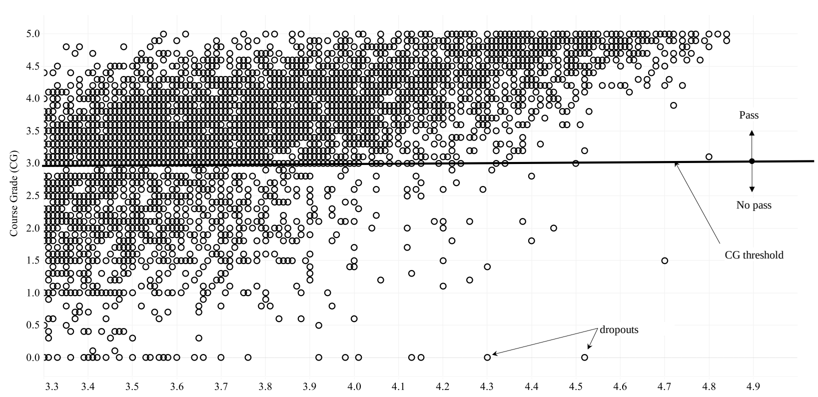

Figure 2: Scatter plot of GPA and CG of the course of Calculus II

2. **Select GPA level of interest and bin the data**

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Define GPA bins from the minimum applicable GPA to the maximum GPA, depending on the institution's standards. Here, we use the range 3.3 ≤ GPA ≤ 5.0, and the bins increments of 0.1. When defining the bin size, one must consider the amount of data available. Fewer data points require larger bins. **Figure 3** shows a bubble plot of CG versus GPA bins. Note, the size of each bubble indicates the concentrations of data around specific pairs of (GPA, CG).

In this stage, also define the CG threshold, which depends on the purpose of the fragility curve. For the case study, CG = 3.0 is selected as a threshold because this is the grade from which a student approves or not a course in the institution under study. However, any other threshold can be selected. For example, in the case study, the so-called *distinguished students* have a GPA ≥ 3.8, so a CG = 3.8 could be another possible threshold to analyze.

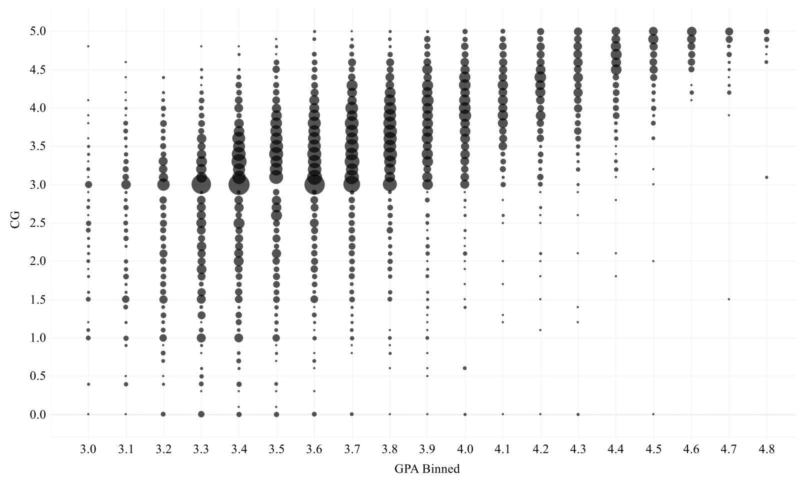

Figure 3: Bubble plot of binned GPA and CG of the course of Calculus II

3. **Estimate logit coefficients and standard deviation**
   Once a CG threshold is defined, it is necessary to create a binary vector with the same size as the amount of data (i.e., of students evaluated). For each student, this vector has values of 1 when the CG ≥ $CG_{threshold}$, and 0 otherwise. The fragility curves are estimated by a generalized linear model (GLM) using binomial probability distribution and logit as the link function in MATLAB (see code in Appendix). The inputs of the function are a vector collecting the GPA of the students, and the corresponding binary vector explained above. The code estimates the logit coefficient of the function.

4. **Computes predicted values of GLM and plots fragility curves**
   Knowing the parameters β_0 and β_1, we can use Equation (3) to estimates the probability of surpassing the $CG_{threshold}$ for each GPA; hence, the fragility curve is estimated as $1 - \pi(GPA = x)$. **Figure 4** shows two fragility curves: the first one evaluates the probability of failing the course of Calculus II, while the second one evaluates the probability of obtaining CG < 3.8 for the same course. These fragility curves must be interpreted in this way: a student with a GPA = 3.6 has a probability of 22% of not passing the course, while the same student has a probability of 75% of obtaining a CG < 3.8. The complement to these probabilities offers another perspective from the same data. **Figure 4** also shows the binary vector plotted against GPA. It is worth mentioning that observations showed in this figure are not binned GPA, so they overlap.

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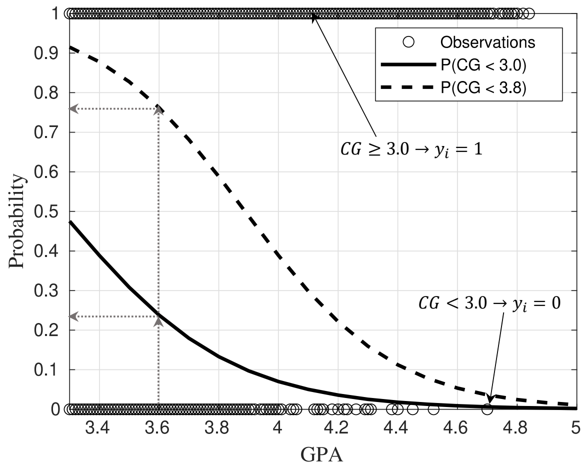

Figure 4: Fragility function of the course of Calculus II for a probability of CG < 3.0

Application case

An application case of these fragility curves compares the estimated academic performance that a student with a specific GPA would obtain in each course of interest. **Figure 5** presents the fragility curves of three courses: Calculus **II**, Physics **I**, and Statistics. **Figure 5a** shows the probability of failing each course given the student's GPA. This figure shows that Statistics is the most difficult subject among these three, and for Calculus **II** the students show a better performance. For example, a student with a GPA = 3.4 has a 40% chance of failing the course of Calculus **II**, while for Physics **I** and Statistics, this student has a 50% chance, approximately. **Figure 5b** presents a CG threshold of 4.0 and depicts a different behavior in comparison with **Figure 5a**. Note that both, Physics **I** and Statistics cross at an about GPA = 4.3, which also coincides with the 50th percentile. This indicates that, in an average sense, for both courses, a GPA of at least 4.3 is required to surpass the 4.0 grading.

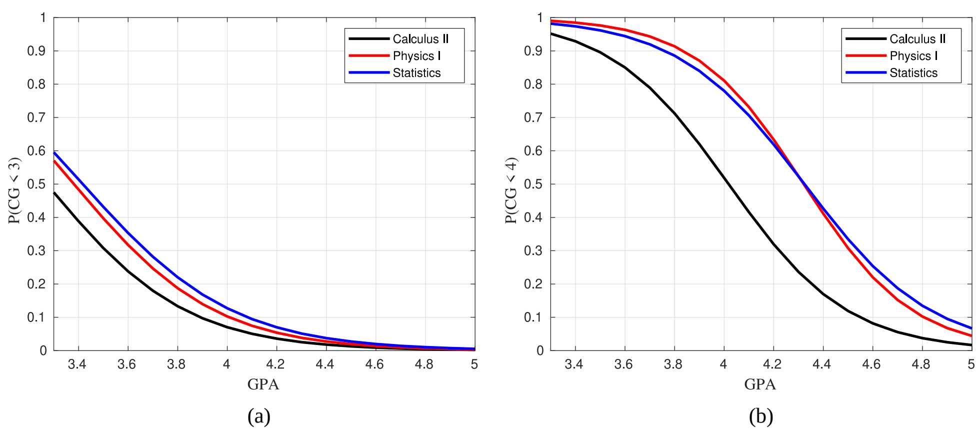

Figure 5. Fragility curves of the course of Calculus II, Physics I, and Statistics comparing: (a) the probability of not passing each course; (b) the probability of obtaining a CG < 4.0

Two important parameters for each curve are shown in **Table 1**. The first parameter is β_1 and its magnitude shows the rate at which the curve is decreasing, that is, the slope of the curve. For instance, **Figure 5b** shows that the curve of Physics **I** is stepper than Statistics and Calculus **II** as confirmed by the values of β_1 in **Table 1**. Note that **Figure 5** shows plots for $1 - \pi$, hence, the slopes are negative. A flatter slope indicates the data is more scattered. A

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second more important parameter is EL_{50} which indicates the 50th percentile of the *GPA* data. As commented previously, one can use the EL_{50} to directly compare the difficulty of each course on an average sense, as it defines the overall horizontal position of the curves along the X-axis. For example, from the $CG_{threshold} = 3.0$ data in **Table 1**, Statistics with the larger EL_{50} value indicates that there is at least a 50% chance of failing the course for students of GPA equal to or less than 3.42. This GPA threshold is smaller for the other two courses; hence, students with lower GPAs are more likely to pass it.

Table 1. Parameters of the fragility curves for different CG of the course of Calculus II, Physics I, and Statistics

Parameter	$CG_{threshold}$ = 3.0			$CG_{threshold}$ = 4.0		
	Calculus II	**Physics I**	**Statistics**	**Calculus II**	**Physics I**	**Statistics**
β_0	-11.61	-11.85	-11.30	-16.70	-19.59	-16.91
β_1	3.55	3.51	3.30	4.15	4.53	3.91
$EL_{50} = -\beta_o/\beta_1$	3.27	3.38	3.42	4.02	4.32	4.32

As was mentioned before, this model may be used for other application cases. Students' academic performance in course offerings may be useful to identify how different strategies have contributed (or not) to student success. Likewise, this model may also be helpful to compare the same courses at various institutions, or over the years.

Conclusions

A significant concern in higher education is to enhance academic success in engineering programs. This paper contributes towards this goal by describing a methodology that enables instructors and decision-makers to predict students' future performance in a specific course from historical past performance in an objective manner. The proposed methodology uses fragility functions with historical course grades and corresponding grade point average (GPA) before taking the course. Once the fragility curves are created, it is possible to predict the probability of exceeding a specific CG given the GPA for a particular student.

Fragility functions were elaborated using a generalized linear model (GLM) with the binomial logistic method. Once fragility functions are created for the courses of interest, it becomes a functional tool to assess the population of risk according to their GPA. When this population is detected, it is possible to create mitigation actions to improve their academic performance.

One application case was presented, which consisted of comparing three courses: Calculus II, Physics I, and Statistics. Knowing the fragility curves parameters of each course is possible to compare the difficulty between one and others depending on the GPA of students and the CG threshold selected.

While we believe that this model can be helpful to inform instructional decisions, we recognize that other factors beyond the GPA may influence student success in a given course. We argue against providing students themselves with the outcomes of this model, as this may affect their self-efficacy towards the course and the program, and may misinform their future decisions. This model may be useful to inform teaching practices and to assess the consistency of the course difficulty.

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Appendix

MATLAB code

```
%% LOGIT - FRAGILITY CURVE

% b: file with 4 columns: 1) ID of the observation, 2) the course grade of each
observation, 3) GPA of each observation, 4) GPA binned each observation

b = importdata('Calculus_II.txt');
values_b = b.data;
GOI = 3.0; % CG Threshold

GPA = values_b(:,3);
GPA_binned = values_b(:,4);
CG = values_b(:,2);
cond = zeros(length(values_b),1);

for i = 1:length(values_b)
    if CG(i)>= GOI
        cond(i) = 1;
    end
end

[logitCoef] = glmfit(GPA_binned, [cond],'binomial','logit');

beta_0 = logitCoef(1);
beta_1 = logitCoef(2);
EL_50 = -beta_0/beta_1;

GPA_x = 3.3:0.1:5;
for i=1:length(GPA_x)
    logitFit_plot(i)=exp(beta_0+beta_1*GPA_x(i))/(1+exp(beta_0+beta_1*GPA_x(i)));
end

%% Graphics
plot(GPA, cond, 'ok')
hold on
plot(GPA_x,1-logitFit_plot,'-','lineWidth',2,'Color', [0 0 0]);
hx = xlabel('GPA');
hy = ylabel('P(CG < 3.0)’);
ylim([0 1]);
axis([3.3 5 0 1])
grid on
```

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Volunteer Professionals in an Undergraduate Design Challenge: Contributing to and Practicing Globally Responsible Engineering

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ABSTRACT

CONTEXT
The Engineering for People Design Challenge is an innovative programme coordinated by Engineers Without Borders UK and Engineers Without Borders South Africa with the aim of developing globally responsible engineering graduates. The programme prompts students to develop engineering solutions to social problems within a broadly framed real-world context. The programme is squarely focused on the student experience, and research is steadily accumulating to support student-related outcomes. Much less is known about the professional engineers who volunteer their time to review the reports, including what they contribute to the framing of global responsibility and how their volunteer experience constitutes a learning exercise not dissimilar from the students.

GOAL
This study seeks to broaden the understanding of how globally responsible engineering is defined, promoted, and practiced in a programme such as the design challenge. Volunteer reviewers are regarded as relevant experts, and their feedback shapes those framings and the student experience. This study also seeks to connect those contributions to aspects of conventional engineering practice and investigate the way in which volunteer reviewing is a learning experience.

METHODOLOGY
This mixed methods study includes a qualitative data analysis of documents produced for and within the design challenge, select interviews, and a participatory ethnography. The document analysis centred on reviewer feedback on student designs, their applications and reflections directly to Engineers Without Borders UK. In this paper the reviewer experience is described through documentation of the reviewer process, recorded experiences of the reviewer's contribution to the design challenge, and through the author's first-hand account as an active participant.

ACTUAL OUTCOMES
This study produced an extensive catalogue of the different ways volunteer reviewers interpret the meaning and encourage the practice of global responsibility. Patterns showing the focus or omissions within the reviewer feedback are parallel to the differences between conventional engineering practice and the ideal of global responsibility that the design challenge seeks to promote. Finally, the design challenge emerges as an educational and practical exercise for the reviewers, strengthening their globally responsible engineering orientation and skills, just as it is intended for student participants.

CONCLUSIONS
In the Engineering for People Design Challenge, the nuances and imperatives of global responsibility are collaboratively constructed between Engineers Without Borders UK, university students, their faculty, and professional engineers. In this unique configuration, conventional practices and forward-looking ideals, for both globally responsible engineering and engineering education more generally, are negotiated in real time. This research can also be considered a preliminary case study for new ways to deliver life-long learning, given the potential outcomes for many professionals volunteering their time on a scalable educational initiative.

KEYWORDS
globally responsible engineering; design challenge; continued professional development.

Introduction

The expectations and demands on those practicing and studying engineering, individually and collectively, are facing a dramatic reimagination. Engineering underpins all the Sustainable Development Goals, sustainable societies and inclusive economies. It is also key to recovering sustainably, regeneratively and inclusively from the COVID-19 pandemic (UNESCO, 2021). Further, engineering outcomes can have significant societal and environmental impact, and engineers must act responsibly to incorporate more than technical aspects of engineering outcomes. A study by the Institution of Engineering and Technology found 93% of engineering companies with a sustainability strategy do not have the staff with the skills to fulfil them (IET, 2021). There is a clear need for engineering curricula to incorporate the skills required to mitigate global and local challenges, societal aspirations and needs, while not compromising the natural environment or resources for future generations. In doing so more complexity, multi and interdisciplinary approaches are required in engineering curricula. The conventionally siloed skills, educational upbringings, and broad outlooks of these societal leaders is being challenged, including with new goals and ideals for global responsibility in engineering. While the curriculum for university education has not rapidly evolved to match these changing expectations, initiatives in and out of the classroom are beginning to incorporate tools and programmes to reshape the future of engineering.

Project and problem-based learning have been demonstrated as effective methods for approaching social responsibility in engineering education, leading students to explore non-technical approaches and consider the needs of people in engineering projects (Rulifson et al., 2018). In project-based learning, students approach complex and real-world problems, often collaboratively, for an extended period of time, culminating in a final product, with teachers acting primarily in advisory roles (Helle et al., 2006). It specifically has grown into a permanent fixture in engineering education following its initial introductions to foster “adept communicators, good team members, and lifelong learners” (Dym et al., 2005, p. 109). Complexity within problem-based learning through theory and application has a positive impact on professional competencies and can bridge the gap between education and industry (Steinemann, 2003; Lamb, et al, 2010).

Context

The Engineering for People Design Challenge is an educational programme run in partnership between Engineers Without Borders South Africa and Engineers Without Borders UK, based on a concept originally developed by Engineers Without Borders Australia. The award winning challenge is delivered collaboratively with universities nationally in the UK, Ireland, South Africa and the USA and invites teams of students to practice using their skills and knowledge to create engineering design proposals to address ethical, environmental, social and cultural aspects of engineering design in complex development contexts (Engineers Without Borders UK, 2021). The design challenge has been consistently growing in scale since it was first launched in the UK in 2011. In 2019/20, 37 universities across the UK, Ireland, South Africa and the USA took part in the design challenge, and to date has reached over 50,000 undergraduates. In the UK, the programme contributes to requirements set out by the Engineering Council for accredited degrees, to demonstrate understanding of the design process and have a broad awareness of the economic, legal, social, ethical and environmental context of engineering.

Different design briefs are issued each year prompting students to tackle problems in different contexts, including in communities in India, Nepal, Cambodia, Australia, Vietnam, Timor Leste, Cameroon, Peru, and Kenya. The challenge explicitly focuses on 1) developing a broad set of skills, 2) designing for the people and context, 3) ensuring appropriateness and sustainability, 4) activating the relationship between the social, economic, and environmental implications of engineering decisions at local and global levels, and 5) broadening the conceptualizations of global responsibility in engineering. The programme is organized into two phases, with students first developing their proposals at their respective

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universities, and later competing against the top teams from across the region toward a grand finals event and celebration.

Volunteer professional engineers have a critical role as the reviewers during the competition phase of the challenge. The volunteer reviewers are pooled from the network of international and domestic professionals that Engineers Without Borders UK has built into its broader movement. Reviewer candidates submit an online application and once accepted are invited to a one-hour training webinar and provided with other fundamental resources for the challenge and their responsibilities. The student reports are paired with individual reviewers, whose evaluations then include both numerical scoring and qualitative feedback across the discrete marking criteria. Once the reviewers have submitted their evaluations, they are later invited to complete a feedback form and have the opportunity to passively follow the final stages of the competitions.

Reviewers' scoring determines which teams advance from the initial round of the competition phase to the Grand Finals, and their comments are the primary source of qualitative feedback that the students receive from outside of academia. The reviewers are at various stages of their careers, from a broad range of technical disciplines, and represent diverse perspectives from within the design challenge and across the broader engineering community as well. Furthermore, while reviewers are provided with standardized training and background materials, their focuses, orientations, and priorities primarily come from their own experience outside the challenge itself.

The contributions of the reviewers to the design challenge can build upon and represent a distinct perspective on globally responsible engineering and the criteria to which these types of designs can be evaluated. While the qualitative feedback from reviewers to the students is structured by the marking criteria and Engineers Without Borders UK’s framing of global responsibility, it is produced freeform and delivered unredacted. Through their reviews of student reports, the reviewers interpret these concepts, bring in their own additions, and focus on the areas which are most central to their conceptions of engineering responsibility.

The applications and post-participation surveys moreover invite additional insights into their orientations, motivations, and visions. Together these contributions speak to the reviewers’ perspectives on: their personal situation within contemporary engineering systems; the direct value of their contributions to the design challenge and its participants; and the underlying value, importance and influence of project-based learning initiatives such as the design challenge to engineering industries and society as a whole.

Research Questions

This paper presents the results from a nine-month study, conducted between January and September 2020, of the concepts of globally responsible engineering and the way that it is promoted and enacted through the Engineering for People Design Challenge. The research questions that this paper explores are as follows:

1. In what ways does participating as a reviewer in the design challenge go beyond industry practice and straightforward volunteering?
2. In what ways can it be considered itself a lesson and exercise of globally responsible engineering?

First, it looks at the way that various actors collaboratively create the definition of globally responsible engineering, with a particular focus on the reviewers’ contribution to that definition. Second, the report takes a closer look at the reviewers, their contributions, and their experiences, including how the reviewers view and approach the design challenge, their role in it, and the globally responsible engineering concepts they are tasked with evaluating. Finally, it draws parallels and differences between professional engineering career experience, the volunteer reviewer experience, and the student participant experience.

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Methodology

This study used decidedly mixed methods to conduct a qualitative data analysis of documents created for and within the design challenge. The main dataset was written contributions from the reviewers throughout their applications, reviews, and post-participation surveys. This analysis looked at 533 total reviews across three years of the challenge, from 2017-2019. Each review included feedback comments in each of six marking criteria plus a seventh for general comments. The data also included official materials and selected interviews with staff from Engineers Without Borders UK. QDA software Atlas.ti was used to code data to identify patterns, trends and themes. A portion of the research is also a participatory ethnography, as the first author made observations and reflections throughout the experiences of volunteering as a reviewer for the design challenge and working internally with Engineers Without Borders UK. These perspectives were unique and complementary, providing varying insights from administration to participation and from creation to contribution to delivery.

Results

While explicitly titled as an engineering design challenge and delivered exclusively to engineering students, neither calculations specifically nor technical outcomes related to engineering skills more generally are called out in the learning outcomes, submission guidelines, or marking criteria. Engineers Without Borders UK's intended learning outcomes emphasize targets related to globally responsible engineering, including designing for people and context, the social considerations in engineering decision making, and the central importance of engineering in guiding human development and protecting the planet. There is also a strong emphasis on other complementary professional skills that students develop, including in communication, project management, and teamwork. The guidelines presented to academics and students highlights the importance of working across disciplines and cultures, as well as finding a personal role in and connection to engineering. The version presented to the reviewers additionally notes that engineers in general need to learn to do all of these things better.

Report guidelines and marking criteria closely reflect these definitions and learning outcomes. The submission guidelines encourage a focus on and description of the processes of reaching their design and justification of its contextual appropriateness; consideration of its implementation and its many potential consequences; academic and professional presentation; and a reflection on their work as a team. The subset of comments that were analysed in detail are summarized in Table 1, categorized by the marking criteria they were pulled from and the global dimensions they were coded to.

Reviewing the global dimensions

The global dimensions outlined in Table 1 were recognised as interrelated. For example, environmental and economic considerations were notably mentioned when considering material sourcing and use. Material selection and component manufacturing were related to costs, embedded carbon, and place in product life cycle and supply and waste chains; availability of materials was related to local ecological conditions or local economic systems, production capabilities and affordability; and sourcing and material transportation was related to fuel use, emissions and costs. Reviewers recognize these relationships, and regularly describe and identify the synergies and links between the different global dimensions, regarding them as complementary. In addition, the dimensions are also viewed as mutually conflicting. The most common example from reviewers was how economic benefits often come at the expense of environmental harms, or vice versa. Similar trade-offs are referenced when social concerns negatively correlate with environmental or economic considerations. Reviewers further highlight conflicts between the environmental and community consultation dimensions, as communities with immediate challenges may not prioritize environmental protection or other sustainability concepts.

Table 1: Summary of comments coded to the global dimensions and in the marking criteria

Number of reviewer comments coded / Global Dimension	Marking Criteria							Total
	1a – Environmental considerations	1b – Economic considerations	1c – Social community considerations	1d – Other global dimensions	2a – Implementation & appropriateness	2b – Methodical Assessment Process	[3] – General feedback	
Environmental context	**61**	3	2	14	1	1	17	99
Economic context	3	**95**	11	8	2	1	20	140
Social/ community context	2	11	**119**	11	12	2	36	193
Community consultation	7	10	67	**66**	38	5	66	259
Ethical responsibilities	11	14	14	**41**	9	3	51	143
Longevity	0	6	1	**22**	2	0	6	37
Total	84	139	214	162	64	12	196	871

Reviewers often focused on engineering analyses and other technical issues in their comments, despite no marking criteria covering this area. Other comments varied from emphasising the design challenge as an exercise in applying the global dimensions (rather than technical design), to praising technical rigor but encouraging a focus on the global dimensions for their own value and for the sake of good engineering. Notably, technical and social issues were recognised by reviewers as interdependent in engineering design. This relationship sometimes referred to the need to tailor technical features to social conditions, other times to designing technical features to address social conditions. The comments further emphasise that social conflict can result from unequal access to technical benefits or natural resources. Reviewers often comment that learning to navigate these conflicts is at the heart of the design challenge itself. At the same time, many of these same relationships and tensions come out in the reviewers' own contributions and perspectives.

Reviewer Reflections

Reviewer reflections on the marking criteria presented opposing views, with some enjoying navigating the complexity of the criteria, while others felt unprepared. Some reviewers advocated for more technically focussed review standards, including recommending its inclusion in the marking criteria. Noting the subjectivity of many categories, reviewers asked for simplifications, specifications, or elaborations in the training and guidance to help clarify the intended meaning of the criteria for global responsibility.

The reviewers also reflect on what they see as the benefits of participating in the design challenge. Responses range from framing the challenge as a rewarding service that they provide, helping a good cause and providing a path to influence the next generation, to considering it their responsibility to directly contribute to globally responsible engineering projects that help people, improve general welfare, and build a better world. While some of the reviewers describe this volunteer role as a natural extension of their everyday engineering work, most frame it as a fundamentally different type of experience that brought

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them out of their comfort zones and a space to learn new things about technology, innovation, social justice, and the diversity of the world. Contributions as reviewers in the design challenge were also viewed as ways to help engineering be used as a tool for social mobility and environmental guardianship on broader scales.

Notably, responses included that the challenge reminded them of reasons why they became engineers and they feel inspired to bring those notions back to everyday practice, for themselves, their peers, and students they mentor. These responses suggest reviewers see their role in the design challenge as a path to help students, become a part of the same mission that the students are tackling and finally to help change engineering to be more oriented toward those goals.

Discussion

For the reviewers, the experience is educational and practical in many of the same ways as for the students. Reviewers are trained of engineering's relationship to a long list of factors, including the six global dimensions. Further, reviewers consistently integrate additional considerations including political power, health and safety, and equity and justice. Providing minimum services and quality of life to people around the world and the engineers role in building a more environmentally sustainable society are consistently advocated for. Including scaling proposals from short to the long term and from locally to globally.

While not part of the evaluation criteria, technical and quantitative analyses were strongly emphasised in reviewer feedback to the students and advocated for inclusion in the marking criteria. This extends to critiques on economic analysis and quality of writing and presentation. Reviewers' perspectives and comments were sometimes more aligned with technologies and methods they were familiar with in practice, or on aspects that may be relevant to the reviewers day-to-day but would be a small consideration in the student proposal (e.g., selection, sourcing, and transportation of materials). While the social implications of many engineering disciplines are clear, the day-to-day reality of the work likely remains highly technical. Whether deliberately or habitually, the reviewers are demonstrating and passing on this technical focus to the next generation of engineers through their feedback and focus.

This focus on technical feedback may be at the expense of the qualitative and contextual elements. Reviewers commonly referred to a global dimension by name in feedback with limited connection to the proposal or their views. This does not indicate a misunderstanding of the concept but does suggest reviewers may be less comfortable speaking to the global dimensions, particularly if everyday exposure and experience is limited in their professional work. Specific social issues that the reviewers explored often had already been introduced in the design brief or by students in their reports. For example: in 2017, reviewers spoke regularly of the effects of meteorological concerns, after the design brief singled out the El Niño weather pattern as a major social influence in Lobitos, Peru; in 2018, discussions of crime and vandalism were disproportionately common, after the design brief introduced them as fundamental concerns in Kibera, Kenya; and in 2019, the reviewers commonly explored sexual violence and social inequality, after the design brief introduced women's struggles and the caste system in Tamil Nadu, India. This pattern is largely attributed to students setting the stage to focus on these topics.

The reviewers often talk about change in ways that may be in parallel with industry practices and expectations. They routinely compliment and advocate for scalable solutions that can effectively have a multiplying impact with a single design, speak of tailoring solutions to specific problem contexts and to putting oneself in the shoes of users and clients. They also commonly remind students that technical aspects are only part of a project, that each project plays only a part in larger societal systems, and that each project and location is part of progressively larger scale, from local to global.

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In their short contributions to the design challenge, reviewers are expected to represent their technical disciplines as subject matter experts, study the design brief and familiarize themselves with a brand new context, evaluate student reports based on a specialized but broad set of criteria that define Globally Responsible Engineering, and be excellent communicators, educators, and mentors. The reviewer role is framed as a service opportunity for professionals to help lead the next generation of engineering students toward the principles of globally responsible engineering. However, it can also be plainly interpreted as an educational exercise in globally responsible engineering for professionals. The training, guidance and communication directed at the reviewers supports this aspect of the experience, as they are immersed in what globally responsible engineering is, why it is important, and how it can be practiced and promoted. The training webinar in particular is similar to the student launch lectures given at the beginning of the challenge. When the organizers annotate previous exemplary reviewer feedback, they additionally set examples and benchmarks for how to interpret the global dimensions and engage with students.

In many ways, the reviewers also see the experience in the same way as training and practice for globally responsible engineering. They actively engage with concepts of global responsibility in their reviews, sometimes with the tone of a teacher, but often with the mindset of a learner, exploring ideas collaboratively with the students and organizers. Many reflect on ways in which they felt uncertain or unprepared to act as experts in globally responsible engineering and ask for more help in reaching that level, such calibrating their scoring and feedback based on these benchmarks. This suggests reflecting on other reviews and reports is an exercise and demonstration of a desire to personally understand how the context and concepts are most effectively applied, what should be expected of the students, the reviewers own place in the larger schemes of the design challenge and the push toward industry-wide globally responsible engineering. When the reviewers note how different this volunteer role is compared to their everyday industry work, they are valuing the new experiences and the knowledge gained from them. They regret that globally responsible engineering principles are not more frequently exercised in professional practice and praise the design challenge as a beneficial space to revisit them. Finally, when the reviewers look to their peers to build a community, they are acting on the knowledge that they are not alone in experiencing the design challenge this way and seek to scale their impact through these channels.

The reviewers’ contributions and experience broadly fit the description of ‘service learning’, where students “participate in an organized service activity that [addresses] community needs, and reflect ... to gain further understanding of course content, a broader appreciation of the discipline, and an enhanced sense of civic responsibility” (Bringle et al., 2004, p. 5). Similar to project and problem-based learning, service learning has been shown to support learning outcomes, civic engagement, interpersonal relations among college students, and orientation toward social responsibility (Levesque-Bristol et al., 2011), and achieves “higher cognitive levels in some skills and in attitudes and identity outcomes (i.e., social and moral development)” (Bielefeldt et al., 2010, p. 542). When project-based, problem-based, and service learning programmes integrate with the targets of globally responsible engineering, it can provide pedagogical, educational and experiential benefits (Riley & Bloomgarden, 2006). These results further align with the intention of the organizers and the contributions and reflections of the reviewers.

Professional engineers have a responsibility to take all necessary steps to maintain and enhance their competence through continuing professional development as life-long learners. Further, registered engineering professionals are “required to demonstrate a personal and professional commitment to society, to the environment and to their profession” (Engineering Council, 2020, p. 9). Interpreting the reviewer role in the design challenge as a combination of continued professional development through project-based service learning experiences shines a new light on the individual experience, its power as a tool for personal

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and professional growth, and the broad and multifaceted value of the design challenge as a development tool and scalable model for the entire industry.

This research primarily focussed on the reviewer process and contribution to the design challenge. In doing so the participation phase by university students of the design challenge is omitted. During this stage, there are potential parallels to explore between the academics' experience and those of the reviewers contributing to the design challenge, as they are guided by the framing of globally responsible engineering defined at the outset. As the delivery of the design challenge continues to expand internationally, further work could explore how the perspectives and understanding of globally responsible engineering from students, academics and reviewers vary between geographical and cultural contexts.

Conclusion

This research set out to study varying aspects of responsibility in engineering in the context of an undergraduate engineering design competition. These aspects included how that responsibility is defined and described, how it is presumed to be enacted, and how those orientations are practiced and passed on to others. The reviewer experience often does not correlate closely to those in everyday engineering practice, and the experience as a whole does not so closely resemble typical professional volunteer work. Instead, the reviewer experience has much more in common with that of the students, and is similarly a legitimate, valuable, and constructive educational itself in globally responsible engineering.

Problem based learning, such as the design challenge, is a unique and powerful tool for connecting across disciplines, experience levels, and communities, with the goal of redefining engineering and the way that it is taught and practiced. It is a collaboration between activists, industry professionals, students, and academics not just in stepping through the phases of the programme, but also for actively defining the ideals and goals that frame those steps and the desired outcomes.

The reviewer's participation in the design challenge can be viewed as a concurrent and specific learning experience that should be further explored in engineering education and continued professional development. Benefitting both the reviewers' own appreciation and application of globally responsible engineering and how they translate and promote it to student participants. These processes come together to build and form bonds between participating groups, combine their social and technical visions, and provide opportunities to enact and scale the impacts in engineering education and industry.

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Momentum Towards Incorporating Global Responsibility in Engineering Education and Accreditation in the UK

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ABSTRACT

CONTEXT

Engineering is uniquely placed to help address global challenges such as those surrounding the climate crisis, and the sustainable use and management of resources. However, studies have found UK engineering companies that have adopted sustainability strategies do not have enough staff with the skills to achieve them. There is an urgent need to upskill the current workforce and prepare future generations to operate in a responsible and ethical manner in tackling today's challenges. Recent updates to the standard of engineering accreditation in the UK provide notable opportunities to transform university curricula to create globally responsible engineers.

PURPOSE

This preliminary study explores the integration of global responsibility areas of learning and skill sets in engineering education accreditation. Recent revisions to accreditation are to be implemented at the end of 2021. The purpose of this study is to highlight how global responsibility principles are integrated and framed in engineering accreditation in the UK today.

APPROACH

This paper explores patterns within the recent updates made to engineering accreditation in the UK. The previous third edition and newly published fourth edition of the Engineering Council Accreditation of Higher Education Programmes (AHEP) are central to this research. Forward looking strategies from prominent voices in the sector including the Royal Academy of Engineering (2020-2025) and Engineers Without Borders UK (2021-2030), are viewed through the lens of Bloom's Taxonomy, a hierarchical model for categorizing learning objectives into levels of complexity, to generate preliminary findings.

ACTUAL OUTCOMES

Addressing sustainability, global responsibility and the Sustainable Development Goals (SDGs) requires more complexity in a students' learning process than engineering curricula currently provide. Sustainability, ethics, diversity and inclusion are fundamental to engineering education and enable inclusive design solutions and outcomes. The most notable change to AHEP is refining how global responsibility is presented and evolving the way it is taught. Changes incorporated in the new AHEP4 recognise the responsibility and skills needed of engineers to create positive change to society and global challenges. Yet by the time AHEP4 is realised the SDGs will be halfway through the Decade of Action. Achieving crucial SDG benchmarks will require both curricular change embedded in accreditation standards and a notable shift in the culture of engineering that embeds a professional commitment to behave more responsibly, individually and collectively.

SUMMARY

Incorporating global responsibility into engineering accreditation is necessary to prepare students to address global challenges. Newly updated accreditation standards frame engineering education around principles of globally responsible engineering while encouraging more complexity within the curricula, such as through problem-based learning approaches. This provides a strong starting point for engineering curricula and educators to prepare emerging engineers to act responsibly in the face of the urgent and dynamic global challenges.

KEYWORDS

Global responsibility; ethics; accreditation; Bloom's taxonomy; sustainability; climate emergency

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Introduction

The Sustainable Development Goals (SDG) Decade of Action 2020-2030 is well underway. At the same time the world is facing significant global challenges including a climate and biodiversity emergency. This emergency has been exacerbated by the COVID-19 pandemic, which has significantly and unprecedentedly impacted health, society, economy and education, while exposing and worsening existing injustices and inequalities globally (UNDESA, 2020). Engineers have a responsibility to tackle global challenges. Their work overlaps all the SDGs, including goals for a sustainable society, healthy environment, inclusive economy, and a recovery that is regenerative as well as inclusive and equitable. Individually and collectively, engineers need to accelerate their efforts towards meeting the SDGs (UNESCO, 2021). Raworth's (2017) doughnut economics model visually highlights the space at which humanity can thrive, providing both a social foundation (to ensure that no one is left falling short on life's essentials) and an ecological ceiling (to ensure that humanity does not collectively overshoot the planetary boundaries that protect Earth's life-supporting systems). However, at least four of the planetary limits identified by Raworth have already been overshot, specifically, atmospheric carbon dioxide, biodiversity, nitrogen/phosphorus loading, and land conversion (Raworth, 2017). At the same time, millions still lack access to basic human rights such as clean water and energy, unsustainable practices and materials are used across the engineering sector, and limited consideration is given to broader impacts on society and the planet. For example, concentrations of carbon dioxide discharged into the atmosphere are at the highest levels in the past 3 million years, pushing the climate to the point of catastrophic change within the next decade (IPPC, 2018). The majority of carbon emissions contributing to the climate emergency originate from industries enabled by engineers, with the building and construction sector alone responsible for 38% of global emissions (UNEP, 2020).

Sustainable development ensures people have their basic human needs met, that solutions are equitably shared, and that they do not drain and deplete the planet's fundamental ecosystems and natural resources for the future generations. Engineering graduates need a range of skills in order to create, develop or apply new or existing technologies, tackle today's global challenges and deliver on the SDGs. However, a study by the Institution of Engineering and Technology found that only 7% of engineering companies that have a sustainability strategy also have the staff with the skills to fulfil it, and only 53% of survey respondents believed it was possible for their companies to meet net zero by 2050 (IET, 2021). UNESCO (2021) recognises there is a responsibility for engineers to incorporate more than technical aspects into their solutions, and adopt approaches that consider social, environmental and economic impacts. There is therefore an urgent requirement to upskill the current engineering workforce and transform engineering education to prepare future graduates to practice engineering responsibly. Engineering curricula must be revised to incorporate the skills required to mitigate global and local challenges, societal aspirations and needs. This goes beyond an understanding of the impact engineering has to people and planet, and includes consideration of the values, principles and skills engineers put into practice every day. However, the UNESCO (2021) report recognises these values are generally yet to be incorporated into most educational institutions' engineering curricula.

Context

Strategies calling for globally responsible engineering

To frame what global responsibility in engineering looks like, this study draws on recent strategies released by prominent voices in the sector. It looks at strategies by Engineers Without Borders UK on 'Reaching the tipping point for globally responsible engineering 2021-2030' and another by the Royal Academy of Engineering (RAEng) titled 'Strategy 2020–2025 Engineering for a sustainable society and inclusive economy'. Both documents recognise

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engineering's role, and its responsibility to society, in tackling social and environmental injustice.

The Engineers Without Borders UK movement works to put ‘global responsibility at the heart of engineering’ for a safe and just future for all, by inspiring, upskilling and driving change within engineering education and profession (see: www.ewb-uk.org). The Engineers Without Borders UK 2021-2030 strategy sets out four key principles for global responsibility that should be embedded into the culture of how engineering is taught and practiced (Engineers Without Borders UK, 2021). Engineers and engineering needs to be: Responsible (to meet the needs of all people within the limits of our planet); Purposeful (to consider all the impacts of engineering, from a project or product’s inception to the end of its life which should be at a global and local scale, for people and the planet); Inclusive (to ensure that diverse viewpoints and knowledge are included and respected in the engineering process); and Regenerative (to actively restore and regenerate ecological systems, rather than just reducing impact).

The RAEng is the UK’s National Academy for engineering and technology. It brings together engineers to advance and promote excellence in engineering for the benefit of society (see: www.raeng.org.uk). The RAEng’s overarching goal for 2020-2025 is ‘to harness the power of engineering to build a sustainable society and an inclusive economy that works for everyone’ (RAEng, 2020). The strategy recognises that ‘engineers are influential agents of change in the drive for a more sustainable society’ and works to ‘embed sustainability and global responsibility as a core element of engineering education, training and professionalism’.

Accreditation Bodies and Updates

In the UK, the Engineering Council sets the requirements and degree standards for the Accreditation of Higher Education Programmes (AHEP) in engineering. These standards are developed through consultation with the engineering professions, employers and academics. AHEP standards align with the Engineering Councils UK Standard for Professional Engineering Competence (UK-SPEC). These standards set out the competence and commitment for Engineering Technicians (Eng Tech), Incorporated Engineers (IEng) and Chartered Engineers (CEng). Learning Outcomes are included, to guide assessment of the competence and commitment of individual engineers; they can be interpreted in the context of a particular disciplinary or multidisciplinary engineering practice, and level of study.

There have been four iterations of AHEP since its original publication in 2004. The third edition of AHEP is applicable for all accredited modules from September 2016 and the fourth edition of AHEP is to be introduced by the end of 2021, with the learning outcomes implemented by August 2024. AHEP4 reduces the total number of learning outcomes to focus on core areas and it strengthens the focus on inclusive design and innovation, equality, diversity, sustainability and ethics (Engineering Council, 2020a), as evident in the statement below.

> ***The Engineer and Society****: Engineering activity can have a significant societal impact and engineers must operate in a responsible and ethical manner, recognise the importance of diversity, and help ensure that the benefits of innovation and progress are shared equitably and do not compromise the natural environment or deplete natural resources to the detriment of future generations. (Engineering Council 2020a)*

Methodology

This preliminary study explores how the principles of globally responsible engineering are integrated and framed in engineering education accreditation in the UK. This follows on from a previous exploratory study of globally responsible decision-making in civil engineers’ day-to-day practice (Chance, et al, 2019, 2020). This paper investigates the social, environmental, ethical and economic considerations in recent updates to engineering education accreditation and the principles of globally responsible engineering, which are

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central to strategies published by the Royal Academy of Engineering (2020-2025) and Engineers Without Borders UK (2021-2030).

Global responsibility in engineering requires more than solely knowledge and understanding. It requires engineers to have the ability to critically analyse, reflect and critique the role of engineering, its relationship with humanity, and its impact on our past and potential futures (Engineers Without Borders International, 2021). This paper contributes new understandings, extending prior work, by investigating the language surrounding skills development for globally responsible engineering. It uses the framework of Bloom's taxonomy (a hierarchical model that categorizes learning objectives into levels of complexity) to explore how engineering students can most effectively develop skills prior to graduation. Bloom's taxonomy is presented in Figure 1, based on revisions to the original taxonomy made by Armstrong (2010). Lower order skills include Remembering, Understanding and Applying. Higher order skills include Analysing, Evaluating and Creating. This framing is not used to dismiss the lower levels of teaching but rather to understand where accreditation leans more towards building lasting skills to enable change, rather than simply delivering content for students to memorize and remember.

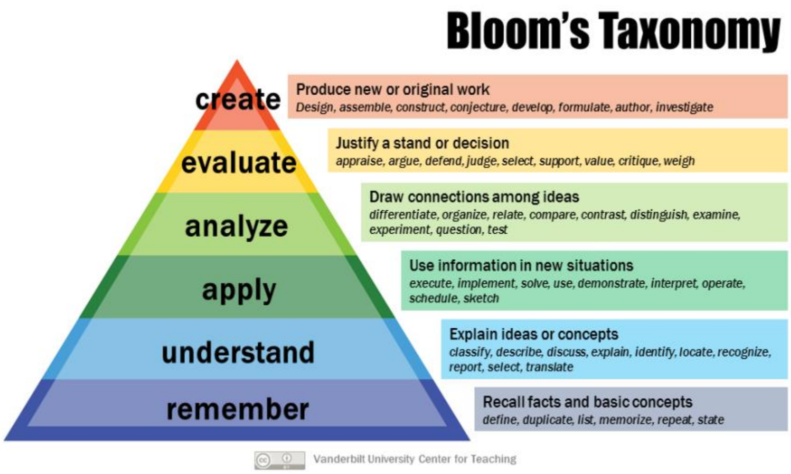

Figure 1: Bloom's Taxonomy, source: Armstrong (2010)

To facilitate comparison and gauge change over time, the learning outcomes of AHEP3 and AHEP4 were coded. The meanings of the words used with regard to globally responsible engineering principles and Bloom's taxonomy were carefully considered and tabulated the results to facilitate comparison of frequencies. Bachelor and Masters degrees that fully meet the requirements for IEng and CEng level accreditation courses were specifically considered in this analysis. This preliminary study is part of a larger body of work in progress by Engineers Without Borders UK, to define and broaden competency frameworks. The subsequent competency frameworks will support the engineering workforce to develop values and competencies in producing globally responsible outcomes.

Results

Table 1 presents the frequency of coded global responsibility aspects within the learning outcomes of AHEP3 and AHEP4. The principles and definitions of globally responsible engineering, as set out in the Engineers Without Borders UK strategy, are also presented. These cover specific goals of the RAEng strategy involving progression towards a 'sustainable society' and 'inclusive economy'.

Table 1: Frequency of coded learning outcomes associated with global responsibility

Areas of learning global responsibility	AHEP3 (IEng)	AHEP4 (IEng)	AHEP3 (CEng)	AHEP4 (CEng)
Social	1	2	1	2
Environment	4	4	4	4
Economic	1	0	1	0
Ethical	2	2	2	2
Sustainable	0	0	0	0
Responsible	1	1	1	1
Purposeful	1	0	1	1
Inclusive	0	5	0	6
Regenerative	0	0	0	0

The learning outcomes terms associated with global responsibility remain similar between AHEP3 and AHEP4, with the exception of learning outcomes with Social and Inclusive considerations. Although Economic considerations were not mentioned in learning outcomes of AHEP4, they are stated alongside the learning descriptions, which highlight the importance in economically viable designs e.g., “development of an economically viable product, process or system to meet a defined need”. While Sustainability is not specifically mentioned within the learning outcomes in AHEP4, it is described as an area of learning that is defined by a learning outcome, i.e.:

- “Evaluate the environmental and societal impact of solutions to Broadly-defined problems.” (IEng)
- “Evaluate the environmental and societal impact of solutions to Complex problems (to include the entire lifecycle of a product or process) and minimise adverse impacts.” (CEng).

AHEP3 does not cover Inclusive in its learning outcomes, however, there is sharper focus on inclusive design and innovation in AHEP4, as reported in Table 1. Regenerative considerations are not evident in AHEP3 or AHEP4 learning outcomes.

Engineers need the skills to put global responsibility into day-to-day practice as well as their broader engineering culture. Table 2 presents the frequency and proportion of skills to meet learning objectives, coded through the lens of Bloom's Taxonomy. AHEP4 also frames learning outcomes in the context of problem-based learning, addressing varying levels of problem complexity. These include Broadly-defined problems (that involve a variety of factors which may impose conflicting constraints, but can be solved by the application of engineering science and well-proven analysis techniques) and Complex problems (that have no obvious solution and may involve wide-ranging or conflicting technical issues and/or user needs that can be addressed through creativity and the resourceful application of engineering science). Table 3 presents the frequency of problem complexity highlighted in the learning outcomes, as defined by AHEP4.

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Table 2: Frequency and proportion of coded words associated with Bloom's Taxonomy

Bloom's Taxonomy		AHEP3 (IEng)	AHEP4 (IEng)	AHEP3 (CEng)	AHEP4 (CEng)
Higher-order	Create	4 (9.52%)	4 (11.76%)	6 (9.52%)	5 (15.63%)
	Evaluate	2 (4.76%)	7 (20.59%)	5 (7.94%)	8 (25.00%)
	Analyse	0 (0.00%)	0 (0.00%)	2 (3.17%)	0 (0.00%)
Lower-order	Apply	18 (42.86%)	8 (23.53%)	20 (31.75%)	10 (31.25%)
	Understand	9 (21.43%)	5 (14.71%)	15 (23.81%)	8 (25.00%)
	Remember	9 (21.43%)	10 (29.41%)	15 (23.81%)	1 (3.12%)
Total		**42 (100%)**	**34 (100%)**	**63 (100%)**	**32 (100%)**

Table 3: Frequency of problem complexity in learning outcomes

Level of problem complexity	AHEP3 (IEng)	AHEP4 (IEng)	AHEP3 (CEng)	AHEP4 (CEng)
Broadly-defined problems	0	9	0	0
Complex problems	0	0	1	10

The frequency of words associated with Bloom's Taxonomy is lower in AHEP4 than AHEP3, which can be attributed to AHEP4 specifically reducing the number of learning outcomes to present a sharper focus on the learning outcomes overall. However, proportionally there is a notable shift from lower-order skills to higher-order skills: IEng (AHEP3: 85.71% lower-order and 14.29% higher-order; AHEP4 67.65% lower-order and 32.35% higher-order) and CEng (AHEP3: 76.92% lower-order and 23.08% higher-order; AHEP4 55.88%% lower-order and 44.12% higher-order). IEng accredited courses predominantly focus on Broadly-defined problems while CEng accredited courses predominantly focus on Complex problems. This supports the distribution of lower-order and higher-order skills between IEng and CEng. As this framing is new to AHEP4, the limited use of these terms in AHEP3 is expected.

Discussion

The changes to AHEP recognise the role of globally responsible engineers in tackling global challenges and make efforts to incorporate such values into engineering accreditation. Global responsibility concepts have been refined between AHEP3 and AHEP4 in how they are presented and taught. Analysing these through the lens of Bloom's taxonomy, it is evident there is a shift from lower-order skills to higher-order skills in approaching learning outcomes, encouraging more critical skill development. The changes to accreditation are also synonymous with recent revisions to the International Engineering Alliances graduate attributes and professional competences (IEA, 2021). However, these share similar scope for improvement and expansion. Particularly around deeper comprehension of ethical issues and complexity in curricula to aid critical thinking and reflection of the role of engineering (Engineers Without Borders International, 2021).

Stratford (2016) describes how accreditation can provide a process to aid reflection on embedding complexity within design project delivery. Implementing AHEP4 will be slow, however, the newly announced AHEP4 provides educators an opportunity to reflect how learning outcomes are currently being delivered in engineering curricula and where more complexity and critical reflection of the role of engineering is needed. It is recommended that accreditation should not be framed as the ceiling for acrredited modules but rather educators

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should view it as the starting point to go further. For example, a CEng learning objective associated with sustainability, is to 'Evaluate the environmental and societal impact of solutions to complex problems (to include the entire life-cycle of a product or process) and minimise adverse impacts'. While this learning objective aligns with the Purposeful principle of globally responsible engineering, it needs to go further to question the impacts in the first instance. Minimising the adverse impacts to society and planet is insufficient, as evident from the privacy and security implications with Artificial Intelligence (UNESCO, 2021), the urgency of the climate emergency as it exceeds the tipping point (Ripple, et al., 2021) or the four overshot planetary boundaries (Steffan, et al., 2015). Additional reflection is also required when considering the levels of problem complexity. Confining Broadly-defined problems to IEng accreditation and Complex problems to CEng accreditation could potentially be narrowing and restrictive in practicing the higher-order skills required to tackle global challenges. Much of the curricula success will be attributed to how problems are identified and defined in education and professionally.

Embedding the principles of globally responsible engineering explicitly and relevant global challenges into the learning outcomes of engineering education is another opportunity for accreditation and accredited modules to go further to tackle the global challenges emerging graduates will face. For example, while not specifically embedded in the learning outcomes, a call for Regenerative approaches and use of the UN SDGs are mentioned and encouraged in the Engineering Council's guidance for sustainability in accredited programme design and delivery (Engineering Council, 2020b). This guidance closely aligns with the strategies and principles of globally responsible engineering as set out by the RAEng and Engineers Without Borders UK. This is also supported by the Joint Board of Moderators (a group licenced by the Engineering Council who coordinate accreditation activities for educational programmes in the built engineering sector) which recognises that the climate emergency should not only be learnt but embedded in the culture of how engineers are taught.

> *In particular, we see the extraordinary challenge of the Climate Emergency as a very necessary central cultural feature in the education of civil engineering students, and our guidelines should be read with this strongest intent in mind. (JBM, 2020)*

Addressing the global challenges and SDG benchmarks requires complexity within engineering curricula to recognise the responsibility and skills needed of engineers to create positive change to society and global challenges. AHEP4's use of Broadly-defined and Complex problems in its learning outcomes has the potential to provide holistic delivery of multiple learning outcomes within a programme while also developing the critical thinking, skill set and professional commitment required in tackling global challenges such as the climate crisis. This is reflective of the already well-established problem-based learning approach (and supported by UNESCO (2021), which encourages educators to move from a knowledge based approach to a knowledge and a problem-based approach), allowing further complexity in a student's learning process that has a positive impact on professional competencies and increasing awareness of sustainability throughout the process (Kolmos, et al, 2020). The Engineers Without Borders UK Engineering for People Design Challenge is an example where this has been successful. The undergraduate design challenge, delivered as an accredited module, enables students to explore ethical, environmental, social and cultural aspects of engineering design, while providing an avenue to put critical thinking skills into practice. Existing approaches, such as accredited design challenges, can enable educators to facilitate the complexity needed to develop globally responsible engineering graduates, align with the teaching and learning objectives required of accredited modules, and embed globally responsible engineering values and commitment for emerging graduate engineers to take into their professional roles and continued professional development.

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Conclusion

There is growing momentum towards including globally responsible engineering principles in engineering education accreditation. It’s clear accreditation for higher education won’t be the sole solution to tackling today's global challenges, but opportunities and recommendations for transforming traditional lecture-based education into approaches (such as problem-based learning) that incorporate complex and critical reflection on the role of engineering are evident. Between AHEP3 and AHEP4, the areas of learning remain largely unchanged but do present a stronger focus and clearer communication around areas and skills of global responsibility. Furthermore, the guidance to the learning outcomes covers valuable information that should not be ignored for accredited module development. The key update to accreditation is moving from solely understanding of the areas of engineering to identification and critical evaluation of engineering solutions and how engineering solutions affect society. For educators looking to AHEP, a crucial aspect of success will be viewing accreditation as a starting point to go further, to improve the culture of engineering and a professional commitment to be more globally responsible. Following this preliminary study, the next steps are to define and broaden competency frameworks to support the engineering workforce develop and embed their values and competence in global responsibility from the classroom learning outcomes into the professional workplace.

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Influence Of Academic Education Imparted In Basic Sciences On The Scientific Reasoning Skills Of Engineering Students

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ABSTRACT

CONTEXT

In the academic world and more specifically in engineering education programmes, the aim is to develop teaching activities, which promote the achievement of formal thought in students. Cognitive theories insist that knowledge is meaningful and therefore opinions of students about themselves and their environment should be considered. Consequently, professors need to take into account how mental processes are manifested during learning.

PURPOSE OR GOAL

This work aims to measure and detect significant changes in the scientific reasoning skills of university engineering students. In particular, it wants to determine if the curriculum map of courses belonging to the core of mathematics and physics, which is typically seen in the first two years of the curriculum of engineering programmes, contributes significantly to the academic education and learning of students

APPROACH OR METHODOLOGY/METHODS

A case study was developed in the College of Engineering of the Universidad del Norte. It was composed of two important chronological stages. Stage 1: In the first semester of 2015, it was applied the modified LCTSR to all students who will complete their first semester in the engineering programmes (more than 800 students). Stage 2: In the first semester of 2017, the same test was applied to a large group of students. As a result, it was obtained that 126 students presented the same LCTSR in both 2015 and 2017. The exposed analyses seek to answer the following two questions: i)Has basic sciences education contributed to the development and enhancement of formal thinking in Engineering students?, ii)Is there a correlation between the academic performance of students and the thought stage measured to students through the Lawson Classroom Test of Scientific Reasoning (LCTSR)?

ACTUAL OR ANTICIPATED OUTCOMES

These descriptive results indicate that even when there was an improvement in 2017, this improvement does not seem to be large enough for most students to develop formal thinking.It should be taken into consideration that in 2017 at least 40% of students are still under 19 years old. Also, the results supported the idea that there is a positive correlation between the LCTSR score and the academic performance of students

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

On average, the training received by the students from Engineering programmes in the core courses of mathematics and physics, actually develops their logical thinking/reasoning skills. However, these seem not to be sufficient for students to show an ideal academic performance in the basic core courses of engineering programmes. Finally, the overall results of this study show an opportunity for improvement in engineering programs.

KEYWORDS

Lawson Classroom Test of Scientific Reasoning (LCTSR); concrete thought; transition thought; formal thought; engineering students

Introduction

In the academic world and more specifically in engineering education programmes, the aim is to develop teaching activities, which promote the achievement of formal thought in students. The renowned researcher Piaget defined in his studies four states of thought, which are progressively achieved by a person from birth to adulthood. In this classification, the fourth and last state is called formal thought. In this state, an individual is able to formulate hypotheses and test them, and therefore has the ability to isolate and control key variables of the problem, while excluding those irrelevant (Inhelder & Piaget, 2013; Picquart et al., 2010).

The academic community has also sought ways to quantify or categorise types of thought through the use of tests applied to students. Consequently, several types of tests have been developed, such as the Scientific Creativity Test (SCT), the Mathematical Creativity Test (MCT) and the Novel Creativity Test (NCT). Each of these tests measures the level of creativity in their respective domain of interest. Such tests consider three indicators: the originality of their responses, the fluency in the use of scientific knowledge to develop the solution, and the flexibility in the use of different areas of knowledge (Huang et al., 2017; López Martínez & Ramón Martín, 2010). There are also other alternative tests. The test of thinking style seeks to determine the strengths and tendencies of individuals to channel their thought when addressing specific types of problems (López Martínez & Ramón Martín, 2010). The multiple intelligences test aims to determine the potential of the predominant type of intelligence and its benefit in the development of certain tasks (Stecconi, 2010). The Test Of Logical Thinking (TOLT) seeks to evaluate the different schemes of formal thought (Acevedo & Oliva Martínez, 1995). The Lawson Classroom Test of Scientific Reasoning (LCTSR), which evaluates the capacity for scientific reasoning according to proposals made by Piaget (Jensen et al., 2015; Lawson, 1978, 2000; Piraksa et al., 2014).

The aforementioned indicated that the construction of concepts and the development of formal thought are topics that have been studied by several scientific disciplines. Within these disciplines are basic sciences and pedagogy; since an interdisciplinary approach is required. In particular, the research developed in this work is the result of a Teacher Learning Community (CAD in Spanish) called Shared Projects. This Community was supported by the Center for Teaching Excellence (CEDU in Spanish) from Universidad del Norte, Colombia. Our research proposes a case study to determine if the academic education imparted in basic sciences promotes significant improvements in the scientific reasoning skills of engineering students. For the development of the case study, a sample of students belonging to different programmes of the College of Engineering from Universidad del Norte was randomly selected. Each selected student presented the LCTSR twice, but at two different times: in the first and fourth semester. The exposed analyses seek to answer the following two questions: (i) Has basic sciences education contributed to the development and enhancement of formal thinking in Engineering students? (ii) Is there a correlation between the academic performance of students and the thought stage measured to students through the LCTSR?

Literature review

This section presents a literature review that discusses learning theories and defines the applications and key features of the LCTSR. The main objective is to establish a conceptual basis that allows responding to the previously mentioned questions.

Theories of learning

Behavioural theories express that professors must generate a teaching environment that allows students to respond appropriately to stimulus. Cognitive theories insist that knowledge is meaningful and therefore opinions of students about themselves and their environment should be considered. Consequently, professors need to take into account how mental processes are manifested during learning. That is, the way in which learning occurs not only

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depends on the structure and how the information is presented to the students, but also on what are the best activities that should be proposed to them (Guanipa Marquez et al., 2007; Linares, 2009; Picquart et al., 2010). Piaget suggested that intellectual development is necessarily slow and essentially qualitative. Hence, the evolution of the intelligence supposes the progressive appearance of different stages that differ to each other by the construction of qualitatively different schemes (Severo, 2012). The theory of Piaget defines several stages of cognitive development from childhood to adolescence. He explained that psychological structures are developed from inborn reflexes; they are organized during childhood in behaviour patterns, are also internalized during the second year of life as models of thought and are developed during childhood and adolescence in complex intellectual structures that characterize adult life (Delgado, 2001).

As was explained in the Introduction, in studies made by Piaget, it is shown four stages of thought that progressively reach from the birth of the individual until adulthood. Similarly, the LCTSR and the Piaget questions are based on constructivist theories. These theories propose that the human being or individual is no longer a passive organism conditioned and shaped by the environment, but that the individual follows the four stages of thought described below: (i) Sensory-motor stage (0 to 2 years of life): the individual is considered active and can learn the thought oriented to means and ends. (ii) Pre-operational stage (2 to 7 years of life): the individual is intuitive and develops symbols and words in their thoughts. (iii) Operational stage (7 to 11 years of life): the individual is more practical and learns logical operations of serial, classification and conservation. His thought is related to the phenomena and objects of the real world. (iv) Formal operational stage (greater than 11 years of life): the individual is able to reason with propositions without the need for objects, able to think in an abstract and hypothetical-deductive way, and able to analyse the possible combinations or variations that may occur in certain situations. Initially, Piaget proposed that it would be necessary to wait until 20 years to consolidate formal thought (Linares, 2009; Opitz et al., 2017; Rodríguez et al., 2010).

Lawson Classroom Test of Scientific Reasoning: LCTSR

The literature widely reports that one of the main goals of education is to ensure that students are able to use the concepts and methods learned in solving problems in their professional practice and daily life. Consequently, the framework of the Organization for Economic Cooperation and Development (OECD, 2006) for the Programme for International Student Assessment (PISA) includes the following three skills: identifying scientific problems, explaining phenomena scientifically, and using scientific evidence (Opitz et al., 2017). Similarly, literacy is now considered as a central objective and a critical learning outcome for the standard of scientific education in several countries (Piraksa et al., 2014).

Lawson explains that reasoning is the process of deducing conclusions from principles and testing of new conclusions. He also argues that scientific reasoning includes the thought skills involved in research, experimentation, evidence evaluation, inference and argumentation. Thus, scientific reasoning consists of a general pattern of reasoning that includes hypothetical-deductive thought and various sub-patterns. These sub-patterns can be characterized as formal operational schemes, such as proportions, combinatorial and correlations (Lawson, 1976, 1978, 2010; Picquart et al., 2010). In particular, our research was conducted to explore the scientific reasoning ability of engineering students through the application of the modified LCTSR; which was designed to assess the ability of scientific reasoning according to proposals made by Piaget. This test consists of 12 questions of 2 levels and, therefore, 24 items, each question has a second-level question designed to measure the scientific understanding of the process by the student. Note that, a score of 1 point is obtained for each of question, if and only if, the two levels of each question are answered correctly. Thus, the overall score obtained by a student in the LCTSR is minimum 0 points and maximum 12 points. The validity and reliability of the LCTSR has already been demonstrated by several authors in other researches (e.g., Fulmer et al., 2015; Lawson, 1978, 2000; Lawson et al., 2007; Piraksa et al., 2014).

At following, the six aspects of scientific reasoning that are measured through the modified LCTSR (Jensen et al., 2015; Piraksa et al., 2014): (i) Conservation of physical magnitudes (items 1 to 4): It seeks to evaluate what is the relationship of magnitudes such as mass and volume when their shape is manipulated. (ii) Proportional thought (items 5 to 8): It evaluates the relationship between two data series, which can be mathematical or scientific. (iii) Identification and control of variables (items 9 to 14): It seeks to have the ability to identify and isolate variables, and to reason in an experiment to conclude which was the cause of the problem. (iv) Probabilistic thought (items 15 to 18): The notion of probability, related to the understanding of chance and causality, is related to notions of proportion as well as combinatorial schemes and would be useful both for the solution of mathematical problems and for the understanding of non-deterministic scientific phenomena. (v) Correlational thought (items 19 and 20): The notion of correlation is linked to both proportion and probability and would be necessary for the analysis of data and scientific experimentation in complex tasks or before probabilistic phenomena. (vi) Combinatorial thought (items 21 to 24): Combinatorial operations, given a series of variables or propositions, make it possible to exhaust all possible combinations among them to achieve a certain effect. Operations of this type would be combinations, variations and permutations.

It is important to note that dominate the last three aspects of scientific reasoning requires a higher skill level of the student. Besides, the development of these last three aspects is essential for the student to reach a level of formal thought. Finally, according to the overall score obtained by a student in the LCTSR, which has a minimum score of 0 and a maximum score of 12, the student can be classified in one of the three categories of thought: (i) Concrete (0-4 points); (ii) Transition (5-8 points); and (iii) Formal (9-12 points).

Experiment, results and discussion

Experimental design

As previously explained, this work aims to measure and detect significant changes in the scientific reasoning skills of university engineering students. In particular, it seeks to determine if the curriculum map of courses belonging to the core of mathematics and physics, which is typically seen in the first two years of the curriculum of engineering programmes, contributes significantly to the academic education and learning of students. Specifically, it is expected that once the engineering students complete the first four semesters, they will have the mathematical logic skills required to show adequate academic performance in the basic core courses of the engineering programmes.

A case study was developed in the College of Engineering of the Universidad del Norte, Colombia to achieve the objective of this research. It is composed of two important chronological stages. Stage 1: In the first semester of 2015, it was applied the modified LCTSR to all students who will complete their first semester in the engineering programmes (more than 800 students). Stage 2: In the first semester of 2017, the same test was applied to a large group of students. As a result, it was obtained that 126 students presented the same LCTSR in both 2015 and 2017. Finally, for each of the 126 students, the scores obtained in the following seven categories were recorded: (i) conservation of physical magnitudes (PM); (ii) proportional thinking (PR); (iii) identification and control of variables (IV); (iv) probabilistic thinking (PT); (v) correlational thinking (CT); (vi) combinatorial thought (CM); and (vii) overall (OV). The last category represents the total score obtained by the student in the LCTSR, which is the result of adding the scores obtained in the six aspects of scientific reasoning.

Results of the case study

The results and discussion of this case study are divided into the following three subsections: Characteristics of the samples; Lawson test; and Lawson Test vs Academic performance.

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Characteristics of the samples

The purpose of this subsection is to provide detailed information about the individuals that make up the two data samples that were used in this case study. Note that, by definition, these samples are not independent and therefore are considered paired, since the 126 experimental objects are the same in both samples.

It was observed that 99% of the population in 2015 and more than 40% in 2017 is in a range of age less than 19 years. Thus, as stated by Piaget and various authors of constructivist theories, it can expect that their levels of reasoning have not yet wholly reached formal thought (Aguilar Villagrán et al., 2002; Linares, 2009; Rodríguez et al., 2010). In addition, Figure 1a indicates that in the samples there is a majority of male students. Although it is not the object of work, previous studies carried out by (Piraksa et al., 2014), have concluded that there is no significant correlation between gender and the ability to reason scientifically. Finally, Figure 1b shows that, in the samples, there are students belonging all the engineering programmes offered by Universidad del Norte.

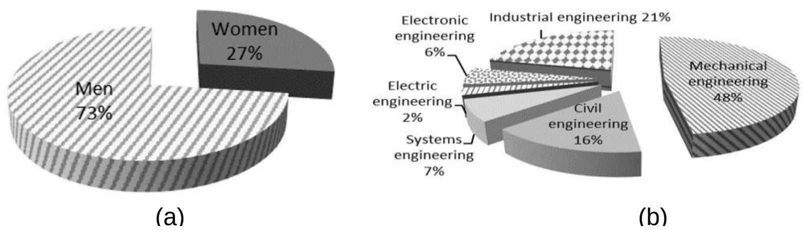

Fig 1: Distribution of students by (a) gender and (b) academic programme.

Lawson test

This subsection presents the results of the LCTSR using two types of statistical analysis.

Descriptive analysis

Table 1 presents several statistics that allow describing numerically the characteristics of the studied samples. Note that, the statistics presented in the third column require a previous arithmetic operation between the data of the 2015 and 2017 samples. Specifically, for each student is calculated the difference between the overall score obtained in 2017 minus the overall score obtained in 2015. It is observed that the average score obtained by the students in 2017 was higher than in 2015, specifically there is an average increase of 1.42 points in the LCTSR. Similarly, the analysis of the 25, 50, and 75 percentiles for 2017 indicates that the three percentiles show an increase of 2 points compared to the results obtained in 2015. For example, the 75 percentile for the year 2017 states that 75% of students scored at or below 9 points, while for 2015 the 75 percentile says that 75% of students scored a maximum of 7 points. Note also that the 2015 and 2017 samples have an almost identical variability since their respective standard deviations are very similar.

Table 1: Descriptive measures on the samples.

	2015	2017	(2017 - 2015)
Mean	5.18	6.6	1.42
Percentile 25	3	5	-
Percentile 50	5	7	-
Percentile 75	7	9	-
Desv. Standard	2.64	2.63	2.07

Additionally, Figure 2a shows the percentage of students who improved, worsened or maintained the same score on the LCTSR and Figure 2b gives more details about the students who obtained an improvement in their score. For example, Figure 2a indicates that 65% of students improved their score. In turn, Figure 2b shows that 22% of students improved their score by 1 point. It is interesting to note that 55% (22 + 16 + 15 + 2) of the students showed an improvement in their score of maximum 4 points. That is, few students achieved an exceptional jump in their logical reasoning skills since only 10% of students achieved an improvement of 5 points or more. This result is especially valuable since only an improvement equal to or greater than 5 points would allow a student who in 2015 was classified in Concrete Thought could be classified in 2017 in Formal Thought. It must be remembered that this last category represents the ideal state of thought. It is worrisome that 19% of students will not improve their scores and that 16% of them will present a setback.

However, according to Piaget and Vygotsky, learning is a slow and qualitative process that is presented in stages. They also explain that learning requires an intellectual, cultural and historical development that depends on the experiences lived by each student. In addition to this, Vygotsky suggests that the development of scientific concepts ("non-spontaneous") can be achieved, focusing attention on the processing related to the context of the concept. Consequently, it seeks to promote spontaneous thinking and therefore the understanding of the concept of science, in a period that may be slow, but in the long term, students will develop high levels of thinking Ramos Serpa & López Falcón, 2015; Severo, 2012; Vygotsky, 1978).

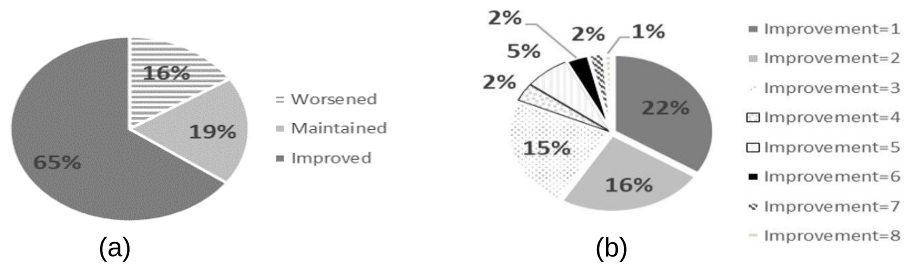

Fig. 2: Student performance: 01-2015 vs 01-2017.

Finally, for the years 2015 and 2017, Figure 3 presents the percentage of students that were classified in each category of thought, according to the scores obtained in the LCTSR. The results are intuitive since it shows how the percentage of students in concrete thought decreases in 2017, but also how the percentage of students in formal thought increases in 2017.

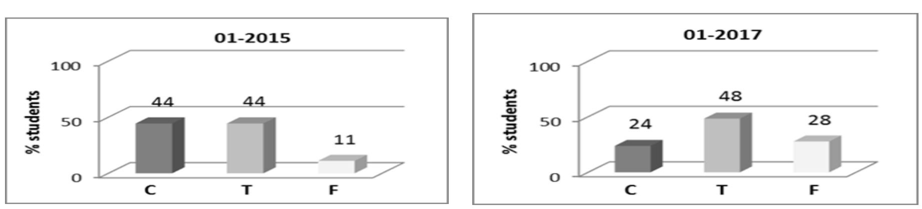

Fig. 3: Percentage of students by category of thought in 01-2015 and 01-2017. (C: concrete; T: transition; F: formal).

Inferential analysis

The purpose of the inferential analysis is to determine if there is a significant improvement when comparing the average scores obtained from the LCTSR in 2015 and 2017. That is, we seek to prove that the average scores for the year 2017 are higher than the average scores of the year 2015. In order to achieve this objective, it is proposed to apply tests of hypotheses of the difference of means that determine the validity or falsity of the statements made. In particular, seven tests of unilateral hypotheses (right) are proposed; one for the overall scores of the LCTSR and the other six for the scores of the six aspects of scientific reasoning that are also evaluated in the test. Note that this study considers two random samples dependent (i.e., paired). Furthermore, since the sample size is large enough (i.e., n= 126), the Central Limit Theorem can assume that the distribution of the means follows an approximately normal distribution. Therefore, the paired t-test statistic can be applied.

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For each of the seven proposed hypothesis tests, the null hypothesis H0 expresses that the difference of the average scores between both populations is equal to zero. On the other hand, the alternative hypothesis H1 expresses that the average score for the year 2017 is strictly higher than the average score of the year 2015. Table 2 presents the results for the seven tests of right unilateral hypotheses.

Given that several hypothesis tests are being carried out simultaneously on the same data set, false rejections of the null hypotheses should be avoided. Therefore, it was used the Bonferroni method to adjust the level of significance (α) about the number of statistical tests performed simultaneously. The method says that, if it seeks to guarantee a level of significance for the set of M pairwise comparisons, it is enough to take a corrected significance level that can be expressed as $\alpha_* = \alpha/M$. In this way, the possible error that can be made by making many comparisons in pairs is compensated. For this study, a level of significance of $\alpha = 0.05$ was considered, obtaining a corrected significance level $\alpha_* = 0.05/7 = 0.0071$. Note that, if for any of the seven tests the calculated P-value is less than α_*, this means that H0 is rejected in favour of H1. Otherwise, H0 is not rejected.

Table 2: Results of the comparison test of means: 01-2015 vs 01-2017.

	Aspects of Scientific Reasoning						Overall
	PM	PR	IV	PT	CT	CM	OV
Statistic T	3.81	6.96	3.96	2.38	2.38	1.69	7.70
Value-P	1.09E-04	1.02E-07	6.24E-05	0.0095	0.0095	0.0467	1.04E-07

Table 2 shows that in four of the seven tests there is statistical evidence that there is a significant improvement in the average scores of 2017 concerning the average scores of the year 2015. However, for the scientific reasoning aspects Probabilistic (PT), Correlational (CT) and Combinatorial (CM), the hypothesis test says that there is no significant difference between the average scores of the years 2015 and 2017.

Lawson Test vs Academic performance

The purpose of this subsection is to detect if the results of the LCTSR have a positive association with the academic status of the students, the latter measured by the academic average. That is, through simple exploratory analysis, we evaluate whether there are indications that students with a high overall score on the LCTSR also have a high academic average, and vice versa. For the year 2017 and the 126 students sampled, Table 3 shows in percentage, how students are distributed concerning the LCTSR score and the Thought Category. In turn, the table groups the students according to their academic status: (i) Trial period (2.95 - 3.24); (ii) Normal (3.25 - 3.94); and (iii) Distinguished (3.95 - 5.00). Consider that in the sample there are three students in a trial period, 92 are in a normal academic state, and 31 are in the distinguished state. Note also that, in Colombian universities, the academic grade is measured in a range of 0.0 to 5.0, such that 2.95 is the minimum passing score.

Table 3 presents fairly intuitive results; that is, all students who are in the trial period are in the lowest thought category. In turn, most students who have a normal academic status are classified in the Transition thought category, which represents a state of intermediate thinking. Finally, students who are in a distinguished academic state are classified in the categories of Transition thought and mostly in Formal, 42% and 52% respectively. This analysis supports the idea that there is a positive correlation between the LCTSR score and the academic average.

Table 3: Percentage of students according to the LCTSR test score and the Thought Category: 01- 2017.

Academic average	Concrete					Transition					Formal				
	1	2	3	4	Sub-total	5	6	7	8	Sub-total	9	10	11	12	Sub-total

(2,95 - 3,24)	0.0	33.3	33.3	33.3	100	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0
(3,25 - 3,94)	0.0	8.7	9.8	8.7	27	10.9	16.3	13.0	12.0	52	12.0	5.4	2.2	1.1	21
(3,95 - 5,00)	0.0	3.2	0.0	3.2	6	6.5	12.9	16.1	6.5	42	12.9	25.8	9.7	3.2	52
Total	0.0	7.9	7.9	7.9	24	9.5	15.1	13.5	10.3	48	11.9	10.3	4.0	1.6	28

Conclusions

This study focused on answering two key questions:

(i) What is the contribution of basic science education to the development and enhancement of formal thought in Engineering students? The descriptive analysis showed that in 2015 there were 44% of students in concrete thought, 44% in transitional thought, and 11% in formal thought. For the year 2017, there were 24% of students in concrete thought, 48% in transitional thought, and 28% in formal thought. These descriptive results indicated that even when there was an improvement in 2017, this improvement does not seem to be large enough for most students to develop formal thinking. On the other hand, the results obtained by the inferential analysis show a partially positive result. That is, with respect to the overall scores of the LCTSR and the first three aspects of scientific reasoning (i.e., Physical Magnitudes, Proportional Thinking, Identification and Variable control), the students presented significant improvements. However, in the aspects of scientific reasoning that require a higher level of skill in the student (i.e., Probabilistic Thought, Correlational Thought, and Combinatorial Thought), there was no significant improvement. These results indicate that, on average, the training received by the students from Engineering programmes in the core courses of mathematics and physics, actually develops their logical thinking/reasoning skills. However, the mathematical logic skills attained in said core seem not to be sufficient for these students to show an ideal academic performance in the basic core courses of engineering programmes. It should be taken into consideration that in 2017 at least 40% of students are still under 19 years old. It is important to emphasise since Piaget's postulates explain that individuals must wait until 20 years to consolidate their formal thinking.

(ii) Is there a correlation between the academic performance of the students and the level of thought measured to the students through the LCTSR? The results of the LCTSR indicated that, students with a high overall score on the LCTSR also have a high academic average, and vice versa. This result supported the idea that there is a positive correlation between the LCTSR score and the academic performance of students.

Finally, the overall results of this study show an opportunity for improvement in engineering programs. That is, it makes sense to make a more significant effort so that at an early stage of the engineering programme (first four semesters), students will develop the six aspects of scientific reasoning with a higher level.

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Fostering a capacity for relational agency in undergraduate engineering and IT

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ABSTRACT

CONTEXT

Relational agency is the capacity for professional practitioners working in complex, inter-professional environments to align actions with others, interpret and solve complex problems - a core skill required in engineering practice. As part of a review and redesign of groupwork activities in large cohort, group project based, professional practice subjects at the University of Technology Sydney, we investigated using relational agency as a lens through which to evaluate and update our groupwork activities. Initial research investigated the capacity for relational agency in students and proposed a framework that described the development of this capacity from “novice” to “professional”. This paper extends and reports on this work.

PURPOSE OR GOAL

Our goal was to verify our proposed framework by applying this to data collected from two students and two tutor focus groups. The aim is to gain further insight to inform the design of activities and assessments that develop the capacity for relational agency in students.

APPROACH OR METHODOLOGY/METHODS

Focus groups were held with tutors from one second-year and two first-year subjects (the same subjects as in the pilot study). Tutors’ perspectives on the development of relational agency were compared to previous findings. Additional focus groups were also held with students. The proposed framework was used to characterise the relational agency displayed by students and an inductive qualitative analysis done to identify any additional themes that emerged from this sample. The results from the student focus groups were triangulated using self and peer review data from the students and their group members.

ACTUAL OR ANTICIPATED OUTCOMES

Relational agency is a useful tool for understanding the skills that engineers need in professional practice. Our framework has value in characterising the development of this capacity and may be most useful in planning curriculum and learning over multiple subjects, rather than the development of group activities and assessments at the individual subject level. The focus group data confirmed the enablers and inhibitors for relational agency. We argue that these are valuable independent of the context of the framework.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Initial research identified the capacity for relational agency as a valid lens for reviewing group work activities. However, we conclude that it is more useful at a subject level to focus on the enabling and inhibiting factors identified in this study, rather than on the broader scope of capacity for relational agency. Future work may look at a “whole of degree” application of the development of the capacity for relational agency as part of the learning trajectory for achieving graduate outcomes.

KEYWORDS

Relational agency, group work, professional practice

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Introduction

Relational agency is the capacity for professional practitioners working in complex, inter-professional environments to align actions with others (Edwards, 2005). This facilitates the interpretation and solution of complex problems, a core skill required in engineering practice. To review groupwork activities in large cohort, group-project based, professional practice subjects at the University of Technology Sydney (UTS), we used relational agency as a lens to evaluate and update our groupwork activities.

Relational agency is described by Edwards (2005) as “a capacity which involves recognising that another person may be a resource and that work needs to be done to elicit, recognise and negotiate the use of that resource in order to align oneself in joint action on the object.” The concept developed to explain the capacity for professionals from various fields to work on a common object. In an educational context, relational agency has been applied to professional development and used to describe the experience of postgraduate doctoral students (Edwards 2010; Pyhältö & Keskinen 2012). In terms of relational agency in the engineering and IT sector, Kinti & Pouloudi (2019) report on the role of relational agency in a complex, interdisciplinary software development collaboration. Edwards (2010) acknowledges that relational agency has the scope to inform “understandings of relationships between people who are positioned differently within the same practices”. It is this focus that we apply to group work for our students. Relational agency involves collaborators using their skills to work “alongside others towards negotiated outcomes” (Edwards, 2010).

Our preliminary research investigated the capacity for relational agency of undergraduate engineering and IT students. The study proposed a framework that described this capacity as developing from “novice” to “professional” (Machet et al, 2020). The framework outlined the student approaches and behaviours that characterise the various levels of relational agency. It also identified factors that inhibited or enabled the ability of students to develop this capacity. Findings from the initial study were used to iterate activity design and assessments in first- and second-year professional practice subjects containing significant group work projects.

This paper reports on subsequent research gathered in additional student and tutor focus groups run following activity redesign. The aim of this research phase is to apply the proposed relational agency framework to new data to investigate whether this tool successfully evaluates students’ capacity for relational agency. In addition, the student and tutor responses were analysed to determine whether the changes to activity design influenced students’ or tutors’ group work experiences.

Background

Our students are engineering and IT undergraduates at UTS completing one of two first-year or one second-year group project based, professional practice subjects. A team of tutors teach across these subjects and subject coordinators work together to design activities and assessments that help students develop professional practice skills.

The initial research phase reported in Machet et al. (2020) investigated group work through the lens of relational agency and identified five levels indicating the development of students’ capacity for relational agency (see Table 1). It was found that students who had been at university longer (not necessarily in the ‘higher years’) displayed a higher capacity and that, depending on the context, students may describe group work at varying levels.

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Table 1: Levels of relational agency

Level	Description
0	No/little agency Students do as they are told by others. View themselves as objects in the collaboration.
1	Recognising other people as resources Students recognise that others are resources to assist in completing tasks
2	Eliciting work from other people Active agency in eliciting work. Recognition of the value of different resources
3	Pro-active engagement Agency within and outside of the group (e.g. with tutor), recognition of reciprocal contributions, giving feedback to peers to build their capacity
4	Adjusted interpretation Self-awareness of group dynamics and reciprocity, adjusting personal interpretations or behaviour

Three factors that could facilitate the development of relational agency were identified in the study: the psychological safety of students, a strengths-based approach to group work, and the overcoming of communication challenges. Significantly, misaligned motivations were identified by students as a problem impacting successful group work outcomes. However, in most cases, they described themselves as having little to no agency in affecting this.

These factors were considered in the design of assessments and student communication in subsequent semesters. Our teaching was largely online and so group work activities were adapted to this delivery mode. The iterative changes to address these issues included:

- Psychological safety: while icebreakers were already being used for tutorial classes (30 to 40 students each) additional ice breaking activities for project groups (4 to 6 students) were introduced to promote psychological safety.
- Communication challenges: clearer explanation of the importance of using online communication channels. As an example, the second-year subject included an additional timetabled hour for ‘tutor drop-ins’ to student groups’ online meetings. This aimed to overcome students’ communication challenges, such as finding time to meet, or to talk to the tutor as a group, as well as agreement on remote communication methods.
- A strengths-based approach to group work: additional scaffolding for students in the group formation stage was introduced including explicit discussion of different learning and working styles, and individual expectations. While group charters and contracts were already used, students were provided with examples from previous semesters on how a strength-based approach to group tasks may prevent future problems.

Methodology

Data was collected from two tutor and two student focus groups. Students and tutors volunteered to participate and were compensated with vouchers for their time. The focus groups were one hour long and used semi-structured interview protocols developed from the

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outcomes of the initial research study. Tutors and students were asked about their experiences of group work throughout their teaching experience and/or university degrees. There was a particular focus on the subjects under study. Interviews were conducted by research assistants who did not directly teach or supervise the students and tutors. None of the students or tutors had participated in the initial research phase.

Participants were recruited from first- and second-year engineering and IT students who had completed one of three subjects in the previous semester. Each subject had at least one student participant. Seven students (from a combined cohort of ~900 students) were interviewed in a group of four, and a group of three students. The initial research focus groups had involved only high achieving students (volunteers). In this study, an effort was made to include participants with more diverse subject results (students received marks from credit to high distinction in their professional practice subject). For student focus groups, the questions included prompts for students to discuss the issues identified in the initial research, including barriers to communication and how group work tasks were allocated.

The student focus group data was analysed through the lens of the relational agency framework and coded according to the levels described. Where their comments displayed the characteristics of behaviours of one of the levels (0 to 4) they were coded as such. In addition, the inhibiting and enabling factors were coded where they emerged from the data (namely the psychological safety of students, a strengths-based approach to group work, communication challenges and misaligned motivations). Each focus group was analysed by two coders, and there was consistent coding found for inhibiting and enabling factors, and discrepancies in coding the relational agency levels were resolved between the coders before the outcomes reviewed and discussed amongst the broader research team. As the students in the focus groups had all experienced some changed activity design, we were interested in whether this was evident in the focus group.

Self and peer reviews completed in the subjects were used as additional sources of data for understanding student experiences. These reviews formed part of the students' assessment activities for the subjects and were completed before the students were recruited for the study. In the self and peer review, students are required to give feedback to peers at different points in the group project. The feedback was coded for demonstrations of relational agency levels. This data was used to corroborate findings from the focus group data and not as evidence of new levels of relational agency. As these reviews were part of the assessments, they may have inaccurately influenced the results.

Seven tutors (from a teaching team of 22 tutors) were similarly interviewed in one focus group of four and the other a group of three. Each tutor had taught one or more of the professional practice subjects. The tutor focus group discussion focussed on their experiences of facilitating group work in first- and second-year subjects. Tutor focus group data was analysed for emerging themes, and again, considered through the lens of the relational agency framework. It was used to determine whether tutors identified these levels in their students. Where tutors referred to any of the inhibiting or enabling factors, these were identified.

Results and Discussion

Overall, the students in these focus groups demonstrated higher levels of capacity for relational agency in their discussions than those in the initial study. All of the students demonstrated at least a level 2 according to the framework, and over half reached level 4. This is a significant change from the initial research, where the students displayed a wider range and few demonstrated level 4. The higher levels of relational agency are supported by additional comments in the discussion and by their self and peer review comments. A student who was coded at level 4 received the following feedback from peers supporting the rating:

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He provides good feedback when he looks over work and provides suggestions that are relevant and help assist with the project.

The students all expressed an appreciation for the importance of group work and an understanding that we were developing skills they need (rather than their teachers 'saving on marking' or putting them in situations they will never experience in professional practice as has been reported by students previously). Many did qualify that, despite its importance, they did not enjoy it, for example, one student commented that:

That's not to say that I particularly enjoy group work. I just understand that we need to be able to build the skills of group work so that we can more effectively work in groups when we need to.

Those students who understood the necessity of having group work experiences, also communicated that they felt they had learnt and developed their skills at university.

It's a process ... back then I didn't know much about … like working in groups like … how to work in a group in general.

The students in the focus group were a small selection of those who completed the subject. The changes to the subject design were not yet consistent across the subjects and were not the only changes experienced by students (and teachers) since the previous semester. For example, the COVID-19 situation had significantly changed with some students being allowed back on campus. There is no data to directly attribute the higher levels of relational agency to the changes in activity design. However, it is reasonable to conclude that the focus on development of relational agency (in the activities and approaches from subject coordinators) would have contributed to these findings.

We found that the application of the framework to the student focus groups supported the concept that the capacity for relational agency develops with time at university.

The tutor focus groups were conducted with tutors who taught the professional practice subjects across first and second years. This gave them a view of students across the initial years of study and the chance to identify any progress across the cohort. Interestingly, in contrast to the students, no mention was made by the tutors of students' approaches to group work changing across the years of study. This may be because they do not see individual students from one year to the next to be able to evaluate the progression. It may indicate that as a cohort, the progression was not noteworthy, which is worthy of further investigation. The shared tutor team is being extended across later years for professional practice subjects and will enable this trajectory observation. That students (as opposed to their tutors) commented on the development of their groupwork skills also indicates that students themselves are better placed to evaluate their own skill development. In terms of the changes implemented to support the development of the capacity for relational agency, it was the tutor focus groups that identified these as useful. Tutors, having taught the subjects for multiple semesters, have the 'before' and 'after' view of subject design while students do not have this frame of reference. Extended group time in tutorial sessions and the increased explicit focus on the purpose of group work were identified as useful by the tutors:

I found that a short lecture and followed by lengthy group activity where you put them into breakout room …I thought that was fairly effective and then getting then getting people to report back which was the strategy that we all struggled with in the beginning, something I found xxx has done quite well … is trying to spend the first few weeks to really trying to establish I guess the principles of good teamwork.

Tutors supported the findings (and experience) of poor communication hampering the development of relational agency capabilities, whether this be in terms of language level, reticence to speak in public, or the technical limitations of online teaching. However, they did acknowledge that the group chats (which tutors had access to) and tutor drop-ins were valuable in supporting group communication.

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Tutors discussed how using clearly identified group roles in the first-year engineering and IT subjects allowed students to discover their strengths and then apply this to the group work:

> *You can try on roles that you may not have been comfortable trying in high school and you can have one person be the group leader this week and one person be the group leader next week and rotate and sort of experiment.*

And:

> *We used team roles to figure out what your team role will be in a team. Once a team is formed, yes, I have a particular strength in terms of team member and that helps you. It force and encourage them to express who they are and also assess the situation that we have here.*

In talking about group work roles or responsibilities, most students supported a strengths-based approach. However, for many of them it was a matter of achieving the best marks and this meant doing (or redoing) the work of others:

> *I'll be really honest, I work hard and need to get good marks. So while I do think teamwork is important like for the long term like I can't help but be caught up in like the short term like just wanting to do well.*

Followed by:

> *I want to talk to the group and be like OK what do you wanna do? What do you want to do? Like do you wanna do this section but this section I'm happy to do like the longer sections you know if 'cause … I prefer working individually...So for someone like me was hard 'cause I had to really depend and rely on their team effort, especially 'cause they worked really towards the end of the assignment and I really wanted to finish things early so it was kind of hard to wait for them. And I was kind of like slowly doing their parts during the semester.*

The strength-based approach seems to be a hurdle when there is conflict in the group resulting from non-participation and misaligned motivations. In these cases, group members deemed to be poor performers are not given the opportunity to contribute their strengths. Instead, the group member who is (or considers themselves to be) the strongest may complete the work. This response from highly motivated and participating students is understandable. However, the 'unmotivated' or ‘non-participants’ may miss out on skill development. These ‘high-performing’ students have made a judgement that their peers have nothing to contribute and that they cannot learn anything from them. This may not be true. It is a shortcoming of focus groups such as these that students who are reticent to participate in group work are less likely to be represented.

The misaligned motivations were noted by both tutors and students as being a significant inhibiting factor in group work. Students in the focus group exhibited some agency (by honestly completing the self and peer review or requesting help from tutors). Despite this they considered the effect of their actions limited in the circumstances. Of interest is that almost half the students compared groups to the ‘real world’, considering the group work at university to be inauthentic when it comes to misaligned motivations:

> *However, the difference between group work in the workplace and in university is that in the workplace, if someone is not pulling their weight they're gone, but in university if someone's not pulling their weight you have to just keep on carrying them. And there seems to be very minor penalty for not carrying your weight.*

There are significant differences between university group work and professional practice, but these comments indicate that the group work has not been suitably contextualised - students do not see university group work as representative of engineering practice where conflict and management challenges face teams in the workplace (for example Dulebohn & Hoch, 2017). These same students understood (as above) that group work was important to their professional practice, but they have indicated that they believe they will not face problems of misaligned motivations in the workforce. This suggests an opportunity to design scaffolded content that indicates how their experience at university is representative of behaviour in practice. We will trial case studies of group conflict sourced from university and from professional practice which explicitly link these experiences. This will be designed to contextualise and develop students' perception of the authenticity of their group work experiences. In addition, when on-campus teaching resumes, we plan to include roleplay activities around these concepts and case studies.

Conclusions and Recommendations

The results of this study suggest that the activity design and assessment changes have supported tutors in developing students' group work skills (though not specifically in terms of relational agency). In addition, students who have experienced the new activity design were able to express higher levels of relational agency and are aware of their skills progressing as they have exposure to group work. The increased focus on developing relational agency has arguably bought benefits to students in terms of understanding the importance of group work. Furthermore, it has encouraged students to communicate higher levels of relational agency and express how their skills have developed.

Initial research identified the capacity for relational agency as a valid lens for reviewing group work activities. In this paper we have demonstrated that it is useful at a subject level to focus on the enabling and inhibiting factors identified, rather than on the broader scope of capacity for relational agency. In presenting this study to a teaching and learning forum at the university, the feedback from educators (experienced in group work in their own fields) indicated concern that the framework missed some factors that contribute to successful group work. These factors included group composition, personal learning styles, activity design**,** and the temporal aspect of group work. We acknowledge that the framework looks predominantly at a single dimension of group work, and this feedback has encouraged us to critically analyse the framework and to represent some of the 'missing' components.

In essence, it is this progress that we are looking to support and assess in our teaching. We propose that as engineering educators, we take on board a temporal view of the development of relational agency and make use of students' own ability to identify their skills progress (as emerged from the student focus groups). To develop relational agency, activity and assessment design should take a "whole of degree" approach, allowing students to reflect on the development of the skills. This should include presenting students with the framework to indicate how they can develop and to give them a language to question, evaluate and communicate their learning. This "whole of degree" approach to the development and assessment of relational agency could have the added advantage of incorporating students' internship and work experience – it is here that students are likely to best contextualise the framework and appreciate how relational agency may support their professional practice.

As one of the first reported studies of applying relational agency to undergraduate studies, the relational agency framework described and used here is emerging. Through approaching group work activity design from the viewpoint of developing the capacity for relational agency, we have uncovered useful insights into students' skill development. We have also identified areas where the framework can be enhanced and applied.

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What do students care about?: An analysis of topics impacting student evaluation survey results in engineering

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ABSTRACT

CONTEXT

Student Evaluation of Teaching (SET) surveys are commonly used to measure student learning experience in higher education institutions (Spooren et al., 2013). SET surveys are typically administered at a subject level toward the end of a teaching period, with students encouraged to answer Likert-scale questions as well as provide rich comments that explain these scores and recommend improvements (Cunningham-Nelson et al., 2020). The qualitative comment component of SET survey results is often the most useful data for driving teaching, curriculum, and assessment enhancements. This is due to the specific detail and contextual information that can guide strategic actions. However, in recent years, there has been a growing focus on student experience as a key performance metric for higher education institutions. To improve satisfaction metrics (which are measured numerically), it would be useful to understand the relationship between the topics qualitatively discussed by students and their corresponding satisfaction scores. This can support educators and strategic leaders to focus their efforts on those areas that have the greatest influence on satisfaction scores, thus maximising impact within resourcing and time constraints.

PURPOSE

The purpose of this study is to identify the relationship between the topics discussed by students in SET surveys and their corresponding scores in Bachelor of Engineering subjects at a large Australian University. Specifically, the research questions are:

1. What attributes/characteristics do students discuss most frequently in SET surveys?
2. How do these attributes/characteristics relate to overall satisfaction scores in SET surveys?

APPROACH

SET survey results for subjects offered in the Bachelor of Engineering degree taught between 2016 and 2019 at the Queensland University of Technology were extracted. Key subject attributes and educator characteristics were searched for within the text data using lists of phrases. The chi-square test was used to test association between a topic being mentioned and the satisfaction outcome (either positive or negative).

OUTCOMES AND CONCLUSIONS

The subject attribute that students mentioned most frequently was *teaching quality*. The most frequently mentioned educator attribute was *organised*. Student comments mentioning *approachable* or *engaging* terms were more be associated with a positive satisfaction score. These results provide insight into areas which may be targeted to most positively influence student satisfaction scores.

KEYWORDS

Student Evaluation of Teaching, Surveys, Text Analysis

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Introduction

Student Evaluation of Teaching (SET) surveys are commonly used to measure student learning experience in higher education institutions (Spooren et al., 2013). SET surveys are typically administered at a subject level toward the end of a teaching period, with students encouraged to answer Likert-scale questions as well as provide rich comments that explain these scores and recommend improvements (Cunningham-Nelson et al., 2020). It is important to note that these surveys measure student satisfaction with learning experiences, rather than teaching quality.

There has traditionally been a strong focus on quantitative data within SET surveys given this is relatively easy to analyse (Whiteley, 2016). For example, educators can compare their scores to those of others to identify relative strengths and weaknesses. This benchmarking can also be performed at a strategic level to identify high-performing educators and subjects, while prioritising those that require development and support. The qualitative comment component of SET survey results is often the most useful data for driving teaching, curriculum, and assessment enhancements. This is due to the specific detail and contextual information that can guide strategic actions. However, it is much more difficult to systematically analyse this qualitative data, especially when there are large numbers of comments. Improved use of qualitative data can also assist in mitigating against the bias towards gender (Boring, 2017) and culture (Fan et al., 2019) which has been shown in quantitative scores assigned to educators.

In recent years, there has been a growing focus on student experience as a key performance metric for higher education institutions. This is best-evidenced by the recent introduction of performance-based funding for Australian universities, whereby overall satisfaction with teaching quality forms a core measure in the calculation (Australian Government Department of Education & Skills and Employment, 2020). To improve satisfaction metrics (which are measured numerically), it would be useful to understand the relationship between the topics qualitatively discussed by students and their corresponding satisfaction scores. This can support educators and strategic leaders to focus their efforts on those areas that have the greatest influence on satisfaction scores, thus maximising impact within resourcing and time constraints. Thus, the purpose of this study is to identify the relationship between the topics discussed by students in SET surveys and their corresponding scores in Bachelor of Engineering subjects at a large Australian University. Specifically, the research questions are:

1. What attributes/characteristics do students discuss most frequently in SET surveys?
2. How do these attributes/characteristics relate to overall satisfaction scores in SET surveys?

Background

Thematic analysis is a qualitative analysis technique that can be applied to group textual data into broad themes (Braun & Clarke, 2012). This process involves manually identifying themes through a systematic process, and then coding the data according to these themes. As manual coding is time-consuming, various automated approaches have emerged for grouping text comments into topics. This includes Latent Dirichlet Allocation (LDA) (Song et al., 2009) and automatic topic analysis methods in software such as NVivo (Richards, 1999) and Leximancer (Smith & Humphreys, 2006). In addition, predetermined lists of terms or phrases can be used as a basis for distinguishing the prevalence of themes within the data. In this study, the latter approach is adopted for topics relating to subject attributes and educator characteristics respectively.

Firstly, the Student Experience Survey (SES) is run nationally in Australia each year by the Social Research Centre (SRC), with all Universities Australia institutions taking part (Social Research Centre, 2020). Students in their first and final year of their degrees are invited to complete the survey, with quantitative questions broadly grouped into five focus areas (Social

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Research Centre, 2020). These are (1) teaching quality, (2) learner engagement, (3) learning resources, (4) student support, and (5) skills development. The SRC has developed a coding tool called SEQuery (Social Research Centre, 2019) which is designed to classify textual comments. As part of this tool, the SRC has identified specific phrases that align with the five focus areas. These phrases are used in the present study as topics related to subject attributes and are discussed further in the methods section below.

Secondly, educators are required to develop and demonstrate many attributes whilst teaching to be successful. Delaney et al. (2010) asked a large sample of students to rate the most important characteristics of effective educators. From this, seven attributes were identified as most important from students' perspectives. These characteristics were (1) respectful, (2) responsive, (3) knowledgeable, (4) approachable, (5) communicative, (6) organised, and (7) engaging. These are considered as topics relating to educator characteristics in the present study.

Method

Student Comment Dataset

The Queensland University of Technology is a large Australian university which offers engineering degrees across a range of majors including civil, mechanical, electrical, mechatronics, chemical process, and medical. Between 2016 and 2019, the university administered a SET survey toward the end of each semester which was open for 4 weeks. The survey consisted of three Likert questions (answered on a five-point scale from strongly disagree to strongly agree), and one open-ended question. These were:

1. This unit provided me with good learning opportunities (Likert).
2. I took advantage of opportunities to learn in this unit (Likert).
3. Overall, I am satisfied with this unit (Likert).
4. Please provide any further feedback you may have about this unit (open-ended).

For this study, we focus only on subjects offered in the Bachelor of Engineering degree taught between 2016 and 2019. Consequently, the dataset includes responses from students who may take engineering subjects as electives as part of other degrees (such information technology). As the survey responses were deidentified, further demographic information for the responding cohort is unable to be obtained. For this study, we focus on the overall satisfaction score given in Question 3 and the free text comment given in Question 4. Consequently, only responses in which students provided a free text comment and satisfaction score were included. This inclusion and exclusion criteria resulted in a total of 14,088 text responses to be analysed.

Identification of Subject and Educator Terms

Before analysing the survey comments, cleaning of the data was performed using programming packages in Python. The text data was converted to lowercase, stop words (such as *the* and *that*) and punctuation were removed, and words were stemmed to their base form (for example, *running* is replaced with *run*). This cleaning ensures that meaningful terms can be found more easily.

The key subject and educator attributes were then searched for within the cleaned data using lists of phrases. We chose to use the five focus areas from the SES surveys (and the terms used in SEQuery (Social Research Centre, 2019)) for the subject attribute lists. Example phrases for each attribute are shown below in Table 1.

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Table 1 – Subject attribute and associated example phrases

Subject Attribute	Phrases	
	Example 1	Example 2
Learner Engagement	*group work*	*online discussion*
Learning Resources	*lecture material*	*unit outline*
Skills Development	*critical thinking*	*employable*
Student Support	*consultation*	*career advisor*
Teaching Quality	*teaching staff*	*lab work*

The seven effective educator characteristics identified by Delaney et al. (2010) were also considered. As lists of synonymous phrases did not exist for the list, these were generated by the authors. The seven characteristics and several examples of the phrases are presented in Table 2.

Table 2 – Educator characteristics and associated example phrases

Educator Characteristic	Phrases	
	Example 1	Example 2
Respectful	*inclusive*	*polite*
Responsive	*accessible*	*receptive*
Knowledgeable	*understanding*	*expert*
Approachable	*friendly*	*welcoming*
Communicative	*communication*	*clarity*
Organised	*clear*	*access*
Engaging	*interesting*	*exciting*

Statistical Analysis

Statistical analysis was performed in SPSS Statistics Version 27. The chi-square test was used to test association between a topic being mentioned (determined using the approach described immediately above) and the satisfaction outcome. The satisfaction outcome was considered *positive* if a student gave a strongly agree or agree response to Question 3 of *"Overall, I am satisfied with this unit"*. In contrast, if a student gave a neutral, disagree, or strongly disagree response to Question 3 then the satisfaction outcome was considered *negative*. Odds ratios and the corresponding 95% confidence intervals were used to assess the effect size.

Results and Discussion

Subject Attribute Analysis

Table 3 summarises the focus area analysis, including the number of positive and negative satisfaction responses by topic, and results of the chi-square tests and odds ratios. Figure 1 visualises the rate of comments mentioning focus areas by overall satisfaction outcome. It can clearly be seen that *teaching quality* is mentioned most often, and this is the case for students with both positive (79.0%) and negative satisfaction (85.0%). This large percentage of mentions signifies the importance of *teaching quality* in students' learning experiences. This is also in line with teaching quality being a key metric that performance-based funding is based upon in Australia (Australian Government Department of Education, 2019).

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Applying the chi-square test of association between students' mentioning a subject attribute and their satisfaction outcome reveals strong support for a relationship for every focus area (Table 3). The odds ratios show that depending on the subject attribute, students with a positive satisfaction outcome had between 0.574 and 0.753 times the odds of mentioning the subject attribute, compared to those who had a negative outcome. That is, students who discussed a subject attribute were much more likely to be unsatisfied with the subject.

Learning resources is another attribute of interest. This area contains the largest chi-square value, and the difference between positive and negative mentions is significant (10.8% positive mentions and 17.1% negative mentions). Students who mention *learning resources* in their comment are very likely to rate the subject with a negative satisfaction. Examining *skills development*, it is the attribute with the second highest percentage of mentions, solidifying the importance of this area with respect to student satisfaction.

Although *student support* was identified as an attribute of interest, examining the results presented below we can see that a very small number of students mentioned terms in this topic group. From this we can conclude *student support* is not a large factor in the free text comments that students provide.

From the subject topic analysis, one common aspect that can be observed is that for all attributes, the percent of mentions is higher for the comments associated with negative satisfaction. This suggests that students make more detailed comments that highlight topics when they are not satisfied with a subject.

Table 3 – Results of focus area analysis (LE = Learning Engagement, LR = Learning Resources, SD = Skills Development, SS = Student Support and TQ = Teaching Quality, CI = Confidence Interval)

Attribute	LE	LR	SD	SS	TQ
Positive satisfaction responses					
Mentioning focus area	352	989	1869	257	7209
Not mentioning focus area	8777	8140	7260	8872	1920
Mentioning topic (%)	3.9	10.8	20.5	2.8	79.0
Negative satisfaction responses					
Mentioning focus area	324	846	1263	222	4214
Not mentioning focus area	4635	4113	3696	4737	745
Mentioning topic (%)	6.5	17.1	25.5	4.5	85.0
Chi-Square Test					
Value	50.438	109.963	46.385	27.009	75.639
Significance	0.000	0.000	0.000	0.000	0.000
Odds Ratio (Negative/Positive Satisfaction)					
Value	0.574	0.591	0.753	0.618	0.664
95% CI Lower Bound	0.491	0.535	0.694	0.515	0.605
95% CI Upper Bound	0.670	0.652	0.817	0.742	0.728

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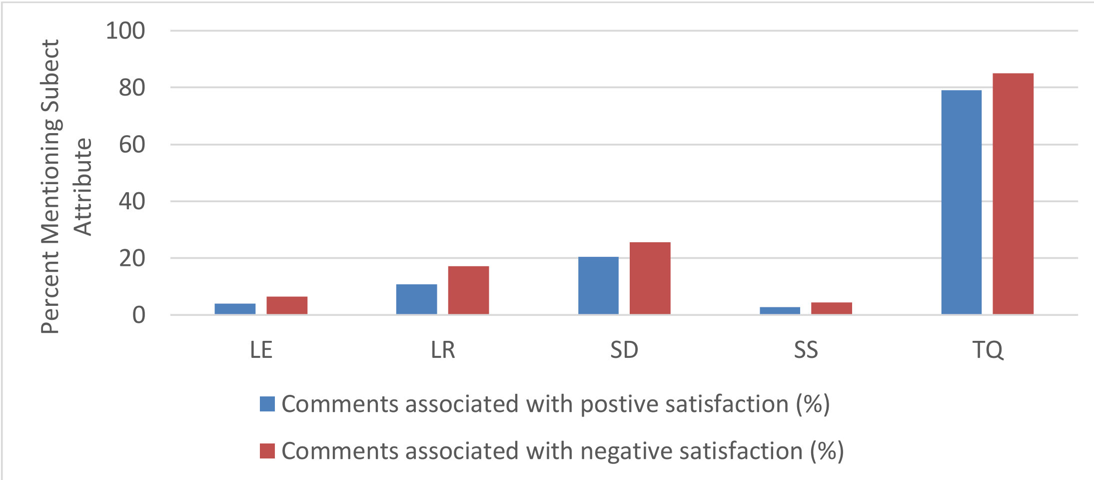

Figure 1 – Rate of students mentioning focus areas by overall satisfaction outcome (LE = Learning Engagement, LR = Learning Resources, SD = Skills Development, SS = Student Support and TQ = Teaching Quality)

Educator Attribute Analysis

Table 4 summarises the results for the educator characteristic analysis. The percentage of mentioned topics is visualised in Figure 2. Applying the chi-square test of association between students' mentioning an educator characteristic and their satisfaction outcome reveals strong support for a relationship for responsiveness, approachable, communicative organised, and engaging (Table 4). However, there is only weak evidence of a relationship for the knowledgeable characteristic, and no evidence of a relationship for respectfulness.

Table 4 – Results of educator characteristics analysis Topic Area Response Analysis (Rf = Respectful, Rv = Responsive, Kn = Knowledgeable, Ap = Approachable, Co = Communicative, Or = Organised and En = Engaging)

Attribute	Rs	Rv	Kn	Ap	Co	Or	En
Positive satisfaction responses							
Mentioning topic	32	284	622	1288	218	2661	1416
Not mentioning topic	9097	8845	8507	7841	8911	6468	7713
Mentioning topic (%)	0.4	3.1	6.8	14.1	2.4	29.2	15.5
Negative satisfaction responses							
Mentioning topic	19	263	383	603	306	2013	624
Not mentioning topic	4940	4696	4576	4356	4653	2946	4335
Mentioning topic (%)	0.4	5.3	7.7	12.2	6.2	40.6	12.6
Chi-Square Test							
Value	0.095	41.39	4.016	10.51	128.4	189.8	22.24
Significance	0.758	0.000	0.045	0.001	0.000	0.000	0.000
Odds Ratio (Negative/Positive)							
Value	0.915	0.573	0.874	1.187	0.372	0.602	1.275
95% CI Lower Bound	0.518	0.483	0.765	1.070	0.312	0.560	1.153
95% CI Upper Bound	1.615	0.681	0.997	1.316	0.444	0.647	1.411

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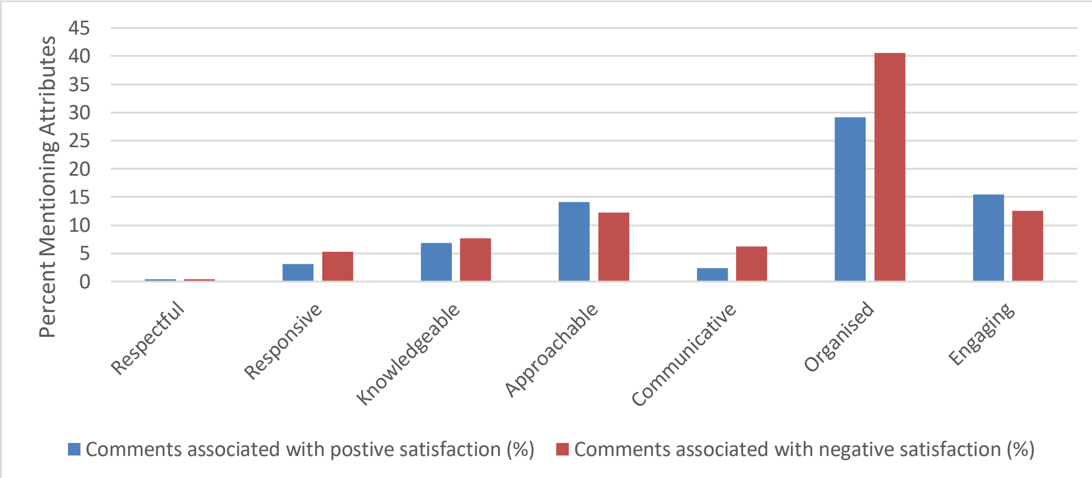

Figure 2 - Educator Attributes Mentioned Topics

Examining the table and figure, *organised* is clearly the most frequently discussed attribute, being mentioned in 29.2% of positive responses and 40.6% of negative responses. The significance of this is reiterated by the large chi-square value and corresponding significance value. This reinforces the importance of educators being organised which is emphasised in the literature (Delaney, 2010).

The *communicative* attribute shows the largest differences between positive and negative mentions. This demonstrates that if students mention words related to the *communicative* attribute, they are more likely to have given a negative satisfaction score. *Approachable* and *engaging* are the only two attributes from both the subject and educator topic lists that have a higher percentage of positive mentions, and this is reflected in the odds ratios which are greater than 1 (Table 4). This can be interpreted as students with a positive satisfaction outcome being about 1.2 to 1.3 times more likely to mention these attributes, compared to those with a negative satisfaction outcome. That is, students are more likely to have given a positive satisfaction rating if they have written about *approachable* and *engaging* educators.

Conclusions

This study analysed the responses from an end of semester SET survey for Bachelor of Engineering subjects. The satisfaction score and free text responses were analysed to understand the relationship between the score and references to five subject attributes and seven educator characteristics. The *teaching quality* subject attribute and *organised* educator characteristic were found to be most mentioned by students. Students who gave comments containing *approachable* or *engaging* terms were more likely to provide a positive satisfaction rating.

Potential future work for this study includes expanding the analysis of comments beyond engineering subjects to ascertain if similar conclusions can be drawn about all students. This will highlight to educators which aspects of their subject or teaching are most likely influencing their student evaluation scores. Analysis of the sentiment of text comments could be included to provide further insight into student satisfaction. Finally, further terms could be added to the existing attributes as well as additional attributes added to investigate the link between student satisfaction and free text comment provided.

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Ethics Approval

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Copyright statement

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First Peoples Engineering – Creating cultural spaces

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ABSTRACT

CONTEXT
We are starting to understand the differences across Aboriginal Australian cultures by acknowledging both the local landscape and experiences which create cultures and identities, yet from these some universal factors emerge. These commonalities are widely acknowledged, and their significance is crucial in terms of growing and improving understanding within and between Aboriginal and non-Aboriginal cultures. They impinge on engineering practices and are both a constraint and an inspirational source of sustainability.

PURPOSE OR GOAL
We are exploring ways to change western perspectives of First Peoples concepts of engineering, education, and learning. For two-way learning to occur in Australia it is essential to understand both the specific and the shared cultural features of Aboriginal peoples and ways of expressing cultural issues. This helps people understand the innovative engineering and technology within Aboriginal Australia culture, a technology that was developed with a very different form of language and educational process. Our purpose is to provide ways and means for educators to alter their understanding and teaching to incorporate Aboriginal knowledges as valid and useful resources.

APPROACH OR METHODOLOGY/METHODS
This is a theoretical exploration of how concepts from First Peoples' cultures can inform engineering practice including provision of evidence from positive outcomes. The work applies different perspectives of Western, Aboriginal, and Engineering cultures to the development of suitable comparisons for stimulating discussions and engendering new insights.

ACTUAL OR ANTICIPATED OUTCOMES
The work reported here can inform classroom practice providing uniquely personal experiences of different knowledges in action, raising key points. The examples in this paper use community experiences and use localised storytellers to illustrate different perspectives available to engineering students and community members, extending sharing of knowledge and enabling learners to learn from First Peoples narratives. The benefits are designed to carry over to all areas of professional practice and increase the incentive to listen to clients and colleagues in an ever more complex world (Mathews, 2020).

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
We want to encourage all engineering lecturers to embed their work in the culture of their country, wherever they are, incorporating local First Peoples' approaches and retain their own awareness of the context in which that knowledge grew.

KEYWORDS Aboriginal engineering, curriculum development, knowledge sharing.

Introduction

The authors have been sharing knowledge across cultures for many years through simulations, role plays and live projects. Our interest is to share these experiences and encourage others to adapt these ideas to their own style and their own stories. We

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acknowledge that the first factor in sharing knowledge is the importance of embedding it in place and experience. Whatever your discipline, the context you work in, and whatever narrative your engineering identity has formed, we want to encourage readers to base their teaching on expanding their work to include First Nations' engineering. Applying your skills to a new domain and encountering new perspectives will expand your understanding of other ways of thinking.

Engaging with First Peoples in your projects and your research will enable your work to retain its authenticity when moving into this new realm. This paper highlights some key areas where Aboriginal Australian engineering, both past and present, has taken us into new perspectives, leading to questions about what has been assumed and to provide new ways of thinking and working. We share examples of how this has worked for us.

Methodology

We are taking a grounded research approach as the concepts described are designed for the instructors to develop based on their own understanding of the context in which the ideas arose. The material shared here is unique and each item belongs in its own Country or space, but the ideas and processes can be adapted to your experience, once you appreciate the relationship between story and context. This is a significant aspect of working with Aboriginal people since there are multiple examples of failure arising from enforced repeats of projects across different communities. In this work we provide background, context, and contingencies as we experienced them to help and guide you to decide how best to use these examples in your own work.

We present them as narratives or vignettes that raise questions that we hope will resonate with your concerns about engineering education and assist you to create a more satisfying learning environment for yourself and your students. Where possible Aboriginal colleagues can evaluate the new approaches you create with this knowledge.

Authority to speak

When we are working in this domain the first step is always to ground our material in place and time. We are academics and project managers researching knowledge flow among disciplines that are emerging outside, although still relevant to, the formalism of technical instruction. We describe our background and culture, to explain the knowledge we carry and our perspective on the material. This is to counter the tendency to talk for other cultures, without appreciating the limitations of our knowledge of others' experiences. The case studies provided below involved the authors or close colleagues. A variety of experiences are included, and those involved in the stories are Aboriginal, or working with Aboriginal people, to integrate Aboriginal knowledge as part of engineering education.

We introduce boundary objects as foundational material for teaching key concepts of Aboriginal knowledge sharing and then provide case studies and scenarios being developed for use in ongoing on-Country projects and broader instruction.

Boundary Objects

The following are boundary objects we use to help students grasp some of the complexity of human knowledges and to start questioning their own certainty. These are not location-based knowledges. They have been developed for western classrooms, mostly first year university introduction courses, to open students to new concepts.

Exploring on-Country boundaries

It is a vital part of embedding this new knowledge that students are introduced to the name of the Country on which they/we are all standing and the names of the people who are its

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custodians. This centuries old tradition is slowly seeping into Australian consciousness and taking root as a familiar courtesy to those on whose sovereign land we live.

Objective Knowledge within Oral Traditions

Discussion of similarities between oral and written methods of knowledge help students to engage with these areas of academic literacy. Table 1 compares protocols or processes of verification of oral knowledge creation and sharing with equivalent Western techniques.

Table 1 Knowledge sharing protocols

Aboriginal approach	Western methods
Collaboration with experts in storytelling to verify the knowledge shared is correct	Peer review of written work
Stories told only to those with prior knowledge to learn	Write for specialist audience in disciplinary journals
Stories told only by those who have authority	University researchers appointed based on their research expertise
Attribution of who stories belong to when re-telling	Referencing in articles
Sharing knowledge as part of a larger narrative to provide context	Narrative teaching and Memory Codes (Kelly, 2016)

Narratives as Knowledge Repositories

We all use narratives to make sense of our life, usually as a personal narrative that grows as we do, adding new experiences. Aboriginal people use narratives, or their Dreamtime stories, as the vehicle for knowledge sharing about community and environment (Sveiby & Skuthorpe, 2016). To emulate this highly effective oral learning process, students in introductory project and design courses are given an exercise to reflect on themselves and their learning. They select an area of Country to which they have strong ties, or where their experiences are set; and an animal, plant or land feature to represent their own characteristics or totem, which they place in their environment.

The students consider some aspect of their learning and their character acts out significant indicators around that learning, for example when to check in on a team member who is not responding. Then they link with other characters from their team, their friends, or teachers, to add attributes to the narrative, with which they interact to illustrate their learning. Sometimes such representations can help clarify our future. Students record this reflection as an oral narrative, which is assessed for how they emulate valuable Aboriginal storytelling features.

Case Studies

The issues we highlight for students form major factors in good project work. These are: a) Dropping our ego to provide a safe space for community engagement; b) Relationships and reciprocity that support teamwork; c) Collective approaches for better consultation; d) Truth in speech to promote trust; e) Managing complex knowledge systems for sustainability and f) Ensuring projects engage with community practice

Drop the Ego #workingwithhumility

Many people have written about the desire for humility in engineers (Lynch et al., 2020; Neilson & Maroone, 2010) and its benefits for engineers both within organisations and when working with clients. However, when dealing with First Peoples who have traditionally been treated as inferior or deficit, more effort than normal needs to be expended to overcome inherent prejudices that otherwise disrupt projects.

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Location: This first project was run by Engineers Without Borders (EWB). We rely on EWB sources who facilitated the project and comments from other participants who were highly impressed by the progress of the design and the outcomes described, for our authority to speak of this.

Actions: A group of professional engineers who were not First Peoples, went to a remote First Peoples' community to participate in a design process for a training and accommodation centre. Each day, the engineers and about the same number of community members were involved in the design process. As the group prepared to present their ideas to the community elders one of the engineers offered to present. They considered themselves technically capable and experienced at presenting. After facilitated discussion, it was decided that the youth community members should present to the elders, despite their inexperience.

The engineers were uncomfortable and suddenly unsure of their role, as they were no longer the experts presenting the ideas. Some were concerned by the perceived limited experience of the youth community members. It took them time to recognise their role as supporting the actualisation of community ideas, rather than solving the design themselves. Initially they did not respect the value of such relationships, nor that relationship was more important than technical merit in this situation, time and place. When the youth presented, the elders were receptive and proud of their young people. The facilitator observed that they expected the elders would have been less receptive if engineers had presented.

Lessons: Aboriginal people have a long experience of infrastructure being provided to communities with only rare chances to consider how it works or how it may be adapted. Technology may be used in a particular way or may be thought to be inherent in the material, rather than subject to a designer's choice. Allowing communities to discuss issues and explicitly valuing the way they conceptualise a construction is an important aspect of community acceptance and taking control of the design.

Downing (1974) describes a similar experience for engineers working with community on road design. While engineers were crucial for technical planning and construction resources, the design was influenced less by road construction technology and more by the shared experience of considering different options in town planning to support the construction.

Relationships and reciprocity #PeopleBeforeProjects

We are told that Aboriginal people hold relationship to a person as a first concern, before working with the person or their knowledge. As First Peoples work with a highly interconnected view of the world, they wish to understand how new knowledge holders fit into their system before they can relate. This is reasonable given that knowledge is contextual, and trust has so often been damaged in prior communications with First Peoples.

In fact a lack of any relationship with community can be used by Aboriginal people when necessary. 'Strangers' are not subject to the strict knowledge sharing protocols. A colleague working at Batchelor Institute was collecting stories. One day an Elder began a story, and he was surprised as he knew her daughter did not know these details. He asked why she was telling him this special knowledge. The Elder explained her daughter was not ready to hear the story, but it was okay to tell him, as he was not human (pers. Comm., David Harrington UNSW 2014). In class we compare this to when Aboriginal people were not citizens.

However, many engineers find it hard to understand such a need for relationships. When we work with engineers conducting consultation in a community setting, they often have a very serious expression on their face and write furiously in a book, forgetting to smile or look at the person they are talking to. When using a translator, they often speak to the translator, rather than to the person they are interviewing, saying things like "can you ask her if the kids wash their hands after going to the toilet?"

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Location: This context is a project in the remote WA desert. An engineer who had previously worked with and been accepted into a community and had a skin name (kinship relation) given them by members of the community, went to work further out west.

Action: The engineer understood kinship is important and introduced themselves with their skin name at the new community, and when meeting local Aboriginal people. The community quickly explained their new relationship to other people in the community: who were their sisters and brothers; who were their aunt and uncles; and who were their 'straights' (those they could be cheeky with). They were also told to avoid certain people, their parents-in-law in effect.

The engineer emphasises that the process eased their work in the community, since relationships were often hard to form. As they were doing short-term projects across many communities dealing with common issues like water supply, renewable energy installation and radio communication, this was helpful. Within a day the engineer had a group of people they could ask for help, knew who to consult about what, and with whom they should do their work, and who they could socialise with after work.

Lessons: When crossing cultures many assumptions are made. We need to respect Aboriginal co-workers and clients by allowing time to build relationships. When projects are based on 'fly-in-fly-out' servicing, there is scope for casual relationships based on kinship names. However, substantial projects need deep understanding of engineers' aspirations, priorities and values to help communities engage with them in line with their aspirations.

Consider collective approaches for better consultation #FirstAsCommunityThenAsIndividual

Through ongoing discussions our students become aware of the knowledge systems with which they currently view the world and the knowledge they consider 'valid'. We want to expand their perspective and appreciate the breadth and depth of knowledge held and communicated through First Peoples' knowledge systems.

Location: We use the story of Brewarrina Fish Traps, told by Aunty June Barker who is not of the Ngemba, the traditional owners of the traps, but tells a story for those who live in the area and would have shared ceremonies at the fish traps.

The traps purportedly had 4' high walls which were opened during floods to allow water and fish in, then closed to hold the fish as a fresh food source while people stayed for discussion. As the waters dropped, traps higher up the river were emptied and lower ones were filled and used, extending the period of meetings (Mathews, 1903).

Action: After the students hear the story, we ask them what they learnt and often they note the landscape features are discussed. These Dreamtime stories are shared with children from a young age, and lessons in navigation of their lands are crucial and important to learn early. We also note that this framework of Country provides the memory code (Kelly, 20016) to help the story remain memorable. Using stories with local features is a highly effective way of holding and communicating knowledge of place in an oral culture. A story can then be expanded with further stories set at these locations, as needed throughout a person's life.

We expand on the knowledge held in this story by noting that black bream lay eggs inside hollow logs and burrows which can be collected and distributed up and down the river to ensure a good spread of the fish for food. This aquaculture was practised by Aboriginal people and the knowledge shared as part of this common story. Finally, the story tells how to create rain, by creating dust clouds during intense dancing, when the dust will billow up into the atmosphere, going "as high as the moon". We know that fine particles into the stratosphere can seed clouds.

Lessons: The community stories which are shared as Dreamtime stories are a repository of collaborative wisdom about the environment and social principles. Other stories about

Brewarrina fishtraps explain that the traps were maintained by clans of Ngemba to ensure they could feed visitors during knowledge sharing ceremonies.

An understanding of how to find your way around and to the traps, how to maintain the fish stock, and how to induce rain were all part of important knowledge to be shared around the area. Managing this in an oral tradition requires ensuring those who tell the stories are well informed and do not mis-represent the complex aspects of the knowledge. This is one place where the boundary setting pre-work on oral knowledge sharing is useful.

Truth in communication #TruthDemonstratedThroughCommunication

Winschiers-Theophilus, H. et al. (2010) said of their participatory design studies that "We are also uncertain as to whether the participants really grasped the purpose of the activity." The outcome of the design differs from the designer's plans in the community eyes. More importantly, ongoing iterations of a design that occur away from the community need to be presented and evaluated by community participants.

Location: These examples are from projects in WA based around water and IT technology. The comments are observations by external engineers and project managers in the community who raise their concerns about ongoing practice that is detrimental to projects.

Action: When projects are funded through external grants with limited consultation prior to starting the project, there will be major learning on the job. Implementation is then difficult as often not funeded, so agreed project equipment may be delivered without accompanying information, or worse broken.

An alternative scenario occurs when a system is installed, and the community has a working system but its members are not well informed about maintenance or system hazards. For example, in Jigalong, a community in the WA Western Desert, there is a three-pond evaporation system for wastewater, surrounded by a fence. However, the children were breaking in, to swim in the third pond, since the “the water guy” had told them that this pond was clean. Asked if they got sick from swimming there, the children said no, but agreed “glue ear” was common, revealing that “sick from bad water” had not been well explained.

A different kind of problem occurred when an engineering consultancy was nominated without community consultation for an award for innovation on a project and then wins, again without reference to the community. By the time an award was made the equipment was not be working and the community's ongoing needs appeared irrelevant to the award process.

Lessons: Conveying the complexities of a technology, especially to the point where a community can take over maintenance, can be difficult. We often hear that when technicians go out to the field, they consider they are already paid for the work so they do not put any care into the product. We suggest that a more accurate interpretation is that the technician, removed from their familiar context, may not be clear about the significance of the regulations nor understand their application in a new setting. Thus, a broader understanding of duty of care, community engagement and careful telling of the whole story of a technology that is being imposed from outside the community, are all important factors to be included in a community engagement process.

In a water project in the Solomon Islands, it was found that some community members would not speak up when the elders were around. In such contexts the rational forms of public argument are not always suited to the way knowledge is shared in yarning, and successful transmission of ideas requires many modes of communication. Workshops organised as social events, such as around eating can be effective, with careful attention given to the after-effects of years of conflict and distrust, if discussions are to find common ground for consensus (Buchy & Hoverman, 2000).

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Traditional workshop opening sessions using questions such as “Tell us who you are and what your interest is in being here” can reinforce entrenched views and recollections of previous unsatisfactory encounters. We have found it is more effective if initial discussions are focused on the collection of factual data about the situation and only later progress to issues requiring opinions, such as: prioritizing values and threats; and consideration of management systems and relationships (Hoverman et al, 2011).

Managing Sustainably #SustainableKnowledgeSystems

The strength of Aboriginal knowledge sharing around sustainability, and the depth of understanding that goes into planning environmental actions such as fire burns or food collection, resides in narratives used to store and share knowledge.

Location: Victor Steffensen has worked for years with fire burning, starting with his elders in the Cape York area around Laura, and using GIS location equipment to map the fire burns and then show that they are systematic and can reduce fire.

Action: Throughout the earlier years of living in Laura, right through to now, I have seen researchers come and go. All sorts of strangers from different universities would come and interview the Elders on whatever topic they were after, sometimes offering the old people a few hundred bucks, or most times nothing at all. They would go away with information and we’d never hear from them again. I remember times in the early 1990s when scientists would interview old people about First Peoples’ Fire Knowledge. The old people wouldn’t tell them much. Understandably, they didn’t trust them with such information (Steffensen, 2020 p.97)

This experience was mirrored in the Northern Territory when Yolngu community members were training scientists in their *worrk* or “the work of setting fire to the bush and managing that fire” (Verran, 2002). When Yolngu did share a burning ceremony, the scientists were uncomfortable when “Yolngu instructors conflated people and lands so that both had inherent relationality” and “in the *worrk* episode, scientists were able to recognize neither valid generalizing about habitats, nor justifiable strategies of burning them.” (Verron, 2002, p 16)

Often researchers would leave thinking that the Elders knew nothing about fire at all. “One scientist I met had come to the conclusion that Aboriginal fire knowledge in Australia was lost forever” (Steffensen, 2020 p.96)

Lesson: Given the history of co-option of Aboriginal knowledge, elders are often reluctant to give information to “strangers” who may wish to gain control over a community project. In fact, the knowledge exists as environmental indicators, a knowledge that is complex and hard to learn, but passed on in the narratives. Here the lesson is that we need to fund Aboriginal people to manage and maintain these skills. Thousands of ranger groups have been set up in northern Australia. Some Ranger enterprises are now built on a business model of payment for ecosystem services, funded by trading carbon credits on the open market. While such a business model is risky and the enterprise is liable if they do not burn country well, this provides a new source of independence (Ricky Archer, NAILSMA).

Engaging with community practice #HandingOverPower

We want engineers to ensure that projects engage with community practice, and to consider how to provide skills for others to take over their role (e.g. in maintenance) and ensure their skills are seen as only a part of the team. The problem when this power is not handed over, is seen in projects such as information technology which include very foreign (unfamiliar) knowledge.

Location: Language learning apps are developed, and funds are largely spent on the development phase which is quite costly. To reduce costs, efforts are sometimes made to re-use a particular system as a template for others to develop their own apps.

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Action: The problem is that during community workshops participants are unclear about how to use an app when they were not involved in its development, and therefore are not ready to take control of assembling further apps from existing material.

Lessons: The issue is twofold. It arises partly around the ongoing issue of getting enough funding for implementation of a project, and from the need to encourage developers to travel to remote areas to make a positive change out of the development experiences. This raises the issue of Aboriginal knowledge being ignored and denigrated when it should be integrated into our management of the highly complicated environment in Australia.

Location: Over the last 20 or so years, Land Councils have been extending their claims to the waters of Australia, as in Aboriginal world views the land and sea are not distinct, but interdependent.

Action: In light of the importance of water in EWB projects and the value of water for Aboriginal people, we introduce Virginia Marshal's work on Aqua Nullius (2017). We highlight the flawed treatment of First Peoples water rights and interests by Australian governments in developing national water reform and describe how the early stages of the process failed to account for First Peoples' inherent rights to water, its use, management, and ownership.

In fact, Aboriginal people had industries built around aquaculture and water management (Frangos et al., 2020) so if we are to value First Peoples knowledge of water, we need to rethink our understanding of water as part of life and land. How do we fit that into our engineering, or do we let First Peoples do this, in a creative way?

Lessons: To value Aboriginal knowledge we need to re-open discussion around such spaces, in this case water rights and interests, and provide for Aboriginal people to set up the discussion on their terms. This is happening more as individuals gain positions at universities that give them time and space to share their knowledge in the format that scientific research will respect. Also, there are other more opensource forms of knowledge sharing developing online to encourage community contribution (Roberts et al, 2020)

Discussion

The research is to bring together our understanding of engineering ways of knowing in different cultural contexts so we can appreciate the different problem-solving techniques used in different societies. We want our students to understand other ways of working that include community as partners and people to be educated in technology from their different perspectives. Also, we use boundary objects to enable our engineering students to see the continuum between Aboriginal and Western perspectives in areas such as our knowledge management and learning techniques as in Figure 1.

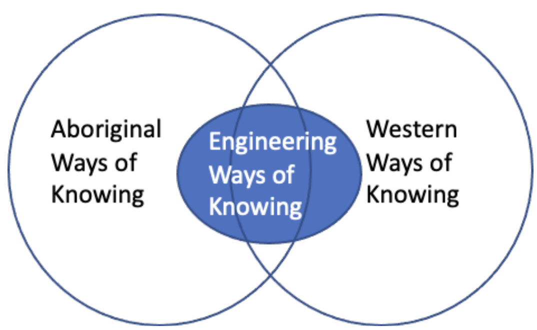

Figure 1 The Relation between Aboriginal, Western and Engineering viewpoints

Hence, we hope to see more Aboriginal people engaged with the academy either as consultants or through community projects in which our students can benefit the community and themselves through two-way learning. However, for this we need to make an environment where Aboriginal people and their knowledge systems are valued. We are

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slowly developing scenarios and activities based on the key issues raised in this paper. However, to do this we need to understand how to change mindsets, what is a trigger that will help people see a new way, or what is the impediment in thinking that we can remove to enable our students to progress.

Boundary objects are supportive of preparing students for explorative discussion, though we have found that at times they need encouragement to enter such discussion where there are no right or wrong answers. We have found this to be challenging for some engineering students and so linking the activity with the skill of managing complexity in their career can be helpful, as is careful facilitation and agreements whereby students identify how they will respectfully discuss the scenario.

Other activities are designed to alert students to their current mindset, way of knowing or approaches, followed by critically analysing the efficacy of this approach, then encouraging consideration and application of alternatives. We have found role plays to be extremely effective as students are able to embody another experience “in the field”, developing empathy and understanding for the roles at play, and practice without impinging on actual communities and people as they learn.

Many activities we use are developed from the same process. We divide students into two groups to take a different approach to a theme. Each group can be told separately to take a perspective eg enact a group of Elders who are hesitant to share fire knowledge (Steffensen, 2020) and talk to a group enacting scientists seeking knowledge. Or we can have each group go through a perspective-based or fact-based consultation process, as recommended by Hoverman et al (2011), when broaching some contentious issue in class. Then the groups share reflections of their experience and how they felt about the others’ experience as they witnessed it.

We also design simulations to help students make the transition from passive to engaged learners. One or more learning outcomes is identified as are the profiles of those for whom the learning is intended. These determine the complexity of the design, the way the action is designed or restrained, and the process through which the learners will proceed. These are all woven into a structure of learning moments that can be repeated and remain stable, although each iteration will have its own unique characteristics from student response and actions. This approach enables us to draw on specific features of the wider context, to build interactive experiences that are engaging, memorable and expand learners’ awareness of themselves in context. Simulations create inbuilt opportunities to cause learners to look further and consider the further possibilities for learning arising from the experience of contributing to the action in the simulation.

Also we engage First Peoples for telling stories based around country the learners are similarly reminded of what the story had to tell them. And both groups of learners have been exposed to learning that has become embedded in their thinking, experience, and future actions. First Nations students engaging in activities should be considered, irrespective of their relationship to identity and ancestry, as having lived experience and learnt experience within the structures of colonialism to which your content is contextualised. If they wish to engage on this level they bring a greater depth to the class.

Conclusion

This is an ongoing project to develop understanding into our teaching in a way that is an authentic contribution to engineering education and provides skills that will help our students create better outcomes in their professional life with a deeper understanding of sustainability and community negotiations.

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Multistakeholder analysis of a novel STEM intervention using physical activity and play

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ABSTRACT

CONTEXT

Understanding the success of any teaching program often needs to look wider than just metrics. This is particularly true for STEM disciplines where the metrics of unqualified success are clear. However, for students who struggle in class it can remain something of a mystery, or worse, it becomes demotivating resulting in failure to engage. Thus by looking beyond performance metrics towards engagement and mitigating attitudinal changes, barriers to learning may be uncovered.

PURPOSE OR GOAL

A previously reported successful multidisciplinary STEM program using physical activity was examined to identify statistically relevant indicators for its success. This was to aid in translational opportunities to other STEM areas that are of a national priority. Success to improve student engagement in STEM subjects was the underlying objective, especially for student cohorts that have been identified by various agencies as typical non-engagers.

APPROACH OR METHODOLOGY/METHODS

This study using a 360 degree stakeholder analysis of technology of a short term STEM intervention to determine measures of its success and failures. It uses semi structured interviews to capture feedback from students, educators and educational system administrators. Traditional hard measures of scholastic of performance was also be used. Measures of academic records is an example of scholastic performance that were used.

ACTUAL OR ANTICIPATED OUTCOMES

Based on earlier work, we anticipate that changes in attitudinal experience of STEM and higher engagement with the education system will be a short term outcome. Reflective analysis from the stakeholders (educators) will likely provide longitudinal information about the efficacy of the program. If the anticipated outcomes are shown as accurate, collaborations with key stakeholders will be established to develop novel curricula based on what has been found, while still fitting the established education curriculum requirements.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

From the earlier research and what is anticipated to be found in this study, greater student engagement in STEM based learning is possible. This will lead to further collaborations in order to develop novel teaching methods built on each student's own physical and play activities.

KEYWORDS

STEM education, technology innovation, student engagement

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Introduction

Science, Technology, Engineering and Mathematics (STEM) are subjects given increasing priority in the developed world, from schools through universities to equip our workforces for tomorrow (Gonski et al., 2018). Despite this, the uptake of STEM courses at universities remains low. One reason is the attractiveness to traditional STEM careers appeals to only a limited subset of students. Critically, this is only after their formative years in primary school where the necessary prerequisite STEM orientated skills must first be developed. Earlier work by the authors has found that STEM subjects are typically 'things' focused, appealing to those that enjoy solitary activities (Su and Rounds, 2015) and comes at an opportunity cost of other activities that may be more desirable to adolescent bodies such as sport (Miller, Vaccaro, Kimball & Forester,2020). Students who are disengaged with STEM have varied reasons, they might find STEM difficult, boring, of little perceived relevance and therefore, do not actively engage when in these classes (Holmegaard, Madsen & Ulriksen, 2014). This can have a significant impact on academic performance and ultimately choice of career and education pathways. For example, entry to many engineering programs requires high level mathematics completed in senior school, which is in turn, only available to those that do well in junior high school, which is often based on primary school engagement in the fundamentals.

Furthermore, in a traditional sense, STEM subjects are typically taught in isolation (McComas & Burgin, 2020). This possibly contributes to what is being taught as perceived relevance. Being able to tie concepts across STEM subjects as well as the relatable activities or experiences may assist in meaningful lessons. Furthermore, it may provide opportunities for teaching efficiency in the classroom with multiple curriculum requirements being met.

Typically, there are cohorts that appear to be at greater disadvantage than others with regard to education in general and in particular STEM. It has been reported that Aboriginal and Torres Strait Islander students, students with disabilities, rural and remote locations, language based (English as a second language) issues, and low socio-economic backgrounds have greater disadvantage in STEM related learning (Gonski et al., 2018). Engaging students from these cohorts may address identified shortcomings in STEM education. Specifically, the declining student numbers in STEM subjects and increasing the numbers of girls involved in STEM areas (Gonski et al., 2018).

After several years of looking at physical literacy in school children, in 2018 a concept was developed to see whether the use of technology in combination with activities where children produce their own data may benefit the learning process of STEM subjects. The technology was developed as a proof of concept. The concept was named "STEMfit" (Lee, Parker, James, 2019). This original phase was to determine what technology could be developed with properties useful for teaching in the classroom. Taking a student centric view, a program that harnessed students' interest in sport as a vehicle to STEM education emerged (James, Parker, Willis & Lee, 2020) using wearable technologies that linked physical activity to classroom STEM activities.

To move past the original STEMfit proof of concept of the technology, we looked at what interested students at a remote and very remote schools. A thorough review of the literature was undertaken to look at why this approach to disengaged STEM students had traction. The literature review found significant drivers around relevance to daily life, play based learning, the inate competitiveness in adolescents (Lee, Willis, Parker, Wheeler, & James, 2020). This had been further extended to examine the pathways of decision making and enablers for the development of STEM careers (James et al, 2021)

For this paper we aimed to seek perceptions from all stakeholders involved in the program, to examine specific areas of success as well as areas to improve. Specifically, the participants (students), principals & teachers, and facilitators & developers.

Methodology

Multistakeholder analysis is a useful tool to examine issues associated with technology innovation (Ringuet-Riot, Hahn & James, 2013). This was combined with a case study approach using semi structured interviews and reflective practice in the educational environment during a STEM intervention.

In this paper we examined the STEMfit educational program (James et al., 2020) in two school communities from the points of view of the educational management team, teachers, facilitators (including a technical innovator) and students. This was based on visits made to a remote school and a very remote school. Both situated in the Northern Territory, Australia. The research was intended to test whether the approach of technology based data collection of school children's movement activities created interest and engagement in STEM in general. It also included insights from teachers and facilitators. Fifteen groups of children participated in the program and were arranged by their grade which ranged between Transition to Grade nine. The facilitators were the researchers and technical personnel who participated in the pilot by overseeing and assisting in the data collection for the program. The number of students to teachers was dependant on the class attendance on the day with an average of 13.0 (±4.0). Ethical clearance was given for the research (HREC clearance: H18089) and approval for the questions used (HREC clearance: H20094) by the Charles Darwin University Human Research Ethics Committee.

Activity design

Outdoor activities chosen for testing were based around running and throwing. These are both typical and popular movement activities. The run was set for 40 metres (m) and the throw was a tennis ball throw. The run was timed using lightgates (Speedlight, Swift Performance, Brisbane Australia) where three gates were used: a start gate; a 20 m split; and a 40 m final gate to record times automatically. Stopwatches were used as a backup to the electronic system. For the throwing, a radar gun (Bushnell Velocity Radar Gun, Bushnell Outdoor Products, Overland Park USA) was used to measure speed and stopwatch to measure flight time.

To generate scientific thinking, the children were asked to make predictions. For example, whether the first 20 m or the second 20 m would be faster in their 40 m run. This could be used later in class by demonstrating hypothesis testing and developing critical thinking on why their predictions were correct or not.

Younger children were given pedometers and asked to count steps manually (Figure 1). Class population data was collected, using steps for a known distance. Open ended questioning around who took the most and least steps were compared and the concept of average was introduced. Higher order thinking, around the relationship between height, leg length (longer legs take less steps) and steps introduced the participants to the meaning of numbers, instrumentation issues (don't hit the reset button) and relationship to physical quantities

The intention was that students could use the data generated in these activities during their regular STEM classes. For example, use the time a ball was in flight multiplied by the speed to estimate the distance thrown. During the physical activities, statements and questions were put to students in order to elicit thoughts that may be used later in critical thinking during classroom activities. While not directly tested in this study, it assisted students responding to questions surrounding this study.

Indoor activities included interactive group discussion based on the biology associated with physical activity including the energy systems of the body, the anatomy and function of the heart and lungs (Figure 1). Physical anatomical models were used for students to take apart and reassemble. Links were made for physiological functions such as lung and heart relationships. A physical model of lung function was utilised to demonstrate concepts like pressure difference and the importance of maintaining proper function of the body.

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Kinaesthetic engagement was ensured through the use of plasticine model construction by students. Co-delivery of public health messaging emerged informally as a part of this education.

Figure 1: Classroom and Sports Field STEM activities

Data collection and analysis

Qualitative data was obtained from the participants through focus groups (students) and semi-structured interviews (teachers, early learning Directors and Principals) post intervention to enable participants to describe their experiences and aspirations and relate them to their current achievements. The collection and analysis of these subjective data followed a phenomenological approach, since the impact of the STEMfit program was examined through the eyes of the participants (Ary, Jacobs & Sorensen, 2010). The focus groups and semi-structured interviews explored the experience of participation in the STEMfit program and (the possible) resulting self-esteem, self-concept and self-reflection.

The phenomenological analysis was conducted by examining significant statements iteratively, where specific themes emerged they were tagged with a meaningful code and ascribed to a node (Bassett, 2012). In responding to the question relating to the impact of the STEMfit program word frequency queries to explore what words are used in each context from each theme (node). Deidentified direct quotes were used to demonstrate the context and validity of the analysis, to directly address the research questions and to give further depth to the study.

Results

Results are grouped into students, teachers, and facilitators. The teacher group includes those with administrative and management responsibilities, the facilitator group includes those doing the face to face delivery of the program together with program developers. Whilst the student responses are a snapshot of the program, teacher and facilitator group includes those with longitudinal views of the program owing to multiple deliveries and iterations of the program.

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Students

Analysis of the survey data asking students about their learning experience around STEM to date found that while one student (Student 3) was “interested in science”, most reported commonly that they were disengaged and “not interested” in the topic area (Students 2, 3, 6, 7, 8, 9). In comparison, following the STEMfit program students were engaged through the physical movements and activities. Students cited that their most memorable part of the STEMfit program was the “running and throwing” (Student 1, 4, 5, 7, 8, 9). Student 2 reported that the STEMfit approach was “more interesting that normal school” and that the facilitators provided “good tips on how to learn and move more effectively.” This was supported by Student 3 who enjoyed exploring “different ways to run faster” using biomechanics. Student 6 recalled the strong interactions with “friends made me excited” to be part of the program.

Some students described the apprehension during the first time they participated in the STEMfit program (Student 1, 2, 3, 4). Student 1 stated “I did not think it was easy”, while Student 3 described feeling “nervous”. Four of the students reported feeling “good” and having “more energy” and this was summed up by Student 6 who described that they were “excited, grateful because I wanted to run”. When asked to reflect on how STEMfit compares to how the students’ might normally feel about STEM learning they replied that they “enjoyed going outside, with one child simply saying “less boredom” (Student 3). This was supported by Student 9 who reported “enjoying class outside.” Student 7 reported that the STEMfit program “made me learn” and Student 8 reported that STEMfit made them “happy to do maths.”

It was identified by the students that they would like to “run more” during the STEMfit sessions (Student 1, 2, 5, 7, 8). Physical activity was a central feature of what the students wanted more of in the program. Student 9 highlighted that they wanted “soccer, more throwing and doing activities” for future iterations of the STEMfit program. Another student identified that they would like “people to cheer and be happy for each other” during their activities. When the students were asked about what impact the STEMfit program had on their identity and self-belief they typically responded that they “don’t know”, but Student 1 responded “yes, interesting”.

Teachers

Analysis of teacher responses found that Teacher 1 reported that they had experience “interpreting Australia Government STEM policy and frameworks relevant to state/territory strategic directions.” This resulted in employing specific STEM based teachers with their remote school and allowed the school to “develop whole of NT initiatives to support school to develop understanding of STEM and STEM programs.” When they reflected on what they found interesting in these STEM experiences they responded that “when learning about STEM people start with a strengths-based approach. Starting with what they know best and branching out from there. A good example is those people who enjoy and use computers and devices competently. They have engaged in STEM through the vast range of resources that can now be added to a computer.”

When asked about what they remembered most about the STEMfit program they identified that the “use of everyday movement activities to develop key concepts and thinking” was an important factor. Along with the “use of a wide variety of technology from simple through to complex to gather data and the richness of the data that is produced through simple activities.” The same teacher identified that they were “curious as to how to link human movement to a range of curriculum areas” during their first encounter with the STEMfit program.

Teacher 1 talked about the development of data entry tools that enable the manipulation of data easy for teachers and students to learn about STEM is something that could be done differently to be more effective in increasing educational outcomes for students. They believe that STEMfit needed to provide “model lesson plans and units of work so that teachers can start to work easily with the concepts and build capability in the area of STEM." Teacher 1 concluded by saying that "the use of basic everyday technologies linked to everyday activities helps students understand the world" is one way to increase participant educational aspirations.

Facilitators

The standpoint of the STEMfit facilitators varied and when asked about their own experience in STEM, Facilitator 1 described "my learning experiences revolved around typical classroom activities. At the time (mid 1970s), there was little or no technology or engineering taught in high schools. Furthermore, there was no science taught in my primary schooling." Whilst Facilitator 2 described how they had "been a tertiary educator in STEM for 13 years, both as a laboratory supervisor and as an academic. "I also discuss STEM in primary schools as a part of STEM Professionals in Schools", run by the CSIRO." Facilitator 3's standpoint was they had "been a STEM professional developer for over 30 years, the last 20 in cross disciplinary areas, bringing STEM into them. The challenge of translating STEM talk and thinking to other disciplines has been one of the major challenges. What I think of as small and what others thing of as small are 2 different things. Something that an end user thinks will be difficult - invariably is easy to do. Something an end user thinks is easy might be almost impossible to do".

What these STEMfit facilitators remembered most about the STEMfit program was "the enthusiasm by the children and their willingness to engage. "The lines of questioning were clearly due to the desire to find out more" (Facilitator 2). Facilitator 3 recalled how they "heard the girl students played with a female facilitator's hair at the second school was very interesting and this says there is a STEM acceptance and relevance of the delivery of the program through relationship based and student centric activities." Facilitator 1 remembered that the strengths of the program to be "children getting to see technology/models that they might not have had previous access too, getting excited about using the technology and as a side effect, learning something new. Students getting to touch, explore and ask questions; the BIG smiles especially from the junior students".

When asked about the activities in the STEMfit program that facilitators thought had a positive impact on them, Facilitator 3 reported "the conversation based activities like playing with models. A focus based on starting with building rapport, then an activity, then STEM." In a follow-up question, the facilitator was asked about which activities has a negative impact. They reported that "in my role as technology developer I am a few steps removed from the end-user …its a frustration…but its Ok too." In comparison, Facilitator 2 when asked about the positive impact on them reported that "it was easy to get excited about the program when you could see the positive impact it had on students. I had some teachers saying that they had never been able to get their students to stay engaged for that length of time before. Also, recognising that every class/experience is different and modifying on the fly one set of students might be really enjoying an activity, so let them go longer, then next group not so much, so move onto something else..." "Loved how the students called out across the school and out in the community to say hi and give a hug."

When asked about improvements to the STEMfit program, Facilitator 1 remarked that an area of improvement is "for students to design the activities to challenge critical thinking. Plus for teachers' involvement in curriculum development." In contrast, Facilitator 3 highlighted that "STEMfit and sensors is a beachhead to engaging students through physical activity and play, broadening the scope to biology and diet and personal health is a natural extension and can really capture student interests as well as deliver across the ACARA curriculum." Facilitator 2 emphasised that "conducting STEMfit in an Aboriginal community really showed how necessary it is to make content relative to the student's context so that they can see how the knowledge is beneficial to improving their own lives." Facilitator 2 then went on to explain that "I identify as a female scientist and I think that it is good for young students, especially

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girls to have that type of role model come into their schools. I like to think I made a positive impact and if nothing else, gave them a fun way to learning even just one thing new."

Discussion

The aim of this study was to determine the impact that the initial proof of concept had on stakeholders. Specifically, whether the initial development enabled interest and what may possibly be used or altered in going forward with curriculum based development. Student centric outcomes revealed a high level of engagement and interest in the activities. Teachers reported that moving from prior knowledge to something new held great promise but needed to be better aligned with curriculum tools. Facilitators reported as tertiary educators struggled with shifting focus of knowledge dissemination to facilitating. It is felt that overall alignment with ACARA curriculum elements will aid in future delivery for all.

Activities

Distance and time for the running, as well as speed and flight time for the tennis ball throw was recorded in the activities. Additionally, in the running, the 40 m runs had the 20 m split time recorded also. These basic data sets offer considerable classroom use in at least three of the four STEM areas. For example: students can take the distance and time data and calculate their average running velocity (maths). From this they could hypothesise how they may be able to run faster (science). To test the hypothesis, how to measure outcomes, students can be given to various options to collect data such as: timing gates, stop watches, wearable devices/pedometers (technology). This approach may enable teachers to address multiple curriculum requirements and in an engaging and meaningful way. Limited innovative teaching activities was highlighted as a deficiency in the Through Growth to Achievement Report (Gonski et al., 2018).

In discussions after the running and throwing sessions, students demonstrated interest in what they had just participated in. For example, one group asked what where their speeds. The facilitator said that he did not know. However, metrics recorded could be used to find out. Questions were put to the children about what was the distance (40 metres), what was recorded (time), what was the time measured in (seconds). This led to questioning about what was speed and what it was measured in (km/hr). With this set as a backdrop, little prompting the children began to see how they could work out their speed. The conversation lasted 15 to 20 minutes with almost every student (approximately 15) participating. The facilitator took the opportunity of the engagement and left the children with the challenge of working out their own speed.

Survey feedback

Student feedback focused on the outdoor activities and little on the physiological sessions. This may have been due to the facilitator who took the running and throwing also surveyed those who volunteered to answer. However, the facilitators reported engagement in this area also. This included positive feedback from teachers. Therefore, engagement with the children was evident to those involved (teachers and facilitator) reflectively. In many of cases, student feedback was limited to one or two word responses. The intent was for open ended questions to let each child genuinely say what felt or wished to say. Therefore, the facilitator did not prompt or lead any questioning. The minimal responses may have been due to factors such as English not being the primary language (Kriol was the language of the area) and the perception that quick answers were required. How the open-ended question approach may need to be carefully considered when moving forward into curriculum development. This is especially the case if co-development principles are to be followed. The use of school interpreters should be considered for effective communication (Taylor & Guerin, 2019).

Opportunities

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At one of the schools, the lightgates failed to function correctly. Stopwatches were used as timing alternatives. The failure of the lightgates may often be considered as a negative. However, in the case of providing opportunities for children to learn STEM subjects, it provides an opportunity to discuss why the technology did not work as there is a reasonable chance that the technology may have been influenced due to the school's location in an approach zone for a military airport and Radio Frequency interference. Therefore, the likelihood of radio blocking technology impacting on the wireless components of the timing system. This could lead to even further discussion in regard to technology e.g. potential impacts on other systems. This demonstrates the versatility of STEMfit in that many scenarios can be offered up for children to learn from. And having directly experiencing the technological shortcoming, would be providing an opportunity to make more sense than giving a "what if something went wrong" scenario.

Looking forward

What is possible in the future, is to combine various activities in order for students to make connections between concepts that are taught. For example, after looking at biology models of the heart and lungs, have students walk a lap of a designated area e.g. the school oval. Taking heart rate measurements pre and post the walk and also noting how they feel exertion wise. Then repeat but instead of walking, the students run. Then carrying out the same measurements and observations. Tying together the use of the models, followed by physical activity that demonstrates physiological changes, increases understanding of the science of how their body works, in this case the need to breath harder and increase heart rate due to physical activity. It also provides multiple data sets that can be used. This is in line with our earlier observations where the relevance of the activity creates greater interest (Lee, Willis, Parker, Wheeler & James, 2020).

Helping children transition smoothly from early childhood learning to school is also crucial (Gonski et al., 2018). The need to develop partnerships between the key stakeholders is important for effective primary school and beyond learning. STEMfit represents an open ended tool and framework that assists in early introduction in STEM education. Specifically, at this point, the implementation of STEMfit is to provide teachers with opportunities and professional development to engage children in STEM subjects that is open ended. Whether teachers wish to continue using STEMfit, or create their own teaching curriculum will be their choice. The initial phase has been largely led by the researchers. Progressing the project from here, will be a process of transitioning from "research-led" via "teacher-led" curriculum design to "teaching-focus". Therefore, the level of autonomy will be at the discretion of individual teachers.

Only a small number of students and adults were surveyed, and this intent was to attain an idea whether the pilot program was heading in the right direction, without telegraphing and possibly influencing future outcomes. What was clear from the surveys were that for the next phase, the construction of questions and how the interview is managed will need to be carefully designed. Some of the responses may have been due to children guessing what the facilitators might have wanted to hear. At this stage of the research, it is difficult to measure direct educational outcomes, growth in educational measures requires a longitudinal approach, however engagement and relationship building is a key to enabling this next stage of research. The educational intervention at one site was the first and was the second intervention at the other site. Repeat visits are planned as well as student field trips to the university (a 7 hour journey), the project will continue to monitor engagement and with school principals and staff, utilise the schools' scholastic measures longitudinally to measure the educational efficacy in the future.

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Evaluating competency development using interactive oral assessments

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ABSTRACT

CONTEXT

Charles Sturt University Engineering students complete four one-year, full-time, paid work placements during their 5.5 years of combined Bachelor of Technology/Master of Engineering studies. During their first and third work placements, students also complete four subjects, in which they are required to compile a professional portfolio claiming and demonstrating their skill development in a number of competency elements.

PURPOSE

Given the 2020–2021 pandemic and lockdowns, many institutions strived to implement assessment approaches that suited their immediate needs in conducting fair and integral online assessments. In the meantime, Interactive Oral Assessments (IOAs) have been gaining popularity due to the benefits they offer. An IOA is an authentic, scalable, interactive and time-effective method of assessing students' achievements of the learning outcomes. This paper discusses the use of an IOA in the Professional Portfolio – Advanced subject in 2021 and presents and evaluates the outcomes of a successful implementation.

METHODOLOGY

This mixed-method study elaborates the experience of the authors in implementing an IOA in the mentioned subject and offers a reflection on the success of the IOA approach to assessing particular aspects of knowledge and experience acquisition. The arguments are supported by self-observation, comparison of the current and previous subject offerings, as well as the results of the end-of-semester subject experience survey (SES).

ACTUAL AND ANTICIPATED OUTCOMES

The results/observation confirmed that adoption of the IOA allowed for an authentic, unscripted conversation between each student and the assessor, shaped by a unique scenario (e.g., engineering skill development, similar to the EA CPEng application process). Implementation of the IOA also resulted in a higher level of student engagement with the content and learning material, as well as better achievement of the outcomes. There were also greater effectiveness and efficiency for the assessors in the marking process, as well as enhanced levels of academic integrity. Finally, students were expected to achieve enhanced employability skills and a sense of connection to their future careers/professions.

CONCLUSIONS

From an assessor's point of view, using an IOA and stepping away from the barriers of traditional assessments, provided greater assurance of the students' quality of learning. Moreover, students' achievements were demonstrated through both 21st-century and higher-order thinking skills, in line with the institution's aspirational graduate learning attributes.

KEYWORDS

Interactive Oral Assessment, Work Placement Learning, Professional Engineering Portfolio

Introduction and Background

Within the context of workplace learning, assessment of students' professional development and competence in engineering is generally performed through assignments, exams, and projects. However, written assessments put limits on the ways that such competence can be assessed. For instance, students respond to a set of given questions or defined tasks that are the same for the cohort, and not necessarily relevant to individual circumstances. Moreover, mostly, the written submissions have limitations for the number of pages or words, in order to make the evaluation plausible with limited staff and time resources, and as such, they limit students' ability to present their achievements in varied aspects of the workplace learning environment. This paper discusses a new approach to efficiently, effectively and verbally assess the level of students' competence development in a number of elements of competency. In the following, the context of the corresponding subjects and their assessment approaches are explained, with the focus on the design and re-design of the relevant subjects and assessments.

Professional Portfolio

Charles Sturt University (CSU) hosts CSU Engineering as part of the School of Computing, Mathematics and Engineering in the Faculty of Business, Justice and Behavioural Sciences. CSU Engineering is known to be one of the emerging engineering schools in Australia and internationally (Graham, 2018). The CSU Engineering's first intakes in the combined Bachelor of Technology/Master of Engineering (Civil System) degree was in 2016 (Lindsay and Morgan, 2021) and is expected to have its first group of graduates in December 2021. Based on the curriculum model, after completing three face-to-face, on-campus semesters, students complete four one-year, full-time, paid work placements towards their degrees. Alongside their employment, students also complete a number of subjects. In this context, a subject is a unit of study in which a student enrols for a semester. Accordingly, Engineering Portfolio (EP) and Performance, Planning and Review (PPR) are two series of five subjects in the degree, their details are presented in Table 1.

The overall aim of the PPR subjects is for students to set and measure tangible, individual goals related to their work placement activities and personal skill development plan, and then work towards achieving these goals by the end of their respective PPR subject. Within the course of any of the PPR subjects, each of the students complete reviews of their progress with their academic mentor and placement supervisor, to demonstrate adequate progress towards achieving their goals.

The overall aim of the EP subjects is to guide students on how to collect evidence of their professional skill development in their workplace, and then document claims of competency against certain indicators of attainment. Such competency elements are ideated from the 'Engineers Australia Stage 1 – Competency Standard For Professional Engineer' (Engineers Australia, 2019) and 'Australian Engineering Competency Standards Stage 2 – Experienced Professional Engineer' (Engineers Australia, 2018). Similar to the Engineers Australia Chartered Professional Engineer (CPEng) application process (Engineers Australia, 2021a), the evidence that students collect from their workplace tasks and projects provide the support and justification required by the EP subjects to make a claim of competence about a number of elements of competency and their respective indicators of attainment. Examples of the elements of competency include 1) knowledge of engineering tools, standard engineering methods, and stages of the engineering design process and approaches to synthesise various design stages; 2) communication and professional skills; 3) ethics and accountability in engineering practice; and 4) expertise and knowledge of information needs, collection and management of information, and collaboration and co-creation of information.

Such elements are not all covered in all of the EP subjects, meaning that at various stages of students' development in their four work placements, as well as the stages of their identity development, they are required to demonstrate achievement of a collection of the

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abovementioned elements. Moreover, the way that each of the elements is described varies across the first four subjects, with an increasing level of complexity and difficulty from the earlier subjects towards the later ones. Consequently, through the EP-Professional Engineer subject, 16 competency elements (the same as Engineers Australia, 2018) for an Experienced Professional Engineer are discussed and assessed, providing the opportunity for students to assess their readiness (or otherwise the gap) to make a strong application for a CPEng status. Currently, there are discussions that CPEng (as a nationally recognised status) becomes a required method of certification for nationally registered engineers in Australia (Engineers Australia, 2021b). Similar lines of thought derive students' desire to succeed in the series of EP subjects.

Table 1 Subject details

<table>
<tr><th>Underlying Degree</th><th>Academic Year</th><th>Subject Name in the PPR* series</th><th>Duration</th><th>Subject Name in the EP** series</th><th>Duration</th><th>Offering mode</th></tr>
<tr><td rowspan="4">Undergraduate</td><td>1st</td><td>Student Engineer</td><td>2 semesters</td><td></td><td></td><td>On-campus</td></tr>
<tr><td rowspan="2">2nd</td><td rowspan="2">Junior Cadet</td><td rowspan="2">1 year</td><td>Introductory</td><td>1 semester</td><td rowspan="6">Online</td></tr>
<tr><td>Developing</td><td>1 semester</td></tr>
<tr><td>3rd</td><td>Intermediate Cadet</td><td>1 year</td><td>-</td><td>-</td></tr>
<tr><td rowspan="3">Postgraduate</td><td rowspan="2">4th</td><td rowspan="2">Senior Cadet</td><td rowspan="2">1 year</td><td>Consolidating</td><td>1 semester</td></tr>
<tr><td>Advanced</td><td>1 semester</td></tr>
<tr><td>5th</td><td>Professional Engineer</td><td>2 semesters</td><td>Professional Engineer</td><td>1 semester</td></tr>
</table>

* Performance, Planning and Review (PPR) subjects
** Engineering Portfolio (EP) subjects

Before the start of the academic semester, students have access to a Subject Outline (SO) containing a description of what the subject entails including assessment regime and descriptions. On that account, for the first four of the EP subjects, the assessment items can be categorised into three groups: 1) discussion on collecting and collating appropriate evidence for particular competence claims; 2) development of the competence claims supported by previously discussed (and agreed upon) evidence; and 3) self-evaluation and reflection (and/or peer-evaluation) of the developed competence claims. Accordingly, the focus of this paper is on the evolution of the reflective assessment items across the two iterations of the EP-Consolidating and EP-Advanced subjects, and the adoption of an Interactive Oral Assessment approach.

Interactive Oral Assessment

Oral assessments have long been used in various disciplines and contexts (Joughin, 2010). They can take the form of an interview, viva voce, oral defence, presentation, or pitch to name a few (Karltun and Karltun, 2014; Learning Futures, 2020). An Interactive Oral Assessment (IOA) approach, on the other hand, is a genuine, unscripted, synchronous conversation between an assessor and a student (or a group of assessors/students) around an 'authentic workplace scenario' (Sotiriadou et al., 2019) which can be performed face-to-face or online.

The unscripted nature of the assessment is related to the fact that, instead of set questions, the assessor uses normal conversational cues based on the individual student's circumstance,

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to assess the student's learning and achievements (Sewagegn and Diale, 2020) in light of the introduced scenario. The scenario (or put it simply, the topic of the conversation) is defined as part of the assessment description for students to prepare themselves (and any necessary supporting evidence for the conversation) in advance. In this regard, the scenario is purposefully outlined as 'authentic' rather than hypothetical, as such an assessment strategy proved to be a lot more effective (Karunanayaka and Naidu, 2021). Such authenticity can easily be achieved when the scenario is strongly linked to students' workplace (or real-life) experiences. For instance, in the context of the EP subjects, the scenario is defined around the students' skill development in their workplace and their preparedness to become chartered professional engineers, and hence is considered authentic as it deals with real and current work experience each of the students is engaged in, as well as their plan for further skill development.

During the conversation (i.e., the assessment process), the assessor may use prompts to steer students in the right direction and ensure the requirements of the assessment are satisfied. However, as there is no pre-defined series of questions to be asked by the assessor, the conversation is interactive in the sense that the assessor uses the student's responses to bring forward the next point for discussion, and identify the clues and evidence to support a given grade. This makes each student's IOA unique because their experiences are unique to their circumstances and workplace. The dialogue continues (within the limit of time) until the assessor covers all that is needed based on the marking rubric and assessment requirements.

Such opportunities truly focus on the assessment for learning paradigm (William, 2011) while adequately assures evaluation of the achievement of the Subject and Graduate Learning Outcomes. Moreover, the genuine and unscripted nature of the conversation about the chosen scenario has proven to be an accurate and effective means of evaluating the students' learning (Sotiriadou et al., 2020).

During this IOA process, the assessor can also provide immediate feedback to students, while being sure that such feedback is in fact heard. This also allows students to immediately ask for clarification, reflect on and synthesise their learning, or present their counterargument if they disagree with any feedback. This assists the conversation to be more engaging and interactive. Such an effective exchange of feedback elevates the conversation to a higher level, and this is how longer-lasting learning is expected from the IOA approach (Sotiriadou et al., 2020; Griffith Business School, 2021).

Context

The first author of this paper coordinated and taught the EP-Consolidating and EP-Advanced subjects during their first two offerings. Accordingly, Table 2 presents details of the four reflection assessment items that were designed in those two subjects. It is worth noting that the subject and assessment designs have always been limited by the given autonomy in the framework of the curriculum, the number of credit points assigned to the subjects, and the designated workload hours. Given these, the main design rationale informing the 2020 offering was to familiarise the students with the concept of reflective writing through the lens of competency claims (Lawson et al., 2015; Lake et al., 2016; Helwig et al., 2019). In contrast, in the EP-Advanced subject in 2021, deeper and more comprehensive reflections were required as technically the students were in their Master's part of the combined degree. Moreover, through longitudinal scaffolding between subjects, the aim in the EP-Consolidating subject was to make students ready for their successive subject; i.e., EP-Advanced.

As depicted in Table 2, one element of competency was deemed sufficient given the imposed limitations for such an assessment in the EP-Consolidating subject in 2019, where there was also a one-page limit (approximately 450 words). However, after the first offering, the quality of the students' reflections soon proved that the written reflection format limited students in terms of discussing all aspects of their achievement and competence development, because there was no space for creativity, or non-textual content (e.g., evidence in the form of screenshots, graphs, tables, etc.). Therefore, the choice of a video recording was introduced

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for the EP-Advanced subject in 2020 – each student could choose one element of competency and record an 8–10-minute video reflection, which equates to approximately 1200–1500 words in written form. Furthermore, autonomy was also given to students to be creative in professionally editing their recordings with the use of audio-visual effects, embedded evidence, etc. Nevertheless, in the end, the results were not satisfactory as a whole, as many of the students recorded a very basic video, with them reading directly from a prepared script. So, the most important aspect of the assessment, i.e., the discussion and evidencing the reflection, was not achieved in most cases. There was also little indication of spontaneous, deep, critical reflection of the chosen competence element (Krych-Appelbaum and Musial, 2007).

Table 2 EP Subject offering details

Subject Name	Offering year (Semester No)	Assessment Title	Assessment Type	Submission Length
Consolidating	2019 (S3)	A Reflection	Written	One page, only text, one competency element
Advanced	2020 (S1)	A Video Reflection	Video	8 to 10 minutes of recording, one competency element
Consolidating	2020 (S3)	Portfolio Consolidation: A Reflection	Written	800 to 1000 words + one evidence page, one competency element
Advanced	2021 (S1)	A journey towards higher-level competencies	Verbal	20 to 25 minutes of conversation, two competency elements

Equally important, the effectiveness of the exchange of feedback between the marker/assessor and the students in their usual written form of feedback was not measurable in either of the subjects. This was reinforced by the observation that few students had ever proposed an actionable plan for further development of their reflective writing skills (i.e., through the relevant PPR subjects) after having access to their personal feedback. Perhaps their decision not to access the feedback was influenced by the fact that the reflective assessment came at the end of the EP subjects when students were focusing on the following semester's subjects.

Informed by these results, the 2020 offering of the EP-Consolidating subject, still comprised the written reflection form, however, with an extended word count, there was also an opportunity to provide evidence. That is, students were allocated 800–1000 words for reflection for one competency element, and one page for evidence (Table 2). This change resulted in significantly better outcomes in terms of the depth and breadth of reflections. However, the efficient exchange of feedback was still the missing element as there was no evidence of cross-subject adjustment of a personal development plan in the relevant PPR subjects. Concurrently, with the aim for a more effective assessment regime, the idea of an IOA was adopted for the second offering of the EP-Advanced subject design in 2021, as explained below.

Development, Implementation and reflection

The development of the IOA assessment within the EP-Advanced subject involved a course of actions with the support of the second author as a mentor within a Community of Practice (CoP) at CSU and the third author as the Educational Designer. Accordingly, a holistic approach was taken to redesign or re-align the different aspects of the subject, various assessments and their respective marking rubrics, subject content and materials, and the subject outline to ensure that the reflection assessment was scaffolded adequately to help prepare students for their IOA.

To start with, the title of the assessment (Table 2) was changed to “A journey towards higher-level competencies” to more carefully align with the concept of an IOA. Moreover, the required scenario for the conduct of the IOA was designed to be about a conversation between a senior and a junior staff, where the latter has planned to apply for CPEng and seeks feedback about their preparedness. In more detail, students were able to choose two of the six competency elements discussed in the subject, and develop their case. This entailed reflecting on how the actions and decisions for each student, in their tasks, projects, and works, had been instrumental in enhancing their competency in their chosen elements from an introductory level to a more advanced one.

The choice of competency elements, on the one hand, provided greater flexibility for students to demonstrate their achievements over the course of their work placement years, given the different places they worked in and the varied journeys undertaken to acquire advanced skills, thus ensured the dialogue to be personalised and unique. On the other hand, it provided more opportunities for the assessor to evaluate different layers of each student’s achievement, which equated to better quality assessment outcomes. That is, the conversations were personalised, genuine, authentic and engaging for each student, offering a more relaxed and less stressful environment. Moreover, using evidence to support the interactive conversation, enriched the authenticity of the conversation as students were able to discuss their lived experience in a semi-casual/formal setting, far from to normally stressful examination venues.

In the second place, the marking rubric was developed in a way to assess students’ soft skills along with their content knowledge, as well as their ability to apply that knowledge to other real-life scenarios. For instance, instead of applying for CPEng, the conversation could be about a staff’s performance review or promotion. The marking rubric encompasses criteria to seek for evidence in the conversation about:

1) A critical reflection, analysis and recognition of the processes involved in students' careers and subjects which were instrumental in the development and improvement of their chosen elements of competency,
2) A critical reflection, analysis and recognition of students’ strengths and limitations, and the changes in their personal assumptions, habits, and values,
3) A critical analysis and evaluation on the relationship between students’ actions and decisions, and any resulted improvements in their chosen competency elements,
4) An examination and discussion of a metacognitive, pro-active concrete, meaningful and attainable action plan for further actions and learning.

In the next stage, the subject content and materials were also updated. Specifically, students were provided with 1) a written guide on how to prepare themselves for their IOA session (including the booking); and 2) two exemplars of mock IOA recordings of different standards that were purposefully prepared for the subject to give students a sense of what to expect in their IOA. Furthermore, in one of the online classes, a separate time was allocated for students and they were given the opportunity to review and discuss the exemplars to enhance their understanding of the assessment requirements. Students applied the assessment rubric to the interactive oral examples and shared their feedback with their class peers, suggesting improvements regarding preparation, presentation, reflection, etc.

At the time of IOA, students were given about 10–12 minutes to present their case and scenario in a typical verbal presentation format, and then the assessor and the student discussed various aspects of the presentation for 10–13 minutes in a simulated workplace setting. The objective was to not reassess students on what they had already been assessed on through other assessment items, rather to provide students with the opportunity to synthesise their knowledge and apply it to other scenarios. Such an approach is key to help develop students' higher-order thinking skills, 21st-century skills and graduate learning attributes. The entirety of each IOA was facilitated via an online meeting platform for two reasons. Since the students were at their workplaces and not on-campus, anyone could join the meeting (i.e., the assessment) without physically attending in person. Moreover, easily achieved using the online

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platform, all the IOAs were recorded for any future quality control, moderation, or accreditation purposes.

Considering aspects of an assessment such as reading a written submission, providing (written/verbal) feedback, completing the evaluation and filling the marking rubric, one of the advantages of IOAs for the assessors is a significant reduction in the time required for evaluation. Because all the abovementioned tasks can occur concurrent with the conversation itself. According to the institutional workload policy details and the context of EP subjects, 45% of the first author's time in the subject was allocated to assessment marking. However, by adopting the IOA approach, the required marking time for an individual student was reduced by about 60%. Such productivity can better be used for the development of resources or student consultation time. Nevertheless, it needs to be noted that while such a reduction would benefit future iterations of an IOA, because it was the first time such an approach was adopted by the first author there was no saving in time experienced overall owing to the time invested in redesigning the subject and developing the necessary resources.

The other advantage of IOAs was a better assurance of the level of students' knowledge and developed skills, rather than a lack of confidence or thorough evidence whether they had actually understood certain concepts based on their in/ability to express themselves confidently via a written medium.

The final advantage of IOAs relates to the exchange of feedback during the interactive discussion. At any stage of the scenario presentation, the assessor can provide immediate feedback or seek clarification. Likewise, the student can immediately ask for clarification, or provide more evidence and justification if required to support their case, and accordingly extend and synthesise the conversation further. For participants with English as the second language, this aspect is deemed very important. These factors equate to a highly effective exchange of feedback with expected longer-lasting learning. Students also found this experience resembling what might happen in their workplace. That is, most of the engineers engage in conversations and exchange of ideas on a daily basis, where they might be spontaneously asked about their opinions which by itself requires drawing upon past knowledge and experience. Accordingly, the authenticity of the discussed scenario in the subject achieves another aim of the IOA, which is learners' performance beyond graduation.

Supporting Evidence

A comparison of the student outcomes from this and the previous offering showed the following. In general, the second offering of the subject was found to be significantly more successful:

1) Based on the subject access analytics hosted on the learning management system site, the average number of access to the subject site increased from 7 to 32. Accordingly, the average duration of access improved from 54 minutes to 271 minutes. This indicated that there was an overall more interest in engagement with the subject materials.
2) The class attendance increased from an average of 60% to about 79%, which by itself was demonstrative of more interest to participate in class activities and successful completion of the subject.
3) The average mark of the students increased by one band from Credit to Distinction. This was partly affected by the improvement in the marks for the peer-review assessment item, and partly related to the IOA, where the average of the marks increased from Distinction to High Distinction.

Apart from self-evaluation of and reflection on the success in implementing the IOA approach, students' feedback was also received. In June 2021, as part of the normal end of session subject experience survey (SES), the students responded to the following statement on their experience with the IOA: "The Interactive Oral Assessment approach supported my learning." The responses could be any of the following five options: a) To a very large extent, b) To a large extent, c) Somewhat, d) To a small extent, and e) To a very small extent.

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With a response rate of approximately 65%, about 78% and 22% of the responses were given as 'to a very large extent' and 'to a large extent', respectively, meaning that all the students had a positive experience with the assessment item. Moreover, overall, the second offering of the subject scored an 88% SES score which exhibited a 48% increase compared to the first offering. Such level of satisfaction has been above expectation as normally students do not unanimously respond positively to fundamental changes. Factors such as dedicated class hours, preparatory activities, scaffolded assessment, and exemplar/sample recordings were found to be effective tools in this regard.

Discussion and Conclusion

In this paper, the design and implementation of an interactive oral assessment approach to an engineering professional portfolio postgraduate subject were presented and discussed. The steps taken by the subject coordinator to prepare the teaching materials and design a robust assessment, in collaboration with an expert mentor and an educational designer, were elaborated. Some qualitative data about the subject performance and students' responses to the subject experience survey were also presented, which indicated the success of the re-design of the subject including the assessment design. It is believed that through assessing students' ability to demonstrate the depth of their knowledge and its application in responding to other 'what if'-type questions and challenges, all the expected benefits of an IOA were achieved. From an assessor point of view, using an IOA and stepping away from the barriers of traditional assessments, provide better assurance of the students' quality of learning, which is expected to be longer-lasting with benefits for their future. Moreover, students' achievements are demonstrated through critical, higher-order thinking skills, 21st-century skills and transversal competencies, in line with the graduate learning attributes.

Based on the success of the first iteration of an IOA, the first author is enthused to implement other IOA approaches within this subject. Moreover, at this stage, the above conclusions, as well as the applicability and possibility of reformatting the existing assessment items, encouraged and justified the adoption of an IOA approach to two more subjects (from the PPR series) within the same course. Limitations of the adopted approach and how this approach can be used in a broader context are briefly discussed below.

Limitations

At this stage, for the discussed EP subjects, and similar ones (e.g., the mentioned PPR subjects) there appears to be no barrier to adopting and implementing an IOA where an authentic conversation between the assessor and students is expected. Having a clear scenario, students should be able to participate in an authentic professional conversation for the purpose of assessment. While in the current subject there was only one assessor for a cohort size of 14 students, IOAs are also considered scalable (Griffith Business School, 2021); that is for larger cohorts, it would be necessary to have multiple assessors, total hours of assessment allocation, and consistency of administering an IOA, as well as marking (which in many cases is not an issue as there are more staff in a teaching team for larger cohorts). Having said that, it would be required to train the staff involved and complete a moderation process to address issues such as bias and ensuring equity and consistency across multiple evaluators (Chakraborty et al., 2021) – a matter which is already practised in different contexts.

Broader applications within engineering subjects

In this paper, the adoption of an IOA approach for individual student assessments was discussed. However, there are also other types of assessments in engineering education, such as assessing group works, team contribution, and peer assessments. Certainly, for a group-informed assessment in a verbal format, an IOA can also be used. For instance, the group should report to the assessor on the steps they have taken to complete a given task, much as they would discuss such steps with a supervisor or client on a team project in the workplace. For the assessors, rather than considering set questions, they can initiate an authentic conversation through which any required aspects of the task can be covered and evaluated.

Likewise, peer evaluation of another student's performance can be shaped as a paired IOA. This provides the opportunity for the student evaluator to ask questions about the candidate's performance, while at the same time, the candidate can defend themselves against any criticism that they might receive from the evaluator, much as they would in a performance review scenario in the workplace. When such paired IOAs take place in the presence of the subject assessor, an evaluation of both the students can also be completed at once, improving efficiency. Whereas, in written form, the main assessor needs to access and evaluate two separate documents (i.e., for the candidate and evaluator), which is time-consuming and unproductive. The two abovementioned opportunities are suggested for readers who are interested in exploring the IOA approach further.

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Improving learning through technology-enhanced dynamic and interactive engineering content

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ABSTRACT

CONTEXT

The rise of flexible degree structures has allowed students to explore a wider breadth of knowledge. This has resulted in an increase in students with diverse backgrounds in different areas of foundational mathematics and physics enrolling in engineering subjects. Teaching engineering concepts while catering to these diverse cohorts is an ongoing challenge. This is compounded by the fact that teaching activities still largely rely on static two-dimensional formats such as PowerPoint slides and handwritten notes. The engineering concepts on which this study is based are those involving spatially and temporally varying elements.

PURPOSE OR GOAL

To improve learning outcomes and the student experience, we explored the integration of new technologies in the development of more effective supplementary teaching and learning materials. We were particularly interested in technologies allowing dynamic phenomena to be fully explored and interrogated by students. The long-term goal is to develop a library of interconnected interactive resources that students can access to fix any gaps in expected knowledge, and to reinforce concepts taught in synchronous learning sessions (i.e. lectures, tutorials) by providing alternative and more visual perspectives.

APPROACH OR METHODOLOGY/METHODS

Applying a design-based research methodology, we initially experimented with the introduction of a series of short concept-focused video tutorials in a second-year engineering mechanics subject. Following positive student feedback, we broadened the scope of this project to include a graduate-level medical imaging subject. In this next iteration, the H5P platform was used to embed interactive quizzes within the videos, which students could use to gauge their understanding and receive real-time feedback. An interactive MATLAB-based virtual lab prototype – simulating a mechanical testing lab – was also developed.

ACTUAL OR ANTICIPATED OUTCOMES

Survey data indicated that students find interactive embedded quizzes helpful in their learning – this was the case for incorporation in both our short concept videos and pre-recorded lecture content. Conversely, students found the current iteration of the virtual lab neither helpful nor unhelpful in their learning.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

While more work remains to be done in this space, our findings suggest that access to more visual, dynamic, and interactive content allows students to explore engineering concepts in more intuitive ways than is possible with traditional two-dimensional formats.

KEYWORDS

Technology-enhanced, h5p, simulation

Introduction

Flexible degree structures such as the Melbourne Model at the University of Melbourne have allowed students to focus their studies in a specific subject area while still exploring a wider breadth of knowledge. This has resulted in an increase in the diversity of students enrolling in engineering subjects, in terms of their depth of background knowledge in mathematics and physics. Catering to this diversity has been challenging, as the cohort is unevenly prepared to tackle the specific challenges of learning new engineering concepts, many of which involve motion, time dependence, and vectors. Teaching these concepts comes with its own set of challenges, as this is still predominantly done using static PowerPoint slides or handwritten notes. Again, as many of these concepts involve spatially and temporally varying elements, the incongruence between delivery using static media of concepts involving dynamic phenomena is especially noticeable. While there are workshops and labs offered for hands-on experimentation, these typically allow for only a small subset of concepts to be explored.

To address the issues above, we investigated the integration of new technologies in the development of more effective teaching and learning materials. We were particularly interested in enhancing existing content with technologies that would allow students to properly explore and interrogate complex phenomena involving motion. Our overarching goal was to develop a library of interactive resources that students would be able to access via the Learning Management System to patch any gaps in expected prior knowledge, or to further reinforce concepts covered in lectures by providing different and more visual and dynamic perspectives.

This paper describes the application of a design-based research (DBR) methodology in the development of technology-enhanced dynamic and interactive engineering content to support the learning of engineering concepts in subjects taught in the Faculty of Engineering and Information Technology at the University of Melbourne.

Approach

A design-based research (DBR) approach was adopted in the development of these new teaching and learning resources. The DBR methodology is characterised by "continuous cycles of design, enactment, analysis, and redesign" (The Design-Based Research Collective, 2003). Scott, Wenderoth, and Doherty (2020) further describe DBR as an iterative process with the following four steps: the identification of problems or challenges, the design of potential solutions, the evaluation of those solutions, and finally, a reflection on those solutions and their implementation. This section describes the two DBR iterations that have occurred to date with reference to these four steps.

First DBR Iteration

Identification

The diversity in foundational physics and mathematics background was first identified as a problem in the subject Engineering Mechanics (ENGR20004). This subject is offered year-round (Semester 1, Semester 2, Summer Semester), with average enrolment of >500 students per year. As a fundamental undergraduate-level engineering subject, it forms the basis for further engineering studies within the following disciplines: biomedical, civil, environmental, mechatronics, mechanical, and structural. In the subject, students are introduced to translational and rotational motions that result in a body subjected to different forces. Upon completing the subject, students are expected to be able to confidently describe and analyse the motion of particles and rigid bodies using two-dimensional vectors. In addition to the challenge of effectively delivering concepts involving dynamic two-dimensional motion while catering to the varied educational backgrounds of the cohort, a major challenge in this subject has also been to maintain high levels of student engagement.

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Design

Multiple studies have shown that videos can be an extremely effective tool in helping students learn (e.g., Rajadell and Garriga-Garzón, 2017). In this context, a dynamic format such as video is essential in teaching concepts that are difficult to visualise with traditional static formats (Dash et al., 2016), such as those involving two-dimensional motion. In line with this, we developed a series of 34 video tutorials to address the previously described problems in ENGR20004. These covered a range of fundamental concepts aligned with what was considered prerequisite knowledge to succeed in the subject. In designing these videos, recommendations previously described by Brame (2016) were followed. These recommendations are divided into three categories based on the elements being considered: cognitive load, student engagement, and active learning.

To enhance germane load (cognitive activity directed towards achieving intended learning outcomes) and reduce extraneous load (cognitive activity that does not help the learner towards intended learning outcomes), text was avoided beyond the use of necessary key words for signalling purposes, and the use of music and complex visual backgrounds was minimised. In addition to this, many of these videos also featured narrated animations, an example of matched auditory and visual modalities that has been shown to optimise cognitive load. To maximise student engagement, all videos were kept short (3-5 minutes in duration), meaning that some of the more complex concepts had to be segmented into multiple shorter videos. Conversational, enthusiastic language was used to foster a sense of connection between the viewer and the instructor, and links to in-lecture material and real-world engineering applications were frequently stressed. To promote active learning, guiding questions were inserted at logical points within each video. One of the later videos in the series covered the concept of free vibration and was accompanied by a simple MATLAB-based interactive interface within which students could alter parameters and observe the resultant motion of a spring-block system.

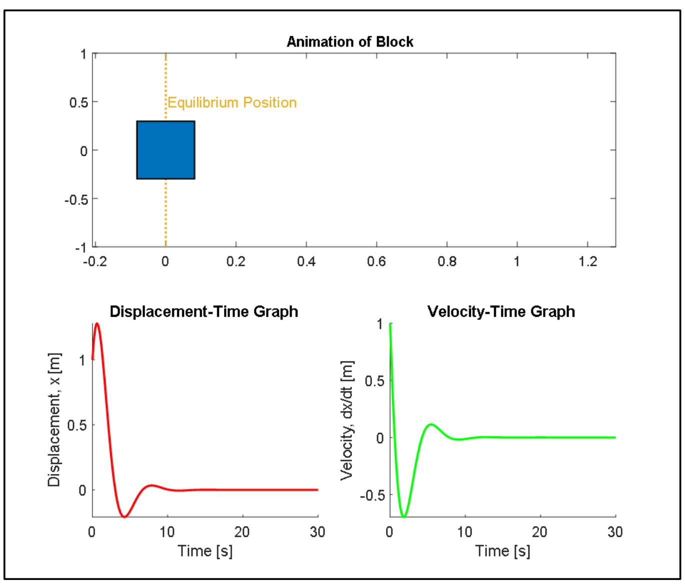

Figure 1: Output of MATLAB-based interactive interface covering the concept of free vibration.

Evaluation

In this first iteration of the DBR process, no evaluation in the form of a formal student survey was conducted on the produced materials. However, the videos were well-received: the 34 available videos registered an average view count of 793 each (averaging to 2.58 views for

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each of the 307 students enrolled that semester). In an informal poll conducted within lectures midway through the semester, of the 51% of the students who had indicated that they had actively engaged with the material, 99% rated the material as being helpful in their learning.

Reflection

Reflecting on this initial implementation, we identified the following as items to address in the second DBR iteration:

- Adding a second, graduate-level candidate subject within which to pilot our developed resources (to ensure representation from both undergraduate and graduate-level students),
- Including more interactive elements to further promote active learning and engagement (in line with the MATLAB-based interactive interface accompanying the video on free vibration),
- Setting up a formal method of evaluating our implementations, beyond simply relying on view counts and informal polling.

Second DBR Iteration

Identification

Medical Imaging (BMEN90021) was identified as a second subject for the study based on ease of access: two of the authors are associated teaching staff. This subject is offered only in Semester 1, with average enrolment of about 60 students per year. It is a graduate-level biomedical engineering elective that introduces students to the physics, engineering, and physiology of medical imaging. It relies on knowledge of various physics concepts including electromagnetism, nuclear and radiation physics, acoustic physics, as well as mathematics of signal and image processing. As such, the major challenges in this subject are similar to that of ENGR20004: it requires solid – and in this case, interdisciplinary – foundational knowledge, and the concepts covered are dynamic in nature.

Design

Following further recommendations described by Brame (2016), all existing and new video tutorials were embedded with interactive quizzes using H5P (Figure 2). H5P is an HTML5-based tool that allows the creation of rich, interactive content and activities that can be embedded seamlessly into online learning materials. The rationale behind this integration was to promote active learning: students are forced to recall – as opposed to just receive – information. Furthermore, it allows students to gauge how well they understand the material in real-time, allowing them to more quickly identify concepts that require revision. Some lecture content was also shifted to pre-recorded video formats, and some of these lecture videos were similarly modified to feature embedded quizzes.

The idea of promoting active learning and engagement via the further development of interactive physics-based simulations was expanded, and the creation of a virtual lab was proposed. This was initially envisioned as a repository of virtual physics sandboxes within which students might perform parametric investigations and develop their engineering intuition (Dalgarno et al., 2009). For example, one might imagine students having access to a virtual materials testing machine after first attending an existing hands-on counterpart laboratory session. In such a simulation, students are free to simulate mechanical tests on various materials and to measure and explore the relationships between engineering quantities such as stress, strain, and Young's modulus. Unlike physical campus-based labs which are time-limited, students are able to remotely access this virtual lab anytime, anywhere. Additionally, students might be able to investigate scenarios that are prohibitively expensive or too dangerous in real life (Heradio et al., 2016).

In this second DBR iteration, we proposed that a virtual lab prototype first be developed based on an existing campus-based practical on materials testing. In designing this prototype, the

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specifications were that its interface be kept simple, with students requiring no prior programming experience to operate within it. All aspects of the simulation should be easy to control using simple virtual levers, drop-down boxes, drag-and-drop objects, numerical entry textboxes, or similar elements. Based on these specifications, a functional materials testing virtual lab prototype was developed using MATLAB App Designer and was deployed in ENGR20004 (Figure 3).

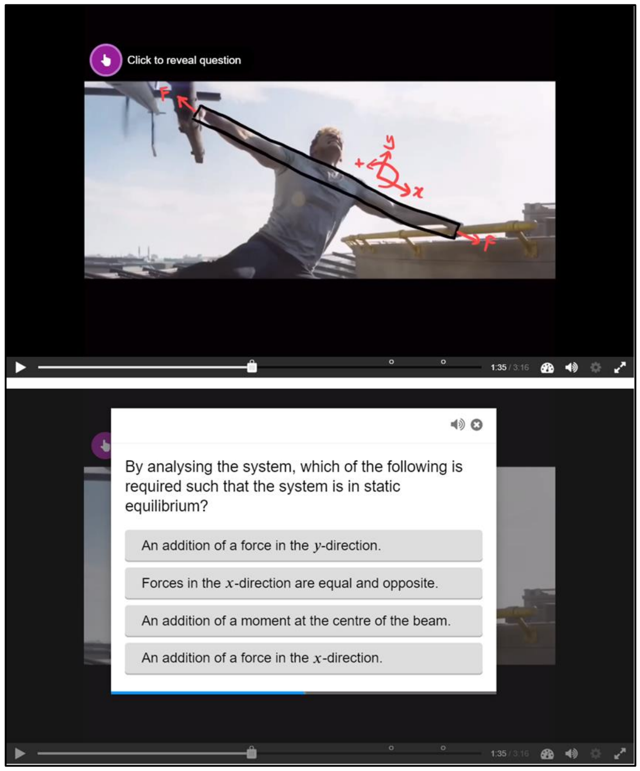

Figure 2: Example of interactive video with embedded questions.

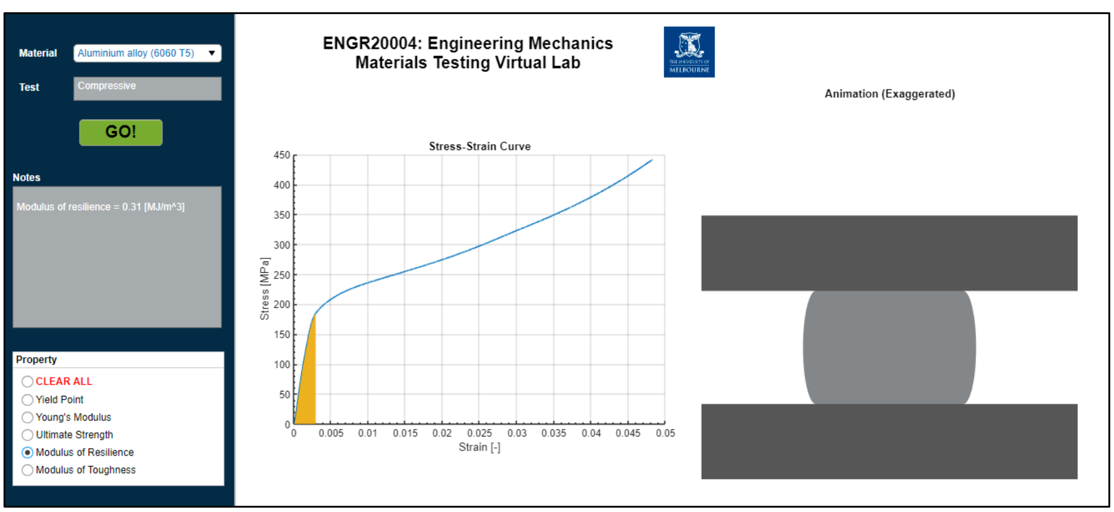

Figure 3: Materials testing virtual lab prototype developed for deployment in ENGR20004.

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Evaluation

To evaluate the resources designed in this second DBR iteration, formal Qualtrics-based student surveys were conducted anonymously within both ENGR20004 and BMEN90021. For both subjects, an opt-out strategy with implied consent was used to gather data from all enrolled students. For ENGR20004, participants scored the following resources (asterisks indicate resources developed as part of this study) on a 5-point Likert scale (1: Did not use, 2: Not helpful, 3: Neither helpful nor unhelpful, 4: Moderately helpful, 5: Extremely helpful):

- Lecture videos with embedded quizzes
- Lecture videos without embedded quizzes*
- Weekly on-campus/online tutorials
- Worked example online lectures
- Concept videos with embedded quizzes*
- Concept videos without embedded quizzes*
- Lecture reading/book references
- Group assignments and laboratories
- Materials testing virtual lab*
- Other

We were particularly interested in comparing how students perceived the helpfulness of similarly formatted content with versus without embedded quizzes (i.e. lecture videos with/without embedded quizzes, and concept videos with/without embedded quizzes). Focusing on content with embedded videos, we were also interested in detecting any differences in student perception of content delivered via lecture videos versus concept videos.

For BMEN90021, participants scored the following resources using an identical 5-point Likert scale (asterisks indicate resources developed as part of this study):

- Lectures
- In-lecture tutorials
- Site visits
- Concept videos with embedded quizzes*
- Workshops
- Workshop reports
- Other

Outcomes & Discussion

Survey results for ENGR20004 are shown in Table 1. Due to low response rates (n=5 for all questions), the results for BMEN90021 have not been reported here. A visual representation of the data for ENGR20004 is provided in Figure 4.

Focusing on ENGR20004, we found that content (both lecture and concept videos) with embedded quizzes was rated as being statistically significantly more useful than content without (Wilcoxon rank sum test: $p<0.001$ for lecture videos, $p=0.006$ for concept videos). For content with embedded quizzes, no statistically significant differences were detected between lecture videos and concept videos ($p=0.4098$). These results suggest that interactive quizzes embedded with H5P are perceived by students as being more helpful in their learning, possibly by promoting engagement and active learning. More data will have to be collected to investigate definitive links between this and student performance.

The survey results indicated that students found the materials testing virtual lab less helpful. This resource had a mean rating of 3.05, considerably lower than that received by the resource “group assignments and laboratories” (3.85). While more detailed student feedback on how to improve this specific resource was not collected here, we propose the following interventions for the next DBR iteration:

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- The materials testing virtual lab was a prototype and served as a proof-of-concept, involving an almost exact simulation of an existing physical laboratory-based activity. As a result, students who had already completed and understood the actual laboratory-based activity might not have found the virtual lab useful for further exploration. Future iterations on this resource should focus on incorporating experimental conditions not feasibly measurable within the physical laboratory, increasing their value.
- Gamification has previously been reported to result in increased student engagement and enhanced learning (Coller and Scott, 2009). Future iterations on this resource should explore the incorporation of more interactive and game-like elements to increase student engagement. These might take the form of accompanying quizzes, or the incorporation of virtual lab resources in design-based activities.

Table 1: Survey results for ENGR20004 resources.

Resource	Did not use (1)	Not helpful (2)	Neither helpful nor unhelpful (3)	Moderately helpful (4)	Extremely helpful (5)	n	Mean	Standard Deviation
Lecture videos with embedded quizzes	1	10	8	16	16	51	3.71	1.16
Lecture videos without embedded quizzes	1	14	15	14	1	45	3	0.89
Weekly on-campus/online tutorials	0	4	7	17	28	56	4.23	0.93
Worked example online lectures	8	8	13	25	25	79	3.65	1.29
Concept videos with embedded quizzes	8	7	10	31	20	76	3.63	1.25
Concept videos without embedded quizzes	9	6	28	23	9	75	3.23	1.14
Lecture reading/book references	10	10	17	23	14	74	3.28	1.29
Group assignments and laboratories	1	10	8	35	20	74	3.85	1.01
Virtual materials testing lab	16	9	20	21	12	78	3.05	1.35
Other	18	3	22	8	4	55	2.58	1.27

The evaluation step in this second DBR iteration has allowed for the usefulness of these technology-enhanced and interactive resources to be quantified. However, evaluation strategies within the next DBR cycle should focus on collecting student feedback on specific ways through which these resources might be improved to aid in their learning. Methods of increasing response rates, particularly for BMEN90021, should also be explored and implemented.

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Lastly, we note the bulk of this technology-enhanced content was developed prior to the ongoing coronavirus pandemic. It was therefore designed to be supplemental in nature, with students completing most of their learning through traditional means such as on-campus lectures. With the rapid shift towards blended (simultaneous on-campus and online) delivery in tertiary education, the lessons learned in developing this content should be harnessed to develop primary teaching and learning materials that are more engaging and effective in such settings.

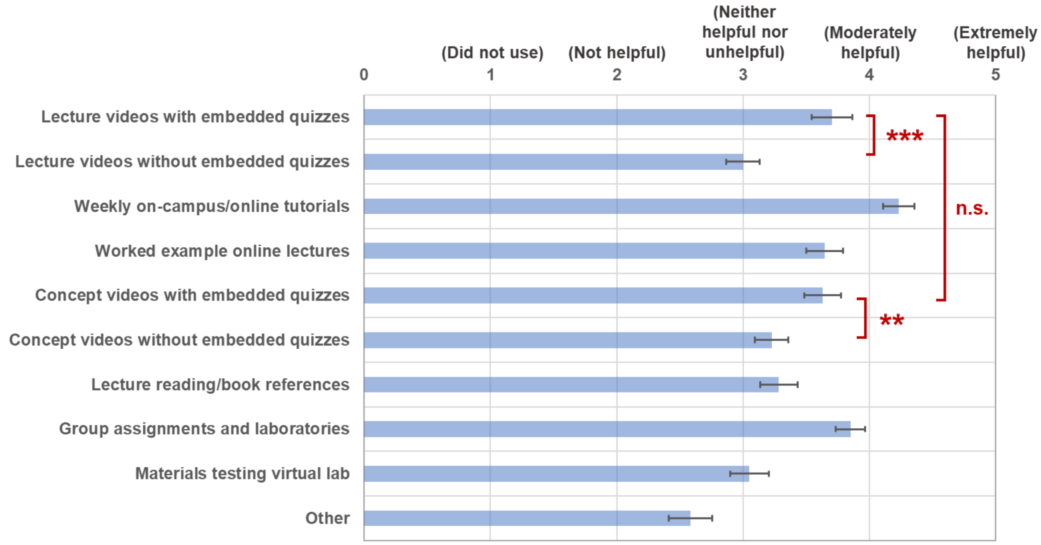

Figure 4: Visualisation of survey results for ENGR20004 resources (: p<0.01, ***: p<0.001, n.s.: not significant)**

Conclusion

A flexible degree structure has resulted our students enrolling in engineering subjects with diverse levels of foundational physics and mathematics knowledge. To address this issue, we applied a design-based research methodology to develop technology-enhanced and interactive content to improve student learning. Two iterations of this approach have been conducted to date, with the main resources developed being concept videos with embedded quizzes and a virtual lab prototype revolving around materials testing. Survey results indicate that students rate videos featuring quizzes embedded with H5P as being helpful in their learning. However, students did not find the current iteration of the virtual lab as useful as existing physical laboratory-based activities. As part of the reflection step of the design-based research cycle, several suggestions were proposed to improve these resources in the next iteration. We also note that these findings might assist in the creation of more effective primary teaching and learning materials in the shift towards blended learning.

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Improving student outcomes through transdisciplinary curriculum design in biomedical engineering

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ABSTRACT

CONTEXT

The boundaries between traditional engineering disciplines are breaking down. It is increasingly important for engineering students to be equipped with the ability to integrate complex concepts across disciplines to tackle real world problems. Biomedical engineering is a discipline that marries concepts from mechanical, electrical, and chemical engineering, as well as computer science to develop technologies that improve human health. Most existing biomedical engineering curricula, however, do not reflect this transdisciplinary integration. These concepts are typically introduced to students in separate subjects with minimal or no cross-curricular references.

PURPOSE OR GOAL

Prior to 2021, the undergraduate Bioengineering Systems Majojr at the University of Melbourne featured a traditional structure with engineering mechanics, electrical engineering, chemical engineering and programming concepts sequestered into separate subjects. This has unintentionally resulted in students over-compartmentalising these concepts: they are often unable to appreciate how the different pieces fit together synergistically to form a coherent whole. To tackle this issue, we launched a curriculum redesign project centred around the student-led collaborative design of a bionic limb. This redesign has allowed us to link four core subjects across the major, covering key concepts in programming and modelling, biomechanics, electronics, and the engineering design process.

APPROACH OR METHODOLOGY/METHODS

A design-based research methodology was applied to form a team consisting of academics, educational technology researchers, and technology designers. We followed a four-stage iterative model involving: (i) initial problem analysis and identification of design principles; (ii) the prototyping of curriculum design solutions; (iii) evaluation and iterative redesign; (iv) and the refinement and sharing of design principles. This led to the design of a prototype bionic limb and associated teaching and learning materials that we have launched in two of our core subjects to date. This paper describes our progress and reflections to date.

ACTUAL OR ANTICIPATED OUTCOMES

While this curriculum design project is still in progress, we envision that it will reduce the degree to which our students tend to compartmentalise taught concepts. We believe that this will improve our students' abilities to recognise and harness the connections – both obvious and not-so-obvious – between different discipline areas, equipping them to push the boundaries of science and technology as more confident, job-ready biomedical engineers.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

We illustrate the application of a design-based research approach in the creation of a transdisciplinary curriculum revolving around the collaborative student-led design of a bionic limb. Progress to date involves interventions in two subjects, with positive student feedback.

KEYWORDS

Transdisciplinary, curriculum design, biomedical engineering, biomechanics, circuits and systems, engineering design, computer programming

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Introduction

The boundaries between traditional engineering disciplines have become increasingly blurred. Modern engineers must be capable of integrating concepts across various disciplines to solve real world problems. This cross-pollination of ideas is evident in biomedical engineering, an engineering discipline that combines concepts from mechanical, electrical, and chemical engineering, as well as computer science to tackle issues related to human health. However, most existing biomedical engineering curricula do not reflect this integration of ideas. Concepts are often introduced to students in separate subjects with minimal or no cross-curricular references. As a result, students tend to over-compartmentalise the knowledge that they have gained (Garnetta et al., 1990). Students find it difficult to recognise and harness connections between those compartments. One possible solution to this is to shift towards curriculum design practices characterised by transdisciplinarity (Ertas et al., 2003).

Here, it is worth differentiating between the related terms multidisciplinarity, interdisciplinarity, and transdisciplinarity. Choi and Pak (2006) have previously described multidisciplinarity as the derivation of knowledge from multiple disciplines while maintaining disciplinary boundaries. Interdisciplinarity, on the other hand, is characterised by the dissolution of those boundaries and the synthesis of links between disciplines to form a more coherent whole. Lastly, transdisciplinarity involves the integration of multiple disciplines in a way that transcends their traditional boundaries (Burnett, 2011; Khoo, Haapakoski, Hellstén, & Malone, 2019). The three terms can all be thought of as states involving multiple disciplines, but to different degrees along the same continuum.

The challenges associated with achieving transdisciplinary curriculum design have previously been reported. For example, Foley (2016) identified the following hurdles in the context of designing a new biotechnology program: the assembly of a committed and flexible team of academics, regular reflections and program reviews, organised management, and sufficient training and/or teaching experience. While challenging, a transdisciplinary approach to curriculum design can help build students' capabilities to properly integrate complex concepts across disciplinary boundaries. This is critical to real world problem solving and devising creative design solutions (Burnett, 2011). This need is particularly so in intersectional disciplines such as biomedical engineering. McKenney and Reeves (2020) argue that Educational Design Research (borrowing heavily from Design-Based Research (DBR) and often used synonymously) provides a pathway to navigate these complexities. Namely, DBR provides a structured approach to transdisciplinary curriculum design (Figure 1) that can be applied to both engineering and medical education research and practice. Designing authentic learning environments is foundational to DBR curriculum design (Herrington, Reeves, & Oliver, 2014; Kartoğlu, Siagian, & Reeves, 2020).

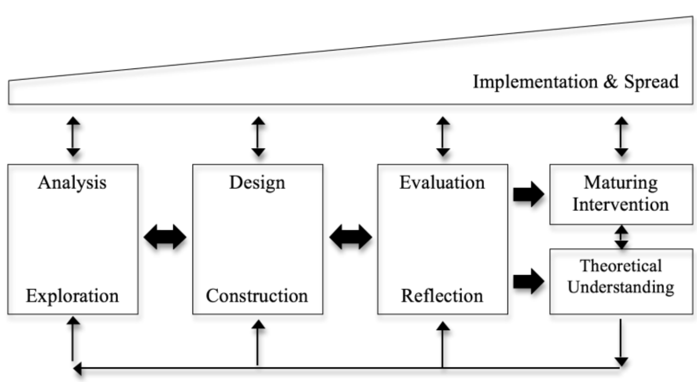

Figure 1: DBR curriculum design, adapted from McKenney and Reeves (2020)

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This paper describes the initiation of a transdisciplinary curriculum design project centred around the design of a bionic limb. A DBR methodology was applied to develop an integrated collaborative project that authentically links four foundations of bioengineering across two years of a degree program: programming and systems modelling, human biomechanics, electronics, and engineering design.

Approach

A DBR methodology was applied to the specific challenge of transdisciplinary curriculum design. The DBR methodology has been defined as one that involves "continuous cycles of design, enactment, analysis, and redesign" (The Design-Based Research Collective, 2003). Each cycle consists of four basic steps or phases: identifying problems or challenges, designing potential solutions, evaluating those solutions, and reflecting on their implementation (Scott, Wenderoth, and Doherty, 2020). Kopcha, Schmidt and McKenney (2015) argue that each phase of DBR produces a story that is valuable to share and reflect upon. Here we describe the identification and design steps of the two DBR cycles that have occurred to date.

DBR Iteration 1

Identification

The importance of incorporating transdisciplinarity in the teaching of biomedical engineering was first identified at the subject-level. Two of the authors were involved in teaching a subject Biomechanical Physics and Computation (BMEN20001). This was an undergraduate-level subject that introduced students to both basic programming as well as fundamental physics concepts from engineering mechanics. Annual feedback via subject evaluation surveys indicated that students found making connections between the two distinct components of the subject challenging. Reflecting on this feedback, we identified three factors that affected the effective transfer of skills and knowledge of programming and mechanics: (i) varying levels of prior exposure to mechanical physics and programming, (ii) a preference in students for the rote-learning of steps or formulae, and (iii) assessment design that was misaligned with transforming student capabilities in using computer programs to perform complex biomechanical analyses (Biggs, 1999).

Design

To address the factors outlined above, the subject curriculum was modified as follows:

(i) Detailed programming tutorial sheets were developed to allow students to practise skills aligned with each of the assessment tasks in the subject. This addressed the varied capabilities in programming amongst our students. We also ring-fenced the mechanical physics content in the lectures and tutorials that were deemed essential and ensured that they were in good balance with the programming content. Specifically, we established a 60/40% weighting in lecture, tutorial and assessment content that reflected the percentage division in mechanics and programming-related intended learning outcomes.

(ii) Assessment weightings and rubrics were altered to increase the integration of the mechanics and programming components and to encourage independent, critical thinking. The mid-semester test and final exam were redesigned to reflect a 60/40% weighting of assessments on mechanics and programming capabilities, respectively. This was essential in signalling to students that mastery of both components was necessary to succeed in the subject. Assessment rubrics for programming tasks were revised from being overly prescriptive to encouraging self-regulated application of programming techniques that were most appropriate for the tasks at hand.

(iii) A final assignment was redesigned around the simulation and animation of a bicep curl (Figure 2). This assignment required students to integrate their understanding of the mechanics governing bicep curl motion and the programming concepts that

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they learned in the subject. Following constructive alignment practices, tutorials and lecture content were modified to incorporate the basic mechanics and programming concepts to achieve the goals of this assignment. Students were then expected to explore, expand, and integrate these concepts as part of their assignment brief, with scaffolding content where necessary.

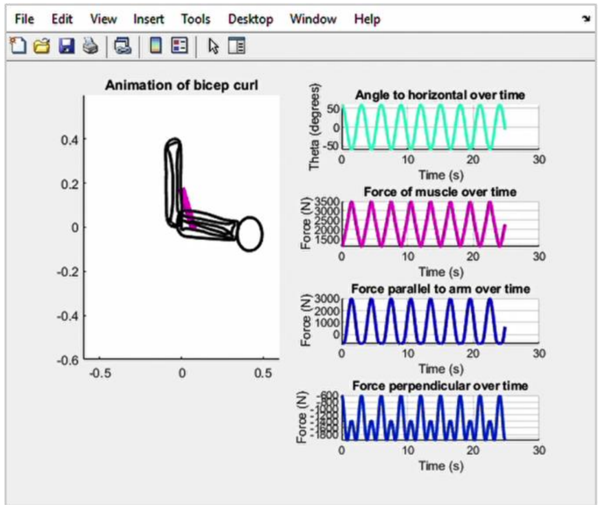

Figure 2: Assignment centred around the simulation and animation of a bicep curl.

Evaluation & Reflection

The progressive implementation of the modifications above resulted in a marked improvement in the student experience, as measured by university-level subject experience surveys. Survey responses to the prompt on whether the subject was well-taught increased from 3.15 in 2017 to 3.94 in 2019 (5-point Likert scale from 1: Strongly disagree to 5: Strongly agree). Student comments received as part of the same surveys indicated a general appreciation for transdisciplinary-aligned modifications; selected statements are included below:

- *"The lectures demonstrated the connection between physics, computation and biomechanics well."*
- *"The physics side was interesting and practical and I found it extremely fun to solve problems then code them up and see them in practice."*
- *"The subject is interesting in the fact that as a student, we are [typically] only taught hard theory, but with this subject we can see that theory applied and how programming is used for physical applications."*
- *"The assignments were interesting and engaging applications of the content."*

Negative comments received reflected inertia in the shift towards more open-ended problem-based learning:

- *"Lecture content rather than just helping us when we were stuck on problems."*
- *"The mid-semester [test] can be more specific on what are the requirements to study and how to prepare [for] it, especially the multiple [choice] questions"*

A course structure overhaul occurring towards the end of this first DBR Iteration provided us with the opportunity to take our learnings in transdisciplinary design from the subject-level to the degree-level, described in the next section.

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DBR Iteration 2

Identification

The pre-2021 undergraduate Bioengineering Systems Major at the University of Melbourne had a traditional structure characterised by the sequestration of concepts into distinct subjects, with minimal or no cross-curricular connections. Much like our subject-level observations in BMEN20001, this led to our students facing challenges in appreciating how different concepts might be combined synergistically to form a coherent whole across the course curriculum. In late 2020, a major course structure overhaul was initiated by the department, providing us with the opportunity to explore curriculum redesign at a larger scale. Expanding our learnings from BMEN20001, we identified the design of authentic transdisciplinary learning environments at the degree-level as the main goal in this second DBR iteration (Herrington, Reeves, & Oliver, 2014; Kartoğlu, Siagian, & Reeves, 2020).

Accompanying this shift in scope from subject-level to degree-level transdisciplinarity, we expanded our design team to include educational technology researchers, technology designers, and other academics involved in the teaching of the following core subjects within the overhauled Bioengineering Systems major (Lam et al., 2021; Rajagopal and Lam, 2021):

- **Applied Computation in Bioengineering (BMEN20003)**: a second-year undergraduate-level subject covering programming and systems modelling concepts
- **Mechanics for Bioengineering (BMEN30010)**: a third-year undergraduate-level subject covering human biomechanics concepts
- **Circuits and Systems (BMEN30006)**: a third-year undergraduate-level subject covering electronics and control systems concepts
- **Biosystems Design (BMEN30008)**: a third-year undergraduate-level integrative capstone-style subject covering engineering design principles

We note that as a result of the course structure overhaul, BMEN20001, the subject of focus in DBR Iteration 1, was split into two new subjects (BMEN20003 and BMEN30010 above). While seemingly contrary to the spirit of trandisciplinarity, the rationale behind this division was to allow for a deeper exploration of programming and biomechanics concepts. In navigating the shift to the new course structure, we ensured that the strong links between programming and mechanics continued by carefully coordinating the sequence of subject content and assessments across the two subjects.

Design

Focused discussions with the design team led to the identification of curriculum design principles informing the design of a collaborative student project integrated across the four subjects above, over two years of the degree. Expanding on the integration of mechanics and programming in BMEN20001 via the computer simulation of a bicep curl, we centred this collaborative student project around the design and construction of a physical bionic limb. Focus areas aligning with each of the four subjects were identified and mapped onto specific sub-systems to be considered in the design of the bionic limb. These, along with accompanying rationale, are summarised in Table 1.

We next considered subject progression order and its implications for staging student exposure to these sub-systems. This was primarily an issue for the non-capstone subjects BMEN20003, BMEN30006, and BMEN30008. In this context, the underlying course sequence meant that our students would encounter programming skills first (in BMEN20003). At this point however, students would not typically have completed BMEN30010 or BMEN30006 and would therefore be unfamiliar with mechanics or electronics concepts. We concluded that the best way forward would be to provide students with a complete functional bionic limb, designing it to allow each subject to focus on a specific sub-system while ignoring the others. This design strategy would allow students to investigate the key features of specific sub-systems, without losing view of how those sub-systems interact and contribute to form a greater functional whole. Upon enrolling into the capstone-style subject BMEN30008, students would finally get the

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opportunity to integrate everything they had previously learned in the construction of their own bionic limbs, or similarly complex projects featuring integrated sub-systems.

Table 1: Alignment of focus areas and relevant sub-systems in bionic limb design.

Subject	Focus Area	Bionic Limb Sub-system	Rationale
BMEN30010	Material design and fabrication, mechanical physics	Overall physical structure of the bionic limb	Mechanics concepts are necessary to understand the forces at play within the bionic limb when it is in motion. This is necessary to identify geometric and material design parameters. The shape and material chosen in the fabrication of the bionic limb must ensure structural integrity during operation.
BMEN30006	Actuation and control of arm motion	Electronics and circuitry	Motors and accompanying electronics and circuitry are necessary to control the motion of the bionic limb. Designing these elements requires an understanding of circuit and control systems analysis.
BMEN20003	User-bionic limb interface, programming and simulation	Conversion and transmission of user-supplied inputs into motion outputs	Instructions to control the arm may be supplied by users via hardware (physical levers, buttons) or software (computer-based inputs). In either case, programming skills are necessary to modulate and transmit these signals to actuator elements and generate desired motion patterns. Programming skills are also necessary to generate models that allow for the prediction of system behaviour and feasibility studies prior to implementation.
BMEN30008	Overarching engineering design and analysis principles	Feasibility studies, safety and risk analysis, assembly	By exploring the previous sub-systems of the bionic limb in isolation, students will gain an appreciation for the necessity of drawing on concepts across disciplines to construct a complete, functional engineering system. This capstone-style subject provides them with the opportunity to independently assemble those sub-systems into a cohesive whole. In the process, students are exposed to key general engineering design principles such as feasibility studies, hazard identification, and risk analysis.

With these considerations in mind, we engaged our technology designers in the actual design and construction of a functional prototype of the bionic limb (Figure 3). There were two intended outcomes of this process. Firstly, it would provide insight into the challenges likely to be faced by students during the design process and therefore identify any areas requiring scaffolding of information. Secondly, it would help inform the design of accompanying, constructively aligned learning activities, as well as the modification of existing ones.

Due to constraints imposed by the university's academic calendar, we have focused on developing and deploying teaching and learning activities for BMEN20003 and BMEN30010 so far, with those for BMEN30006 and BMEN30008 to be addressed in the coming semesters. For the programming focused subject BMEN20003, the bicep curl assignment previously developed in BMEN20001 was adapted for delivery. Because students would not yet be exposed to mechanics concepts at this point, the final mathematical expressions governing the forces at play were provided to students accompanied by explanatory statements foreshadowing the relevant mechanics concepts to be covered in BMEN30010. In the spirit of transdisciplinarity, but not directly related to the bionic limb design project, applications of

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programming in fields other than biomechanics were explored and discussed. These included concepts drawn from electromagnetism, probability and statistics, and systems biology, fields that our students would likely encounter in future subjects. Guest lectures by researchers in these fields were also organised to expose students to the multi-faceted nature of biomedical engineering.

For the mechanics focused subject BMEN30010, teaching and learning activities were modified to assume prior knowledge of programming, encouraging students to recall what they had previously learned in BMEN20003. In addition to this, a series of authentic scaffolded tasks constructed around the material design of the bionic limb (force and moment analysis, stress and strain analysis, materials testing, CAD design) was developed. Two project-based group assignments were established that required students to synthesise concepts of engineering design, mechanics, and computational analysis principles to develop a functional and robust bionic limb.

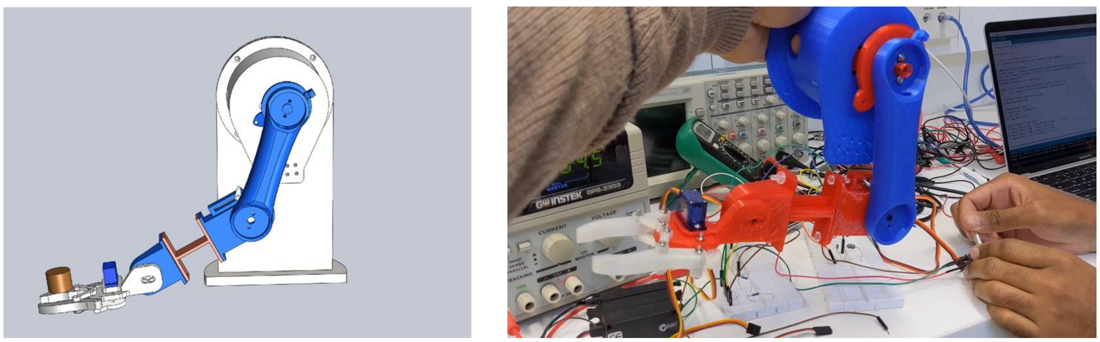

Figure 3: (Left) CAD drawing of bionic limb. (Right) Functioning bionic limb prototype.

Outcomes & Discussion

Preliminary feedback on the interventions introduced as part of the bionic limb project thus far have indicated that students are starting to make connections between the subjects that make up the major.

Within BMEN20003, the bionic limb was featured as an individual assignment adapted from the pre-existing bicep curl assignment designed in BMEN20001. This focused on teaching the core programming concepts of loops and conditional statements by requiring students to program an animation of the bionic limb moving in-sync with traces of the reaction forces at its elbow joint. In deploying this assignment, students were informed that this was a direct virtual simulation of a system that they would be experimenting on and designing in their future subjects: BMEN300010, BMEN30006, and BMEN30008. Subject experience survey feedback indicated that students were motivated and excited by this foreshadowing of future content, and appreciated the efforts made to forge connections with other subjects within the major sequence. Reflecting on this feedback, we might imagine expanding the project to include other bioengineering and biomedical engineering subjects, beyond just the current four.

Within BMEN300010, the two group-based, project-based assignments were focused on: (i) designing a component of the bionic limb to withstand large forces, and (ii) determining the forces during the motion of the bionic limb. Students engaged with the lecture content and tutorial sheets deeply to address the questions within the assignments. Students appreciated the connections being made between the two subjects. We observed students successfully transferring programming skills they gained in BMEN20003 within the two assignments. Within

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the two group-based project assessments we observed students taking ownership of specific tasks based on their strengths and working collectively to synthesise concepts to achieve the final goal.

Together, these preliminary observations suggest that degree-spanning curriculum design and coordination of assessment activities ensures depth of understanding of individual concepts and enables the provision of real-world learning experiences to students that require synthesis of different concepts, teamwork, and creative thinking. We are currently focusing our efforts on developing similar teaching and learning activities for both BMEN30006 and BMEN30008 that will allow students to explore sub-systems of the bionic limb relevant to those subjects in authentic ways. To increase the degree of interconnectedness between the four subjects, it has also been proposed that going forward, a common learner-centric ecology of resources (Luckin, 2008) be introduced to support student collaboration across the subjects. Current plans for this revolve around the student-driven curation of ePortfolios to reflect on their progress and learning as they complete the sequence of four core subjects. This might be supported by technologies and platforms such as PebblePad, GitLab, Microsoft Teams, and Adobe Spark.

Evaluation-wise, there are plans in place to conduct more focused student surveys in future DBR iterations, as opposed to relying on just the regular operational subject experience surveys conducted by the university. In addition to this, feedback from student focus groups will also be incorporated in the evaluation process moving forward.

Conclusion

Reeves and Lin (2020) argue that there is a dearth of examples of implementing DBR for complex real-world curriculum design that go beyond the simple "solutionism" prevalent in educational technology literature (McKenney & Reeves, 2020). The bionic limb project illustrates the application of design-based research to transdisciplinary curriculum design within the context of biomedical engineering. While the project is still in progress, preliminary outcomes indicate that our efforts at incorporating transdisciplinarity in curriculum design are making a positive impact on student learning. We also believe that the specific learnings of this project might be applicable to other courses wanting to reduce the degree to which students tend to compartmentalise key concepts.

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Elevating engineering education via improved pedagogically based course structures.

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ABSTRACT

CONTEXT

In late 2018, the authors commenced a project in their School to improve the quality of student experience and enhance staff teaching within the Moodle LMS. This was motivated by the authors' interest in better meeting organisational strategic goals, related learning and teaching plans, and creating an improved pedagogical platform for their School. At the time, the University had also gone through an academic restructure, meaning that significant re-branding and realignment of disciplines had taken place. This project was timely in addressing these multi-dimensional obligations.

PURPOSE

The overall purpose of this high-level project was to provide course consistency in core structures and improve the educational experience for all students in the school. This consistency was to come primarily through the restructuring and alignment of the user experience, presentation, and provision of resources available to students in each course of study. An additional purpose was to provide a reduction in staff workload through the economic restructuring of resources thereby reducing time in searching for information, and the provision of additional content provided in the template, meant that minimum standards for learning and teaching online were being met at a greater extent. It was anticipated that improved levels of student engagement would also result by virtue of the improved user experience and the ability to individualise the course for each student.

APPROACH

To commence the project, an internal review of all course Moodle (learning management system, or LMS) shells was conducted and benchmarked against set University standards, known colloquially as Blended, Online and Digital Learning and Teaching (BOLD L&T) practices document. Courses were analysed and thematically grouped to identify where the largest gains could be made in the rollout of this work and greatest benefits realised to student and staff experience.

Course priorities were moderated against University requirements and a final template was designed based on a constructivist pedagogy. Early versions of the templates were road tested by academic staff to seek feedback and to implement further template refinements. Rollout of the template commenced in 2019 and continued through 2020.

ACTUAL OUTCOMES

Outcomes include a consistent format that is more easily navigated by staff and students, reducing the time spent searching for information. The format has also reduced the data load on the University and student bandwidth systems by reducing the size of the up and download of each course page. The project implementation had negligible impact on academic staff workloads and occurred with minimal disruption to academic staff time.

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Students and staff have demonstrated their engagement and indicated their enjoyment and preference for the new interface.

SUMMARY

This paper presents a new LMS course template to address several student, staff and strategic requirements. Its core elements and rationale are presented, together with some preliminary statistics on its implementation and use. Some early success stories are used to provide further context.

KEYWORDS

Student experience; improved teaching delivery, aligning teaching practices

Background and Literature Review

The use and reliance on online learning management systems (LMS) for tertiary education has dramatically increased since the beginning of 2020 and the start of the COVID-19 global pandemic. There is a particular focus on the provision of equivalent online learning experiences to students that would otherwise be learning face-to-face, or with blended delivery styles.

For Federation University, Moodle is the current LMS and provides students with access to materials and content that would previously have been printed out in hard copy. As the technology matured over time, expectations of lecturer ability to engage and effectively use the LMS also increased. However, in practice, not all lecturers kept pace (see Venkatesh, et al., 2003) with the requirements of the technology or university expectations for its effective use. This meant that over time, individual courses developed their differences, with some falling significantly behind in the standards expected by students.

In late 2018, the authors' embarked on a project in the School of Engineering, IT and Physical Sciences to improve the quality of student experience and enhance staff teaching within the Moodle LMS. This was motivated by the authors' interest in better meeting organisational strategic goals, related learning and teaching plans, and creating an improved pedagogical structure for their School. At the time, the University had also gone through an academic restructure, meaning that significant re-branding and realignment of disciplines had taken place. This project was timely in addressing these multi-dimensional obligations.

The overall purpose of this project was to provide consistency across courses in appearance and structure and to improve the educational experience for all students in the school. This consistency was to come primarily through the restructuring and alignment of the user experience (Demir, et al., 2021; Khan, et al., 2021), presentation, and provision of resources available to students in each course of study (Santelli, et al., 2020). An additional purpose was to provide a reduction in staff workload through the economic restructuring of resources and inclusion of specific technologies. Research into learning design or learner centred design has tended not to directly address the workload impacts on staff. Khan, et al., (2021) and Ji, et al., (2020) are examples of having a singular focus without recognising the impact on other areas. Reducing time in searching for information, and the provision of additional content provided in the template, meant that minimum standards for learning and teaching online were being met to a greater extent. It was anticipated that improved levels of student engagement would also result by virtue of the improved user experience and the ability to individualise the course for each student.

This paper describes the key features of a contemporary LMS Moodle shell template and provides some preliminary information around the success of its roll out and subsequent use by students and staff.

Implementation

To commence the project, an internal review of all course Moodle (learning management system, or LMS) shells was conducted and benchmarked against set University standards, known colloquially as **B**lended, **O**n**L**ine and **D**igital Learning and Teaching (or **BOLD** L&T) practices document. Courses were analysed and thematically grouped to identify where the largest gains could be made in the rollout of this work and greatest benefits realised to student and staff experience.

Course priorities were moderated against university requirements and a final template was designed based on a constructivist pedagogy. Early versions of the templates were road tested by academic staff to seek feedback and to implement further template refinements. Rollout of the template commenced in 2019 and continued through 2020.

Sequentially, the approach taken was as follows:

Step 1: Establishment of working group between the Associate Dean of Teaching Quality and Learning Designer.

Step 2: Review of the School's online teaching presence against the BOLD L&T guidance documents to identify key issues; collate the issues; and present the case for change to the School leadership.

Step 3: Creation of the new Moodle shells by Learning and Teaching technology support team, including both a Master Template for the School and Master shells for each course to be taught.

Step 4: Collection and analysis of feedback on the first iteration of Moodle shell from a range of university stakeholders, including students, and staff within both academic and professional portfolios.

Step 5: In response to feedback received, changes and updates were made to the Moodle template, in collaboration with the Digital Production team to enhance the use and arrangement of images and graphics.

Step 6: Trialling of the updated template in selected Information Technology and Engineering courses, and collection and analysis of feedback from staff and students involved in those courses.

Step 7: Implementation of final revisions to the Moodle Master Template in response to feedback received.

Step 8: Communications to teaching staff about the finalised Moodle template, roll out schedule across the School, opportunities for training in the new Moodle shell environment and ongoing collection of feedback from staff for continual improvement.

Results

The new Moodle template has several design features to bring the improved consistency and experience intended. These included the incorporation and interweaving of activity completion settings, course structure, teaching team and progress bars. The subsequent sections explain this further.

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Activity Completion

Activity completion reports display the student completion of selected activities within each Moodle shell. These reports can be downloaded into a spreadsheet format for further analysis if needed. The lecturer pre-configures and tailors the selected activities for each Moodle shell.

Figure 4 shows an example activity completion report.

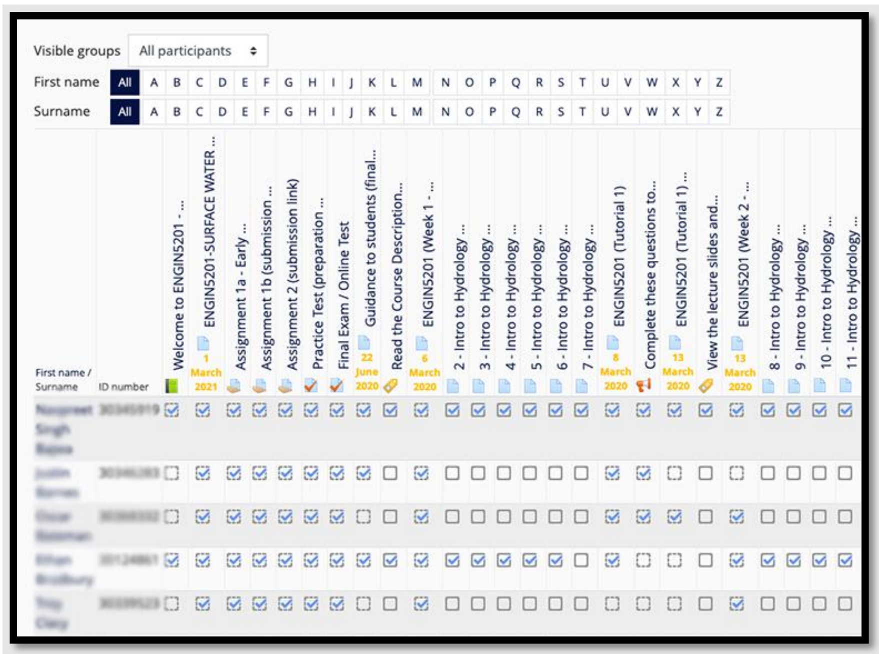

Figure 4: Example activity completion report.

Progress Bars

Progress bars are designed to enable the tracking student progress on chosen tasks or activities and gives the lecturer the opportunity to monitor the overall student completion of the course.

Figure 5 presents an example of the completion progress interface. Figure 6 presents a different version of the same graphical interface, with a focus on assessment progress only. Figure 7 displays the information on the overall cohort when the “overview of students” button is clicked, of the completion of the activities that being tracked.

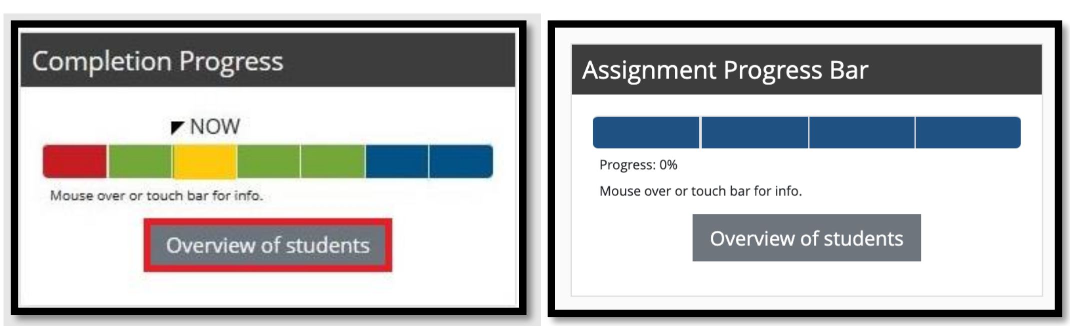

Figure 5: Examples of progress bar. *(Image supplied by Learning Technologies Hub of Federation.)*

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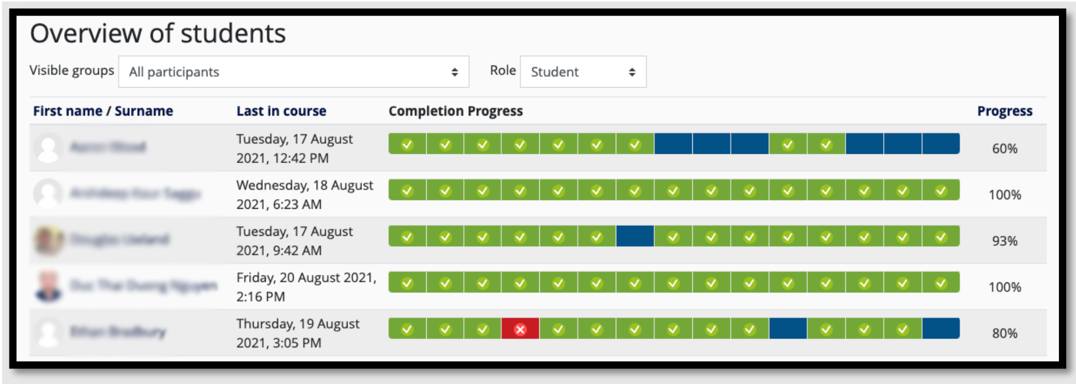

Figure 6: Progress of entire course cohort for selected activities.

Course Structure

Consistent course structures and navigation were made a deliberate feature within the Moodle shell template. Those features included a School banner, two discussion forums and an optional link to a virtual classroom. Additional features included a course information section, followed by an assessment section and then the course topics and materials that can be tailored to suit the course and particular curriculum required.

Figures 8 and 9 shows examples for how each of the courses were structured.

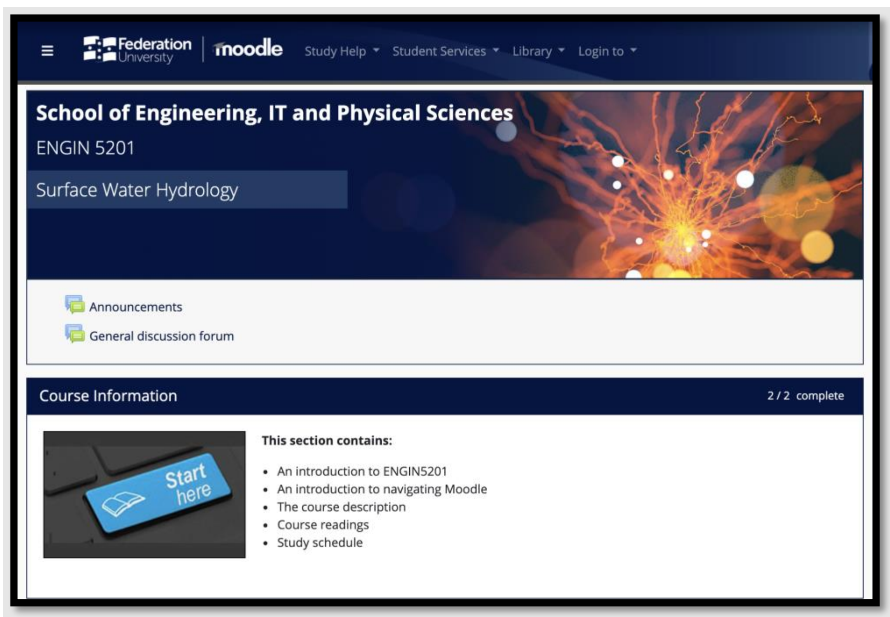

Figure 8: Example of course structure: landing page.

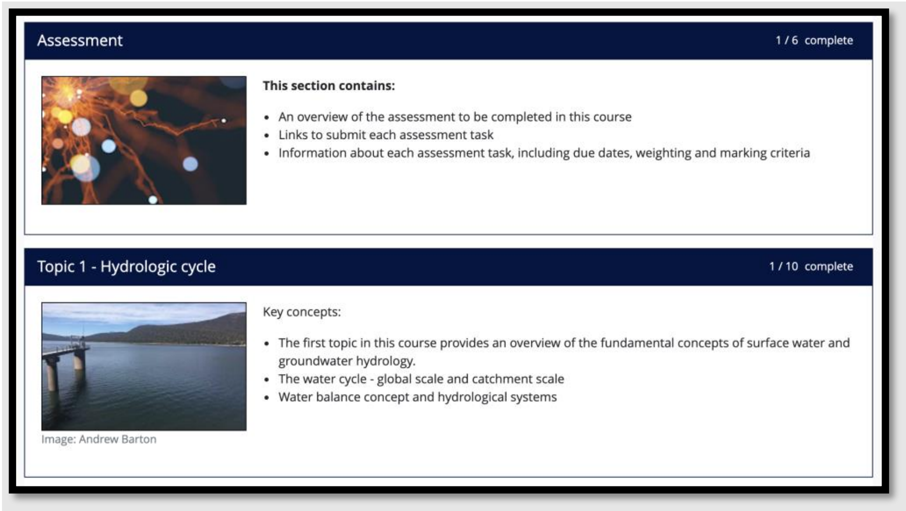

Figure 9: Example of course structure: assessment and content pages.

Teaching team and integration of progress bars

Teaching team information was made available with lecturer information coded in from their professional profiles. The progress bars described above were integrated into the design underneath the teaching team information block for the convenient monitoring or tracking of assessments or course materials.

Figure 10 shows the information relating to the teaching team information and a sample of the progress bar tracking assignment submissions.

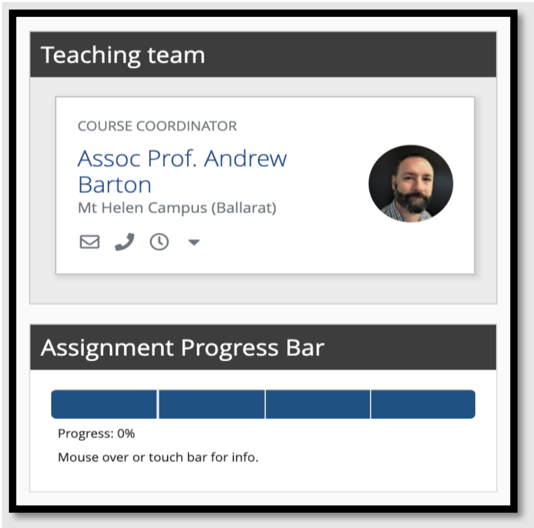

Figure 10: Teaching team block with integrated progress bar.

Discussion

Activity completion report

Activity completion report displays the completion of the activities that have been set up with activity completion settings. This is a two-step process which requires the initial decision of what the student is required to do to 'complete' the activity, for example, in a discussion forum a student might be required to create or respond to a post. This can be manually

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marked off by the student, or for more critical activities, it can be automatically marked as complete when the student has made the required actions. The data shown is for the whole course and for the whole cohort. It can be filtered by name and downloaded into a spreadsheet. It is difficult to view the information at a glance, however, the students can view their own information by scrolling down their course or making more than 12 mouse clicks.

Progress Bars

Progress bars, or completion progress blocks as they are also known, are used to view the progress of students within specific activities and tasks inside the course. This involves a three-step process to set up and integrates the activity completion settings. The benefits of the initial once-off workload are shown by the ease of information at a glance for the lecturer with only one mouse click to view the entire class. The student can also monitor their own progress using this technique. As with the activity completion report, the decision of what the student is required to achieve to complete the activity is chosen, then it can be manually marked by the student or automatically checked off subject to the student's actions. The final process is the create the completion progress bar and allocate the items that are essential to be tracked. Common items to track are assessment submissions and critical course content throughout the semester. Figure 5 displays different colours which indicate which tasks are overdue (red), which tasks are completed (green) and which tasks are submitted but not yet graded (yellow). This allows the lecturer to see which students might need to be contacted for extra support or guidance and provides greater student engagement as there is a clear visual guide of where the students are up to within the course and what is required for them to progress further.

Teaching team block

Always present at the top of the course in the right-hand side is the teaching team block. This block pulls the information from the lecturer's profile and is based on how the lecturer is enrolled. If a lecturer is enrolled into the course as a course coordinator, their information immediately changes position to the top of the block, every other lecturer in that block is placed in alphabetical order. This provides a very easy way for students to contact their lecturer or course coordinator and know the appropriate times and methods of contacting that person. A feature of this block is when students click on their lecturer's email address, it automatically opens their email with the inclusion of the course code in the subject line. This saves the student time and provides clarity for the lecturer on which course the student is enquiring about. An important part of this teaching team block is ensuring that the lecturers maintain the currency of their profile information.

Course Structure

Consistent course structures and layout within the School has proven to be the most impactful factor for students, academics and professional staff alike. Students navigating through multiple courses have a common expectation and familiarity of where to locate critical information like course descriptions, assessments, course readings, learning materials and activities. Initial informal student feedback to staff, such as, "*Wow, what did you guys do to Moodle?*", suggests a positive attitude and response to the new course structure. Academic staff have reported that they enjoy working in a course structure that is "*simple, beautiful and elegant"* and that it "*attracts the students to it*" with the design of the structure "*[enhancing] the efficiency of teaching and learning*" within the course. Professional staff that are required to import information or review documents can easily access the correct area by knowing in advance where to find the information or area that they seek without having to go searching for it, saving time and increasing efficiency.

The first section displays only the course name and School header with two discussion forums (one for important announcements and the other for general discussions) and the option for a link to a virtual classroom. This limited information keeps this area streamlined and reduces the download and upload impacts on the university and the student as this header is loaded every single time another page in the course is clicked on.

The second section is the course information area that contains the welcome book for students, the course description, a course readings link, other relevant whole course information and a discussion forum that is designed to be used to introduce everyone to the cohort. This introductory discussion forum can also be used to find out information about the students, their backgrounds and their goals, which can be then built on and tied into the course activities by the lecturer throughout the semester. This is a key feature of the constructivist pedagogy on which these courses are based.

The third section contains all the information related to assessment. Instructions to students, exemplars, support materials and submission portals.

The fourth and subsequent sections contains the course materials, activities and information. This is designed with a constructivist pedagogical model that suits the course or program objectives, as learning is built on throughout the semester. Other complimentary pedagogical styles such as cased-based learning, flipped classroom approach, project-based learning can also be implemented depending on the needs of the course or program.

Conclusion

The contemporary course template described in this paper has softened the impact of COVID-19, as the improved functionality has helped with lecturer online presence and benefitted the increased online activity for both staff and students.

The combination of a clear, consistent course structure, precise lecturer information with easily accessible student progress and engagement statistics for lecturers and students provides quick navigation to essential information and has lowered the bandwidth demands for the University and the individual users.

Initial analytics obtained from the template use, particularly through reduced number of mouse clicks, indicate a reduction in workload for the staff member in administering the course, however, this information is still preliminary with further evidence being collected.

The template described in this paper has generated much positivity amongst staff and students within the school and has set a new standard within the University. Further improvements are highly anticipated with the constructivist pedagogically aligned template now being considered to be rolled out across the University.

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Exploring Engineering Students' Learning Styles vis-a-vis Students' Demographics

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ABSTRACT

CONTEXT

Learning style plays an active role in engineering pedagogy that frame the strategies in which leaners generally get, retain, and retrieve information. It assists students to increase their cognitive capacity and to deal with the learning difficulties which successively improves their academic performance (Mohamad, Mei Hong, & Tze Kiong, 2014). Every learner has different learning style preference depending on their multicultural and pluralistic background.

PURPOSE OR GOAL

This study aims to identify the learning styles and socio-demographic profile of Engineering students. Specifically, it aims to describe the socio-demographic profile of the participants and establish its relationship to learning styles. Finally, it tests if there is a significant difference on the participants' learning styles when they are grouped according to learning styles and socio-demographic profile.

APPROACH OR METHODOLOGY/METHODS

This study employs the quantitative research design. Descriptive research will be adopted since the study aims to describe participants' learning styles and socio-demographic profile. Two survey instruments (i.e., standardized and researcher-made instrument) will be used to gather the data.

ACTUAL OR ANTICIPATED OUTCOMES

Results of the study will provide the following information: participants' socio-demographic profile learning styles. Likewise, it will establish if there is a significant difference on the participants' learning styles when they are grouped according to their socio-demographic profile and learning styles.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Determining learners' preferred learning styles may support to increase the quality of teaching and learning. Engineering educators may need to reform their teaching styles based on students' learning styles so that better academic performance can be achieved. Misalignment learning and teaching styles causes serious concern and can be detrimental to students' achievement.

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KEYWORDS

learning styles, learning challenges, socio-demographic profile

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Exploring Engineering Students' Learning Styles vis-a-vis Students' Demographics

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1.Introduction

Individual difference is a universal, timeless and encompassing concept. In education, for instance, learners have different ways of obtaining, processing and transforming information. As a catchall concept to describe such differences among learners, learning styles frame the strategies in which leaners generally get, retain, and retrieve information. It assists students to increase their cognitive capacity and to deal with the learning difficulties which successively improves their academic performance (Mohamad et al., 2014). Sadler-Smith's (1996 in Tulsi et al., 2016) onion model distinguished learning styles from learning preferences and learning strategies. For him, learning styles are relatively more stable compared to the two that are influenced more by the environment.

Scholars (e.g., Cross, 1976; Kolb, 1984; Gregore & Ward, 1977) have provided definitions of learning styles (Tulsi et al., 2016). For Cross (1976), it is how individuals collect, organize and transfer information into useful knowledge. Meanwhile, Gregore and Ward (1977) gave operational definition of the term as characteristic set of individuals' behaviors, which describe how their minds connect to the world and therefore, how they learn. For Kolb (1984), it is the preferred strategy that learners deal with given information and how they construct meaning out of stimuli. He further classified learning styles into convergers, divergers, assimilators and accommodators.

The converger learning style combines abstract conceptualization and active experimentation to test theories into practice. Convergers like to work themselves, solve problems and find practical solution. Diverger refers to a combination of concrete experience and reflective observation, and then considers specific experiences from different perspectives. Divergers see things form multiple perspectives, are open-minded and prefer to work with people. Likewise, they are interested in people and good at generating ideas. Assimilator learning style is characterized by abstract conceptualization and reflective observation. They prefer to think than to act and are good at development of theoretical frameworks. Accommodator learning styles combines concrete experiences and active experimentation and uses the results of individual testing as a basis for new learning. Accommodators learn by actively engaging with the world and actually doing things. They have strong preference for doing, are risk takers and tend to solve problems based on their own information (Kolb, 1984; Tulsi et al., 2016; Too, 2009). Recently, Kolb (2005) mentioned that there is no such thing as constant learning style for it learning happens on a continuum ranging from concrete to abstract or from reflective observation to active experimentation.

More recent scholars (i.e., Honey & Mumford, 2000; Felder & Silverman, 1988) re-classified learning styles: reflectors for divergers, theorist for assimilators, pragmatist for convergers and activitist for accommodators. Reflectors prefer to learn from activities that enable them to watch, ponder, and revisit what has transpired. Theorists prefer to approach problems through step-by-step manner. Pragmatists apply new learning to apply learning to see if they work. Activists prefer challenges of new experiences, involvement with others, assimilation and role playing (Honey & Mumford, 2000). Meanwhile, Felder and Silverman's (1988) reclassification originated in the engineering sciences that includes individual's liking along five bipolar continua: active-reflective, sensing-intuitive, visual-verbal, sequential-global, and intuitive-deductive. Hawk and Shah (2007 in Heenaye, 2012) identified the characteristics of Felder and Silverman's learning styles. Active learners prefer doing thing particularly in groups, while reflective learners work better on their own with time to think about the task

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before doing it. Sensing learners like facts, data and experimentation and work well with detail, while intuitive learners prefer ideas and theories specifically when they can grasp new ideas and innovation. Verbal learners like to hear their information and engage in discussion specifically when they can speak and hear their own words, while visual learners prefer words, pictures, symbols, flow charts, diagram and reading books. Finally, sequential learners prefer linear reasoning, systematic procedures, and material that came to them in a steady stream, while global learners are strong integrators and synthesizers, making intuitive discoveries and connections to see the whole system or pattern.

Engineering students are typecast as being inquisitive, having strong analytical skills, drawing attention to detail, mathematically oriented with excellent problem-solving abilities as well as strong communication skills and a significant contributor to team effort and competent technical player (Itcenbas & Eryilmaz, 2011). To develop quality engineers, a closer look at engineering education is necessary.

Though there are several studies that looked into the learning styles particularly among engineering students, the present study remains timely and relevant since determining learners' preferred learning styles and learning challenges may support to increase the quality of teaching and learning. As Felder and Brent (2005) emphasized, the more thoroughly educators explore and comprehend the difference, the better chance they have of addressing diverse learning needs of all of their students. Hence, the present study aims to determine the learning styles of engineering students. It also aims to determine if there is significant difference on learning styles when participants are grouped according to their demographic profile. Further, it aims to establish significant relationship between learning styles and selected demographic profile of the participants.

Research Questions:

The study aims to identify the learning styles of engineering students. Specifically, it aims to answer the following research questions:

1. How can the respondents' learning styles be categorized in terms of active-reflective, sensing-intuitive, visual-verbal, and sequential-global?
2. Is there a significant difference on respondents' learning styles when they are grouped based on gender, civil status, type of student and degree?
3. Is there a significant relationship among respondents' learning styles and their selected demographic profiles?

2. METHODOLOGY

Research Design

The present study is quantitative in nature. The study specifically employed the descriptive, predictive, inferential and non-experimental research design. Descriptive research was used since the study aims to describe the participants' socio-demographic profile and learning styles. Likewise, it involved description, analysis and interpretation of conditions that exist between socio-demographic profile and learning styles. Lastly, the study is non-experimental since no variable manipulation and establishment of neither a control nor experimental group was done (dela Rama et al., 2020; Torres & Alieto, 2019a; Torres & Alieto, 2019b; Robles & Torres, 2020; Cabangcala, 2021; Torres, 2010/2014).

Setting and Participants

The study was conducted in Southern Institute of Technology in Invercargill, New Zealand. Twenty-two engineering students pursuing Bachelor of Engineering Technology (Civil and Mechanical) and Graduate Diploma in Engineering Technology (Civil and Mechanical) participated in the study.

Research Instruments

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To obtain the data needed for this study, a standardized instrument (i.e., Inventory of Learning Styles by Felder and Soloman, 1993) and researcher-made instrument were used.

Much pedagogical research has underscored the concept of learning styles that resulted in a number of measures use to quantify it. These include Kolb's 4-stage cyclic structure, Learning Style Inventory Instrument (LSI), Learning Style Questionnaire (LSQ), Canfield Learning Style Inventory (CLSI), Learning Style Type Indicator (LSTI) and Cognitive Styles Analysis (CSA) (Romanelli et al., 2009).

The ILS consists of four complementary types (i.e., active-reflective, sensing-intuitive, visual-verbal, sequential-global) to address how information is perceived and processed (Felder & Silverman, 1988; Felder, 1993/1996). It has 44 questions that do not have cultural dependency and are chosen maintaining simplicity for responding in mind. The questionnaire can assess the four aspects of learning (i.e., processing aspect, Active-Reflective; perception aspect, Sensory-Intuitive; input aspect, Visual-Verbal; and understanding aspect, Sequential-Global). Its reliability and reliability has been examined and explained in a number of studies (e.g., Zwanenberg & Wilkinso, 2000; Felder & Spurlin, 2005). The instrument was developed and validated by Richard M. Felder and Barbara A. Soloman. Users answer 44 a-b questions and submit the survey, and their four preferences are reported back to them immediately to be copied or printed out. The results are not stored: when the report window is closed, the results are irretrievably lost. It has been widely used for demonstrating a tendency of a dominant learning style preference within a particular group of learners. Zywno (2003) concurs ILS construct validity by showing no significant difference between consecutive years of ILS scores collected from a consecutive cohort of engineering students and with reference to other studies (e.g., Zwanenberg & Wilkinso, 2000) of engineering learning styles showing similar overall style distribution. In addition, Zywno (2003) contends that ILS discriminant validity is supported by a number of studies (e.g., Montgomery & Groat, 1999; Nulty & Barret, 1996) highlighting significant differences in scores for populations with different characteristics.

Data Gathering Procedure

Prior to data collection, the researcher first accomplished the needed forms for ethical considerations. After having secured approval from the institute's ethics committee, data gathering commenced.

The first step was to identify study participants. After they have been identified, an orientation was given to them as regards the extent of their participation in the study. They were informed that they were not entitled to any remuneration or reward due to their voluntary participation. The moment they were familiarized on the context and extend of their participation, participants were requested to sign the consent to voluntarily participate in the study. The participants were then instructed to take the online survey of Felder and Soloman's (1993) ILS. After the participants completed the online survey, they received the results of their learning styles and an explanation of what the results mean.

Data Analysis

For the quantitative part, the study employed descriptive statistics such as frequency, percentage, mean, and standard deviation to analyze data for the participants' socio-demographic profile and learning styles. To establish if there is significant difference on the participants' learning styles when grouped according to their demographic profiles, independent samples t-test was used. In determining the relationship among variables, Chi-square was used.

3. RESULTS AND DISCUSSION

Respondents' Demographics

Twenty-two (19 males, 3 females) engineering students participated in the study. Their ages range from 16 to 36 years old. Nearly-half (9 or 36.30%) were above 36 years old, more than one-fourth (6 or 27.30%) were 26 to 30 years old and the remaining were 21 to 25 (4 or 18.20%), 31 to 35 (3 or 13.60%) and 16 to 20 (1 or 4.50%) years old. Majority (15 or 68.10%) were single and the remaining (7 or 31.80%) were married. In terms of type of students, almost all (18 or 81.80%) were classified as international students and the rest (4 or 18.20%) were domestic students. As regards the degree programs the students were taking, more than one-fourth (7 or 31.80%) enrolled in Bachelor of Engineering Technology (Mechanical). Likewise, more than one-fourth (7 or 31.80%) enrolled in Graduate Diploma in Engineering Technology (Mechanical, 7 or 31.80%; Civil, 6 or 27.30%) and 2 or 9.10% enrolled in Bachelor of Engineering Technology (Civil). In terms of the participants' perceived level of preparation to pursue degree in engineering, majority (14 or 63.60%) reported that they were prepared, 6 or 27.30% mentioned they were moderately prepared and only 2 or 9.10% perceived themselves highly prepared. For their grades in Engineering Mathematics, more than half had grades of B (6 or 27.20%), A+ (4 or 18.20%) and A (4 or 18.20%). The remaining obtained grades of B+ (3 or 13.60%), C+ (1 or 4.50%), C (1 or 4.50%) and E (1 or 4.50%).

Respondents' Learning Styles

Presented in Table 1 is the summary of the respondents' learning styles. Data show that in general, there are more respondents who reported having well-balanced preference in Active-Reflective (13 or 59.10%), Sensing-Intuitive (11 or 50%), Visual-Verbal (8 or 36.40%) and Sequential-Global (15 or 68.20%). This supports the findings of Fang et al. (2017) that students have well-balanced preference for all learning style dimension. It could also be noted that none from among the participants have strong preference for verbal and global.

A closer look at the results reveals that for Active-Reflective, the remaining respondents (9 or 40.8%) reported moderate preference for active (4 or 18.20%) and reflective (3 or 13.60%), and strong preference for active (1 or 4.50%) and reflective (1 or 4.50%). Meanwhile, for Sensing-Intuitive, the rest of the respondents said that they have moderate preference for sensing (7 or 31.80%) and intuitive (2 or 9.10%) and only one for each dimension mentioned having strong preference for sensing and intuitive. For Visual-Verbal, there are more respondents with moderate preference for visual (7 or 31.80%) compared to those with moderate preference for verbal (2 or 9.10%). The same was noted in terms on the strong preference for visual, in which there were more respondents who reported strong preference for visual (5 or 22.70%) and none reported strong preference for verbal. This also concurs with the findings of Fang et al. (2017) that there are more engineering students who prefer visual learning style over verbal learning styles. Finally, for Sequential-Global, the remaining respondents reported having moderate preference for global (2 or 9.10%) and sequential (2 or 9.10%), and with regard to strong preference in both dimensions, none reported having strong preference for global while 2(9.10%) said having strong preference for sequential.

Table 1: Summary of the Respondents' Learning Styles

Learning Styles	f n=22	%
Active-Reflective		
Strong Preference for Active	1	4.50%
Moderate Preference for Active	4	18.20%
Well-balanced Preference for Active-Reflective	13	59.10%
Moderate Preference for Reflective	3	13.60%
Strong Preference for Reflective	1	4.50%
Sensing-Intuitive		
Strong Preference for Sensing	1	4.50%

Moderate Preference for Sensing	7	31.80%
Well-balanced Preference for Sensing-Intuitive	11	50.00%
Moderate Preference for Intuitive	2	9.10%
Strong Preference for Intuitive	1	4.50%
Visual-Verbal		
Strong Preference for Visual	5	22.70%
Moderate Preference for Visual	7	31.80%
Well-balanced Preference for Visual-Verbal	8	36.40%
Moderate Preference for Verbal	2	9.10%
Strong Preference for Verbal	-	-
Sequential-Global		
Strong Preference for Sequential	2	9.10%
Moderate Preference for Sequential	2	9.10%
Well-balanced Preference for Sequential-Global	15	68.20%
Moderate Preference for Global	3	13.60%
Strong Preference for Global	-	-

Difference on Respondents' Learning Styles vis-a-vis Demographic Profiles

Results of independent samples t-test to determine the difference on respondents' learning styles when grouped based on their demographic profiles such as gender, civil status, type and degree are summarized in Table 2. Of all the variables, only the respondents' gender established significant difference on their learning styles specifically on the visual-verbal dimension. In this dimension, female respondents obtained higher mean score than the male respondents. This implies that female respondents were more verbal than their male counterparts, who were more visual.

Meanwhile, there is no significant difference on respondents' learning styles when they are grouped based on civil status, type of students, and degree programs. The foregoing result particularly on the no difference on respondents' learning styles when grouped based on their degree programs does not support the findings of Kuri and Truzzi (2002 in Kamal & Radhakrishnan, 2019) that there is a difference on learning styles preference among the mechanical engineering, civil engineering, electrical engineering, and industrial engineering students. Likewise, it does not concur with the findings of Tulsi et al. (2016) that there exist differences in learning styles of students pursuing master's degree in computer science and engineering, civil engineering, electrical engineering, electronics and communication engineering and mechanical engineering.

Table 2: Results of Independent Samples T-test for Difference on Respondents' Learning Styles vis-à-vis Demographic Profiles

Learning Styles	Socio-Demographic Profiles	N	Mean	Std. Deviation	p-value Sig. (2-tailed)
	Gender				
Active-Reflective	*Male*	19	2.89	0.875	0.416
	Female	3	3.33	0.577	

Sensing-Intuitive	*Male*	19	2.79	0.918	0.826
	Female	3	2.67	0.577	
Visual-Verbal	*Male*	19	2.16b	0.898	0.042*
	Female	3	3.33a	0.577	
Sequential-Global	*Male*	19	2.95	0.705	0.209
	Female	3	2.33	1.155	
	Civil Status				
Active-Reflective	*Single*	14	2.79	0.579	0.222
	Married	7	3.29	1.254	
Sensing-Intuitive	*Single*	14	2.71	0.726	0.494
	Married	7	3.00	1.155	
Visual-Verbal	*Single*	14	2.36	0.842	0.872
	Married	7	2.43	1.134	
Sequential-Global	*Single*	14	2.71	0.914	0.253
	Married	7	3.14	0.378	
	Type of Student				
Active-Reflective	*International*	18	2.94	0.802	0.909
	Domestic	4	3.00	1.155	
Sensing-Intuitive	*International*	18	2.72	0.895	0.576
	Domestic	4	3.00	0.816	
Visual-Verbal	*International*	18	2.28	0.895	0.681
	Domestic	4	2.50	1.291	
Sequential-Global	*International*	18	2.83	0.786	0.707
	Domestic	4	3.00	0.816	
	Degree				
Active-Reflective	*Civil*	8	3	0.926	0.854
	Mechanical	14	2.93	0.829	
Sensing-Intuitive	*Civil*	8	3.13	1.246	0.155
	Mechanical	14	2.57	0.514	
Visual-Verbal	*Civil*	8	2.38	1.061	0.837
	Mechanical	14	2.29	0.914	
Sequential-Global	*Civil*	8	3.13	0.354	0.151
	Mechanical	14	2.71	0.914	

*p value significant at 0.05

Correlation among variables

To determine if there is significant relationship among variables such as learning styles, grades in engineering mathematics, and the perceived level of preparedness to pursue degree in engineering, Spearman rank correlation was used. The results are presented in Table 3. As reflected in the Table, none from participants' demographics established significant relationship with any of the four dimensions of learning styles. Meanwhile, among the four dimensions, two (i.e. Active-Reflective, Sequential-Global) established significant relationship between each other. This means that the higher their preference to Active-Reflective, the same goes with their level of preference for Sequential-Global. The relationship between the two dimensions may be based on the idea that both dimensions have to do on how a learner approaches a specific learning task. For instance, while active learners tend to retain and understand information best by doing something active with it, and reflective learning prefer to think about it quietly first, the sequential learners tend to gain understanding in linear steps, and the global learners tend to learn in large jumps, absorbing material almost randomly without seeing connections and then suddenly getting it.

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Table 3: Results of Spearman Rank Correlation for relationship among variables

Demographic Variables and Learning Styles	Active-Reflective	Sensing-Intuitive	Visual-Verbal	Sequential-Global
Grade in Engineering Mathematics	.149	.688	.121	.235
Perceived Level of Preparedness to pursue degree in engineering	.14	.542	.098	.578
Active-Reflective		.534	.926	.029*
Sensing-Intuitive	.534		.629	.136
Visual-Verbal	.926	.629		.306
Sequential-Global	.029*	.136	.306	

*Correlation is significant at 0.05 level (2-tailed)

4. CONCLUSION

Every learner has different learning style preference depending on their multicultural and pluralistic background. Determining learners' preferred learning styles may support to increase the quality of teaching and learning. Engineering educators may need to reform their teaching styles based on students' learning styles so that better academic performance can be achieved. Misalignment learning and teaching styles causes serious concern and can be detrimental to students' achievement.

Engineering education needs to be more responsive to future needs and more appealing to a wider, more diverse group of students. Hence, as part of their efforts to enhance the teaching and learning in engineering, engineering educators underscore learning style theories in their respective instruction. For instance, institutions of higher learning may consider gender differences in learning styles and challenges into consideration, especially in classrooms which still utilize traditional teaching methods. Engineering educators may also explore the possibility of adopting a multi-disciplinary approach to teaching by incorporating real-life application and practical examples that begin on student interest and hold relevance to the topics being discussed in class.

The recent findings also highlight the recommendation of Fang et al. (2017) that encouraged tutors to tailor their instructional and learning materials based on a balanced approach that cater for both sides of each of the four dimensions, to address for more than one of the learning style preferences. This is to attend to learners who have a balanced preference learning style. However, due to small sampling involved in the current study, it is suggested that the current findings be treated with reservations and precautions until follow-up studies with larger samples are done.

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Image-to-Code: Assisting Engineering Students in Relating to OOP

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CONTEXT

Object-oriented programming (OOP) concerns itself with modelling real-world entities. Not only is OOP widely used in the software industry, it is compulsory for undergraduate engineering students in non-software majors such as computer systems, electrical and electronics, and mechatronics engineering. The computing education literature has shown that OOP is an important threshold concept for novice programmers, and that students often face a myriad of difficulties and misconceptions in their learning of the underlying OOP concepts. Past efforts to alleviate these challenges include the use of visualisation tools designed to capitalise on visual and kinaesthetic learning. Despite such efforts, it remains a burden for instructors to create meaningful and concrete examples to help students relate the concepts to real-world entities.

PURPOSE AND GOALS

The purpose of this study is to reduce the burden on instructors when creating OOP code examples for students. In turn, by making it easier to generate such meaningful code snippets, it is hoped that students will be able to better-relate the OOP concepts to their world. The goals of this study are twofold: (i) explore the feasibility of developing a tool that automatically generates code snippets of skeleton classes, purely from a single input image, and (ii) understand the pedagogical value that such a tool provides to students as they are being introduced to OOP concepts.

APPROACH OR METHODOLOGY/METHODS

The approach included the development of a tool (dubbed Image-to-Code) employing machine learning technologies to automatically generate code from images. This includes the ability to classify images, obtain a description of that classified object, and parse that description to extract attributes of the object for use in a code template. In order to evaluate the pedagogical value of such a tool, an online learning activity was completed by 294 students in a second-year programming course for engineering students. The study included comparisons of student agreements with Image-to-Code, impact on learner confidence regarding OOP concepts, time-to-completion, and reported student satisfaction. The analysis is both quantitative (using statistical techniques) and qualitative (using thematic analysis).

ACTUAL OUTCOMES

There are a few key takeaways from this study. The most important is that the online learning activity improved self-reported confidence in students, and their understanding of how to model key OOP aspects of real-world objects. This is evidenced by the reported student confidence before and after completing the online learning activity, as well as the dominant theme from the open-ended responses that students found the activity effective. In terms of the performance of the Image-to-Code tool, the results highlight that more work is required to improve the quality of the automatically-generated words. In particular, the generation of class names and parent class names were done well, but the quality of member fields and methods need to be improved.

CONCLUSIONS

The experiences of this preliminary work opens vast opportunities for the computing education community to build on, particularly in the development of tools to help engineering students appreciate the relevance and application of fundamental OOP concepts. The Image-to-Code tool, along with the associated online activity, were highly valued by students. To the best of our knowledge, we have not seen such an approach in the literature – and we attribute this to the novelty of the underlying machine learning technologies we are employing. We recommend expanding this study to investigate further opportunities to improve the tool's quality and its impact on learning for engineering students.

KEYWORDS

Object-oriented programming, image classification, natural language processing.

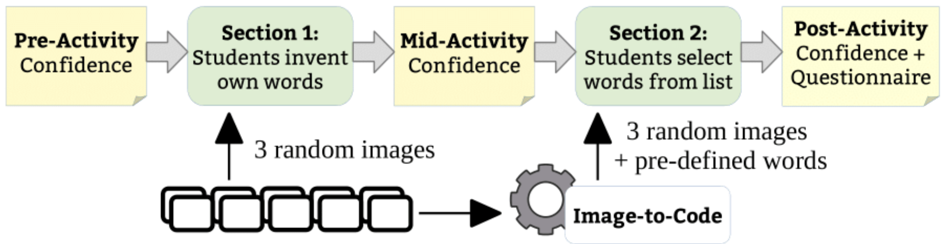

Figure 1: Design of the Image-to-Code study was comprised of two OOP activity sections, with 5-point Likert scale confidence measures in between. Each student was presented with three randomly selected images in each section.

Introduction

For the novice computing student, there are several challenging concepts they need to come to terms with in order to progress in the field (Dale, 2006). Of these concepts, there are a few well-known threshold concepts, such as Object-Oriented Programming (OOP). (Boustedt, et al., 2007) (Rountree & Rountree, 2009) (Sanders, et al., 2012) (Eckerdal, et al., 2006). To combat this, computing education instructors have employed a variety of methodologies to teach students OOP, including the creation of various tools to abstract concepts away from implementation in any one programming language (Jimenez-Diaz, Gonzalez-Calero, & Gomez-Albarran, 2012) (Yan, 2009). Such tools share a common approach: they emphasise the connected nature of objects and ground abstract concepts through the use of real-world examples. However, to create examples that relate to the real world is often difficult and time-consuming.

Related Work

Balasundaram and Ramadoss (2006) developed a tool to help students practice developing object-oriented designs from specifications, with a particular focus on collaborative learning. They found that working together helped students to perform better on this task and learn in general. This task has similarities to the process automated by *Image-to-Code* in generating class skeletons from natural language, and some of the specific challenges involved for humans are detailed. Li and Xu (2010) provide a worked example showing a process of teaching object-oriented teaching through the eight-queens puzzle, with the main takeaway being the concept of object-oriented thinking as a distinct way of viewing a problem, as opposed to simply a collection of disconnected concepts and programming syntax.

Bagert and Calloni (1997) discuss the development of an icon-based programming tool BACCII, shown to improve learning outcomes of novice programmers, which suggests that visual analogies can help students to learn OOP. Jimenez-Diaz et al. (2012) discuss their tool ViRPlay, “a 3D role play virtual environment for teaching object-oriented design”. Each student portrays a class, is given a ‘CRC card’ to represent the classes' responsibilities and dependencies, then made to act out their role in various scenarios. An evaluation of the tool was performed, showing that it improved grades, and that students and instructors both found it a useful learning/teaching tool. Among many things, the timing of teaching OOP itself presents a dilemma for instructors (Pedroni & Meyer, 2010). CS1 has the drawbacks of students not having yet mastered dependency concepts, while CS2 has the drawback of a ‘paradigm shift’ (Adams, 1996). Our work is therefore partly inspired by the arguments made by Adams, of enabling an intermediate approach that helps students identify objects and their operations early on.

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```
class Bookcase: public Furniture {
  private:
    string books;
    string shelves;
  public:
    Bookcase(string books, string shelves);
    void store();
```

Figure 2: An example image with the generated code (C++ header) from the *Image-to-Code* tool

Image-to-Code Tool

Here we introduce *Image-to-*Code, a tool designed to create simple OOP code snippets that will help students appreciate the object-oriented nature of OOP in relation to real-world objects. The tool workflow takes in an image, leverages APIs to obtain information about the image content and uses this information to construct a class skeleton in C++, Java and Python. This approach was selected because it is geared towards making it easy for instructors and students to generate compilable code, and to do so simply from images. While other approaches are possible, they would have involved more effort from instructors and therefore run counter to the intent of this research. Figure 2 illustrates the results of running this tool on a given image.

Implementation

Image-to-Code was written in Python 3, utilising the Google Vision API (Google, 2020) for the classification of input images, and a third-party Wikipedia API (Goldsmith, 2014) to scrape Wikipedia articles for content. The spaCy NLP framework (Explosion, 2020) is used to generate dependency graphs from natural language, and NLTK (Natural Language Toolkit - NLTK 3.5 documentation, 2020) is used to obtain part-of-speech statistics for a particular word in a large corpus (specifically, the Brown corpus).

Methodology

Figure 1 illustrates the evaluation design, a survey-based activity presented to students enrolled in a CS2-level course. This activity was aimed to challenge students' understanding of OOP concepts near to the time they were first introduced to them, as well as assisting in evaluation of the *Image-to-Code* tool. It was comprised of two main sections, each consisting of three randomly-selected images chosen out of a pool of ten images. Although all images had an equal chance of appearing in either section, an image would not appear more than once across both sections for any given student. In addition to these two core sections of the activity, students were also asked to rate (using a 5-point Likert scale) their level of

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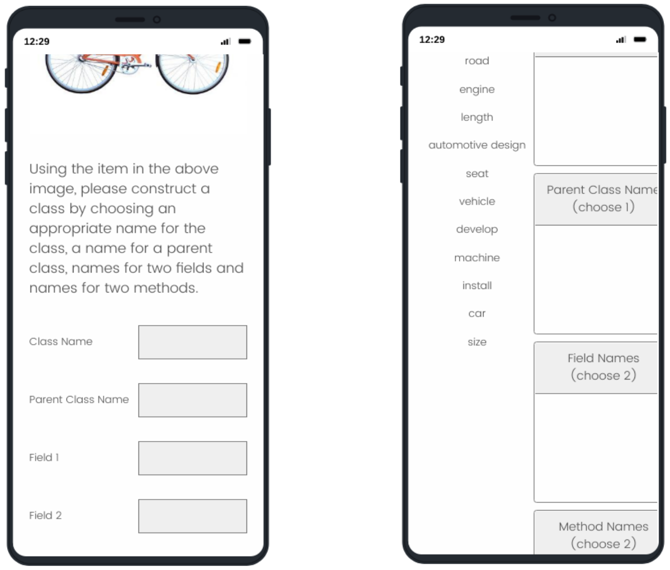

(b) Section 1 example (a) Section 2 example

Figure 3: Examples screenshots from Section 1 and Section 2 of the activities. The activities were web-based, and therefore accessible on either a computer or mobile device.

confidence on understanding what is a *class name*, a *parent class name*, a *field*, and a *method*. The purpose of these three confidence checks was to gauge how the activity was contributing to students' self-perceived confidence in understanding the respective OOP concepts.

Figure 3 (a) shows a screenshot example from one of the images selected to appear in Section 1 of the activity. It requires students to come up with words on their own for the given image. For each image presented in this section, students were required to provide:

- One class name,
- One parent class name,
- Two member fields,
- Two methods,
- Two 5-star ratings:
  - Level of satisfaction *with the words they selected*
  - Overall *quality of the class* representing the given image

Figure 3 (b) shows a screenshot example from Section 2. This required the students to complete the same steps of Section 1, except this time they were only allowed to select words (using drag-and-drop) from a pre-defined set of words produced by the *Image-to-Code* tool. Similar to Section 1, students were asked to rate their satisfaction of the short-listed words from the pre-defined set, and the overall quality of the class.

Table 1: Average Student Confidence

OOP Aspects	Confidence Average		
	Beginning	**Middle**	**End**
Class	4.20	4.62	4.67
Parent	4.07	4.60	4.65
Fields	3.81	4.40	4.48
Methods	3.84	4.30	4.40

Evaluation

Of the 300 students that the activity was delivered to, a total of 294 students (98%) completed the activity in full; demonstrating the simplicity of the activity that would help support such a high completion rate.

Taking into account the random allocation of images (questions) to students, there were 90 responses per image on average in each of the two sections. The number of optional feedback submissions given by students at the conclusion of the activity was 87. These responses were annotated with a tagging tool and themes identified using thematic analysis (Braun & Clarke, 2006).

NLP Vs Student Agreements

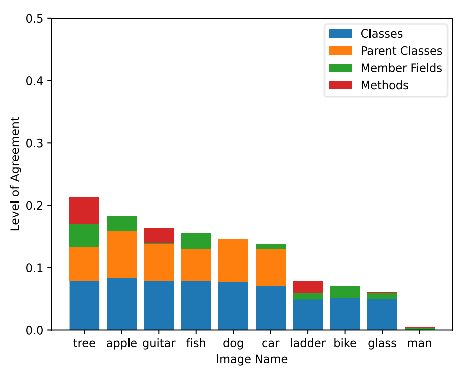

Figure 4: Average level of agreement between the Image-to-Code NLP tool and students (Section 1).

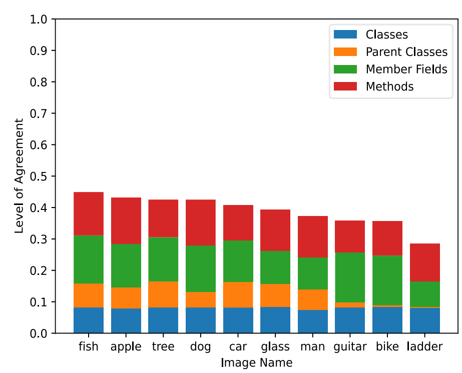

Figure 5: Average level of agreement between the Image-to-Code NLP tool and students (Section 2).

In an attempt to measure some element of quality of the *Image-to-Code* tool, a comparison is made between the word choices of students in each section of the activity, and how that compares to the word choices produced by the *Image-to-Code* tool. For Section 1, where students manually created a class description, we are interested in the agreement (or lack thereof) between the words picked by students and the words generated by the tool; the results of this comparison are represented in Figure 4. For Section 2, we were interested in seeing how students categorised the words provided to them, compared to how the tool intended them to be categorised; the results of this comparison are represented in Figure 5.

A lower level of agreement was seen in Section 1 compared to Section 2, as students were able to brainstorm their own words. With regard to Figure 4, we see that for most images *Image-to-Code* was able to at least choose a class name that students agreed with (with the exception of the 'man' image). For most images, *Image-to-Code* chose a parent class that students mostly agreed with, but noticeably fewer cases where member fields and methods were chosen that matched those picked by students.

Reported Satisfaction and Quality of Words

As another measure of quality, we can compare students' satisfaction (across the two sections) with the selection of words they chose to represent the given images. The expectation is that one would be able to be ‘more satisfied’ when they are not confined to selecting from a short list, and we see this in Figure 6. Students reported an overall higher satisfaction in Section 1 ($\bar{x}$=4.30) compared to that of Section 2 ($\bar{x}$=3.67). Using a two-tailed Mann-Whitney U test, this difference is statistically significant (W=476932, p<0.0001). As a result of being less satisfied with the selection of words, this also led to students rating their overall OOP design ‘solutions’ a lower quality in Section 2 ($\bar{x}$=3.70) compared to that of Section 1 ($\bar{x}$=4.23), as demonstrated in Figure 7. Again, this difference is statistically significant (W=454565, p<0.0001).

Impact on Learner Confidence

The self-reported confidence of students was recorded at three distinct stages during the activity: at the beginning, in the middle between Sections 1 and 2, and at the end. Students were queried concerning their confidence relating to class names, parent class names, member field names and method names, and asked to rate their confidence according to a 5-point Likert scale. Averages (out of a maximum of 5) are shown in Table 1 for each of the OOP aspects. The one-tailed Wilcoxon signed-rank tests between each of these stages are shown in Table 2, showing a statistically significant increase in confidence between each stage for all categories.

Time to Completion on Images

Table 2: Comparison of Student Confidence

Stage	Category	p-value	W-value
Before Section 1 (beginning)	Class	<0.001	243.0
	Parent	<0.001	431.5
	Fields	<0.001	899.5
	Methods	<0.001	1269.0
After Section 1 (middle)	Class	<0.001	243.0
	Parent	<0.001	26430
	Fields	<0.001	799.0
	Methods	<0.001	1294.5
After Section 2 (end)	Class	0.009	183.0
	Parent	0.011	299.5
	Fields	0.002	667.0
	Methods	0.001	958.5

Figure 8 and Figure 9 show the distribution of time it took for students to select words pertaining to various OOP aspects for Section 1 and Section 2 respectively. In each chart, these are given in ascending order by median time within the respective section. This may provide us with some insight to possibly infer which images presented a bigger challenge to students. For example, Figure 8 shows that the median student needed twice the amount of

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time for the ‘tree’ image (about 100 seconds) compared to the ‘dog’ image (about 50 seconds). The median time across all the images in Section 1 was 88.4 seconds.

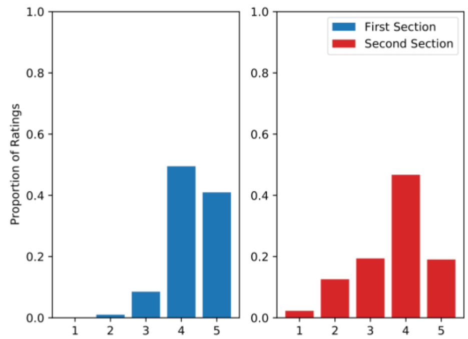

Figure 6: Students’ overall reported satisfaction with the words used in each of the respective sections.

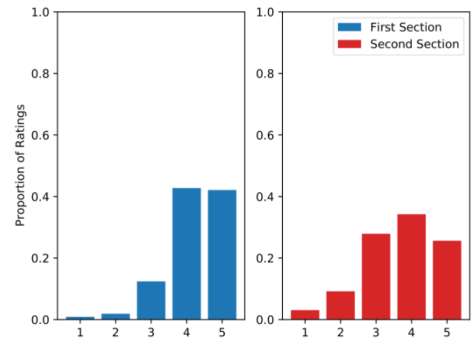

Figure 7: Students’ overall reported quality of the OOP ‘solution’ representing the images in each respective section.

Discussion

Lessons from this Experience

There are a few key takeaways from this study. The most important of which, at least in terms of what it can mean for instructors, is that the activity improved self-reported confidence in students' understanding of how to model key OOP aspects of real-world items. This is evidenced by the reported student confidence before and after completing each section of the activity, and the theme of finding the activity helpful identified in the open-ended responses. This shows that there is inherent merit to the exercise of requiring students to identify class aspects from images of real-world objects.

Even with disregard to the *Image-to-Code* tool, instructors can use the findings reported here to inspire students in CS2 courses concerned with introducing OOP. Of particular note, is that the significant increase in confidence was achieved with relatively little effort (for both instructors and students), and in itself is a worthy low-stakes assignment to consider. Considering the simplicity of this exercise, and the benefit to learners, we believe this activity will be attractive for ‘objects-first’ or ‘objects-early’ programming courses (Pedroni & Meyer, 2010).

Limitations

Although the evaluation was quite positive, there are inevitably some threats to validity. Particularly, as the activity inherently relies on the responses of students, there is the possibility that some of the data collected is not completely representative. While the timing data does show a reasonable level of dedication, there may have been students more interested in completing the activity as quickly as possible with little regard for the quality of their solution. The evaluation was conducted on students enrolled in a CS2 course for a single semester. While the number of students was reasonably large, it is difficult to infer the impact of the activity more generally. As the timing of the activity was constrained to a single point of time (when students were introduced to the basics of OOP), we may see different results if the activity was delivered at a different time in the semester. It is therefore unclear what the long-term value of this activity is. Similarly, the study did not investigate its learning impact in terms of timing, such as CS1 versus CS2, ‘objects-first’ versus ‘objects-late’, and so on.

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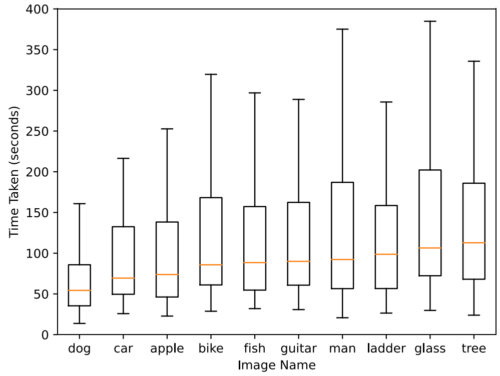

Figure 8: Time taken per image (Section 1).

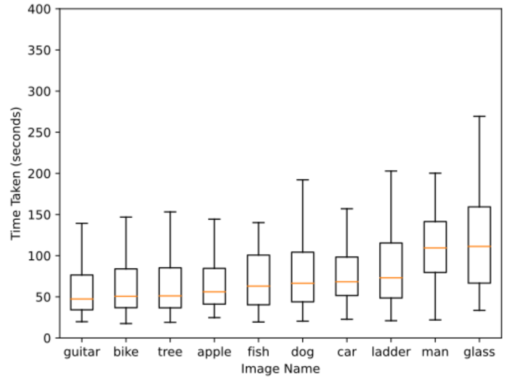

Figure 9: Time taken per image (Section 2).

The *Image-to-Code* tool itself faces some limitations which affected the quality of the output it was able to produce. The first of which being it is highly dependent on the Google Vision API proposing the initial labels for determining what the image pertains to. Although powerful, the image classification does not always label images as a human might expect, such as focusing on the clothing a person is wearing rather than the person themselves. The second of which relates to the use of Wikipedia as a knowledge source. Although the content on Wikipedia is fairly wide-ranging and comprehensive, there are several cases where the description simply lacks the key verbs or nouns that a human would associate with that object due to the academic nature of the page summaries.

Conclusions and Future Work

A tool, dubbed *Image-to-Code*, was developed as part of an attempt to address the difficulties faced by instructors in conveying OOP concepts to students. An activity was created to evaluate this tool, with discussion around the results focussing on the implication that the completion of said activity is useful for students' learning. Several much-needed improvements were identified in regard to the performance of the tool, and the quality of the output it produces. The key limitations were twofold; one being the classification of images via Google's Vision API and the other being the processing of Wikipedia's descriptions.

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Roles and Functions of Supervisors: Impact on the Learning Outcomes of Professional Engineering Doctoral Students

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ABSTRACT

CONTEXT

Professional engineering doctorate degree programs (awarding a Doctor of Engineering degree, Eng.D.) was established in response to an increased demand for application-oriented, strong industrial-based high-level technical personnel, which is different from the aims of the research-oriented degree programs (offering a Doctor of Philosophy, Ph.D.). For the development of professional engineering doctoral students, the professional ability, mentoring skills and attitudes of supervisors are key factors that will directly affect their learning outcomes.

PURPOSE OR GOAL

Using mentoring theories on the roles of mentors, this research focuses on exploring the role and functions of supervisors in process of doctorate studies for these professional engineering doctoral students.

APPROACH OR METHODOLOGY/METHODS

This study used a mixed research method to collect the data from a leading Chinese research intensive university. A questionnaire was used to examine the views of professional engineering doctoral students on their supervisors' mentoring. Follow-up one-on-one interviews were adopted to get a deeper understanding of supervisor's role and functions in the mentoring process.

ACTUAL OR ANTICIPATED OUTCOMES

Preliminary data analysis showed that the students had a high overall satisfaction with their supervisors. They perceived that the supervisors had played a positive role in promoting their learning outcomes. In particular, while serving as a guide in engineering knowledge and research methods, supervisors also offered technical advices and provided additional resources for students' projects and tasks as related to their professional roles in respective corporates. Such a diversity of supervisors' roles and functions seemed to promote the students' role in facilitating the cooperation between universities and enterprises.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

By elaborating on the roles and functions of supervisors in promoting the learning outcomes of professional engineering doctoral students, this study will provide practical and innovative suggestions for the design and evaluation system of mentoring for professional engineering doctorates.

KEYWORDS

professional engineering doctoral students, supervisor, mentoring

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Introduction

To respond to the changes in the industrial structure and meet the needs of economic development, there is an urgent need to cultivate a large number of high-level talents in engineering to meet the needs of social development. Different from traditional engineering doctoral education (offering a Doctor of Philosophy, Ph.D.), which aims at developing research-focused talents, professional engineering doctorate degree programs (awarding a Doctor of Engineering degree, Eng.D.) aims to cultivate high-level talents geared towards industrial needs and technological applications (Kot, Hendel, 2012; Hawkes, Yerrabati, 2018), which can greatly promote the transformation from frontier technology to its application, and effectively alleviate the social pressure of the shortage of engineering talents. The British Association of Engineering doctorates (AEngD) points out that professional engineering doctoral students are more professional-oriented than traditional Ph.D. students, which better adapt to the needs of business development and thus help engineering and technical personnel with research experience to take up leadership positions in future businesses. Therefore, various countries and universities have been committed to building a distinctive training model to promote the continuous and effective progress of professional engineering doctorate degree programs. Due to the cultivation of knowledge and engineering quality of professional engineering doctoral students, the in-school supervisors are under more arduous mentoring pressure in the current cultivation system.

For example, the Engineering Doctorate (Eng.D.) in Composites Manufacture of the University of Bristol in the UK is a four-year doctorate program for researchers who aspire to key leadership positions in the industry. The Eng.D. is undertaken as a partnership between industry and academia, they spend 75% of their time at their sponsoring company carrying out the industrially focused research project, while the remaining 25% of their time is allocated to completing bespoke taught units. The program has very high requirements for in-school supervisors to make full use of students' school time. Besides, Delft University of Technology the Netherlands started its engineering doctorate program in 1990, and there are currently four engineering doctorate programs. In the school's two-years professional engineering doctorate degree program, each professional engineering doctoral student will have a supervisor. The supervisor for the first year is the instructor, and the supervisor for the second year is a professor who is responsible for the student's work. The relevant comprehensive quality and mentoring of the supervisors are key factors for students' learning outcomes.

The manufacturing industry in China is transforming, from the original labor-intensive type to the current technological innovation type, in which leading talents in engineering technology are the key strategic resource. China began to set up the professional doctorate degree in engineering in 2011, and since 2016, a considerable number of pilot universities have officially recruited engineering doctoral students. However, the current training of engineering doctoral students, especially the level of supervisors' mentoring, does not fully reflect the unique needs of professional engineering doctorate degree programs. The current mentoring system of engineering doctoral students in China is the "dual supervisor system" combining an in-school supervisor and an enterprise supervisor. However, in the specific implementation process, the mentoring on the professional doctoral students by the in-school supervisors received criticism that such mentoring practices can be quite homogenous with that offered to the academic Ph.D. students (Liu, Li, Zhao and Xu, 2016; Wang, 2018). The innovative and practical characteristics of the engineering doctoral students put forward higher requirements for the mentoring content and effectiveness of the supervisors.

Based on the above analysis, it is of great significance and value to explore how the mentoring of in-school supervisors play its due effect and role in the cultivation of engineering doctoral students. Therefore, this study tries to clarify the roles and functions of the supervisors in the cultivation of engineering doctoral students. So, this study mainly focuses on understanding: (1) the impact of the mentoring of supervisors on the learning outcomes of engineering doctoral

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students. (2) the role and functions of supervisors in the mentoring process of engineering doctoral students.

Literature Review

To ensure the quality of the cultivation of engineering doctoral students, the supervisor is often the key factor (Lee,2008; Murphy, Bain and Conrad, 2007). Excellent supervisors often have rich academic experience, unique academic thinking skills and perspective, and a noble academic personality. Under their mentoring, students are more likely to develop scientific spirit, form their academic values, enrich their knowledge structure, and thus produce better learning outcomes and promote the rapid growth of academic ability (Lee, 2008). Roberts (2000) interpreted the connotation of mentoring from the perspective of management. He believed that mentoring is the role of a knowledgeable and experienced person who acts as a supporter, supervising and encouraging the academic and personal development of a less knowledgeable and experienced person (Roberts, 2000). From a psychological perspective, Levinson et al. (1978) defined mentoring as the process by which one person guides another person's psychosocial development by providing moral and emotional support. Jacobi (1991) elaborated on the content of the mentoring of supervisors from the perspective of pedagogy. He believed that the relationship between guidance and mentorship focuses on the growth and achievement of the mentee. This mentoring relationship is personal and reciprocal, and the mentoring process is not limited to professional progress, it also includes career development, role demonstrations, and psychological support (Jacobi, 1991). With the continuous advancement of doctoral education, researchers have increasingly studied the relationship between supervisors' mentoring and the quality of doctoral cultivation, and they tried to understand the relationship from different dimensions of supervisors' mentoring, such as the effectiveness of mentoring, the content, frequency, and the various ways of mentoring.

Supervision is considered one of the most influential factors in doctoral experiences (Sverdlik, Hall, McAlpine and Hubbard, 2018). Gardner (2009), Lin (2012), and Gube, Getenet, Satariyan and Muhammad (2017) also concluded that supervisors' mentoring has a significant effect on students' satisfaction, persistence, and academic achievement. In addition, the quality of students' learning and the final learning outcomes are closely related to the mentoring of the supervisors (Gube, Getenet, Satariyan and Muhammad, 2017). Therefore, a good mentoring relationship, along with appropriately designed mentoring content and mentoring process can effectively promote students' sense of accomplishment and satisfaction, thereby producing high-quality learning outcomes (Sverdlik, Hall, McAlpine and Hubbard, 2018). On the contrary, poor quality supervision may negatively affect the students' learning outcomes. Specifically, previous research by scholars has shown that poor supervision will significantly extend the time for students to complete their studies and reduce the quality of research results (Cullen, Pearson, Saha and Spear, 1994; McCulloch, 2010), and reduce the number and quality of publications (Cullen, Pearson, Saha and Spear, 1994). In addition, poor supervision may cause students to encounter various obstacles in the process of completing their research, and even lead to physical and mental health problems, which will negatively affect students' learning outcomes (Haag et al., 2018).

In addition to learning and research, the professional engineering doctoral students will have more project connections and cooperation with their supervisors, and even serve as the link between the in-school supervisor and the enterprises (Zhong, 2013). Therefore, the professional engineering doctoral students will have a closer connection with their supervisors both in learning and work. In addition, due to the uniqueness of the cultivation objectives of the professional engineering doctoral students, there will be unique practical difficulties and needs in the mentoring process (Yang, wang and Ding, 2019). Therefore, it is really important to do research on the influence of supervisors on the learning outcomes of professional engineering doctoral students, and explore the role and functions of the supervisors which can effectively enhance the quality of mentoring. However, summarizing the previous research, the articles

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and theories on mentoring are relatively mature, but there are not many articles focusing on the professional engineering doctoral students, the students in most research are treated indiscriminately. However, there are obvious differences between professional engineering doctoral students and traditional Ph.D. students. The innovative and practical characteristics of professional engineering doctoral students must be paid attention to in research to better apply the mentoring theory to the cultivation of engineering doctoral students.

Methods

This study used a mixed research method to collect the data from a leading Chinese research-intensive university H. Participants were all professional engineering doctoral students from 7 different schools, including the School of Naval Architecture, Ocean and Architecture Engineering, School of Mechanical and Power Engineering, School of Electronic Information and Electrical Engineering, School of Materials Science and Engineering, School of Biomedical Engineering, School of Chemistry and Chemical Engineering, and School of Aerospace Engineering. All the students are part-time students with full-time jobs (the students of professional engineering doctorate degree program in University H are all part-time students). While participating in the professional engineering doctorate degree program, they also hold certain positions in off-campus companies or research institutions.

First, a quantitative method was used to explore how the mentoring of supervisors affect the learning outcomes of professional engineering doctoral students. A survey was designed based on the different aspects emphasized by prior mentoring theories (Johnson and Huwe, 2003; Johnson and Ridley, 2004). The survey also included questions for exploring other areas of professional engineering doctoral students' learning experiences, such as motivation and course learning experiences. This study focused on their mentoring experiences. Questionnaires are distributed uniformly to all first-grade professional engineering doctoral students enrolled in 2020. A total of 100 participants are included in this research and 66 valid questionnaires were collected finally, the participation rate was 66.0%.

To further explore the perception of professional engineering doctoral students on the role and functions of supervisors in the mentoring process, the research conducted one-to-one interviews and collected relevant data by recruiting professional engineering doctoral students who have already participated in a questionnaire survey. Because the first-grade students need to complete the courses, to better understand the role and functions of supervisors, this study further follow-up interviews of the second-grade professional engineering doctoral students who have already participated in their supervisors' groups and projects. A total of 31 (20 in first-grade and 11 in second-grade) professional engineering doctoral students from different majors participated in the interviews for this study. Sample interview questions include, how often do you communicate with your supervisor, and how long does each exchange last? What kind of mentoring and help did the supervisors provide to you in your work and life, and did it solve the problems? So far, we have interviewed and analyzed 31 interview transcripts.

Preliminary Findings

Regarding the evaluation of the mentoring of supervisors, the questionnaire mainly surveyed the students' evaluation of their supervisors' professionalism, personality, and supervisors' attitudes towards the professional engineering doctoral students. Preliminary data analysis showed that students' overall satisfaction with their supervisors averaged about 87%, which means more than 80% of students believed that their supervisors have good professionalism, moral qualities, and communicate frequently with them. Percentages of respondents are shown below in Figure 1. The data showed that professional engineering doctoral students have reached a high level of satisfaction with their supervisors, and they have a positive attitude towards their supervisors' mentoring on their learning outcomes.

Figure 1. Evaluation of supervisors by the professional engineering doctoral students

In addition, this research classified the roles and functions of supervisors in the mentoring process through interviewing the professional engineering doctoral students on three aspects, which including the mentoring frequency, mentoring contents, and the ways of mentoring. Because the professional engineering doctoral students in first-grade need to complete their professional courses, not all of them fully participated in their supervisors' groups and projects. The preliminary interview of them found that the mentoring of supervisors on the first-grade students cannot reflect consistent patterns, the individual difference was large. Therefore, to better understand the role and functions of the supervisors in the mentoring process, this study further follow-up interviews on the second-grade professional engineering doctoral students who have already work with their supervisors, the purpose was to gain a comprehensive and in-depth understanding of the role and functions of the supervisors in the mentoring process.

There are totally 20 professional engineering doctoral students in first-grade took part in the interview. The interview data showed that students' views on the mentoring frequency of supervisors were quite different among individuals, students who have participated in their supervisors' groups or projects indicated that the mentoring of their supervisors are frequent enough to meet their needs, while the students who have not yet participated in their supervisors' groups or projects said that supervisors do not mentor them very often. In terms of mentoring contents, first-grade students generally referred that supervisors' mentoring included professional knowledge, work, and life, but few of them specifically explained. When regarding the ways of mentoring, students who participated in their supervisors' groups and projects indicated that supervisors' mentoring often took place in the discussions and meetings of the projects, while others mentioned the main ways of mentoring is separate communication and group meetings.

In view of the special situation of first-grade students, this study specifically followed up the interviews with second-grade professional engineering doctoral students, with a view to obtaining more comprehensive information of supervisors' mentoring. A total of 11 students participated in the interview. In terms of mentoring frequency, preliminary qualitative data showed that 5 of the professional engineering doctoral students thought that the frequency of their supervisors' mentoring was high enough to meet their daily learning needs and solve learning problems in time. Even when time and space are limited, regular communication and discussion were still conducted online. An engineering doctoral student answered the question about the mentoring frequency of the supervisors:

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I communicate with my supervisor often. I don't attend the group meeting every time, but I must attend it often, which is required by my supervisor. Whether academic or other activities, I can participate in team activities as much as possible…... The learning requirements are the same as for full-time students.

The remaining students (6) hold different views. They said that there was a disparity between the mentoring frequency and the actual needs of the professional engineering doctoral students. They concluded that the supervisors' mentoring and exchanges with them were not very frequent. Due to the limitations of work, time, and space of professional engineering doctoral students, it was difficult for the supervisors to provide regular mentoring for them. A student said:

There is a big difference in the mentoring frequency of my supervisor. He will not urge me to ask about the progress every day, because he knows that I am busy at work and I also need to balance the time between work and study. I may give him a special report for two weeks or even a month.

In terms of the mentoring contents of supervisors, 4 of the students believed that the supervisors' mentoring contents were the same as that of full-time Ph.D. students, and put forward the same requirements. They were given frequent mentoring in terms of professional knowledge, academic research, and their dissertation work, especially the frontier knowledge of the field and the topic selection of their dissertation. The student mentioned:

My topic has been selected. After I have selected it, in terms of what method should be used to explain the problem clearly, and how to analyze the data to draw some conclusions, my supervisor will give me guidance. My supervisor will mentor me to analyze these topics from the surface to the deeper aspects, and use different statistical tools, which are of great help to the research on this topic.

More than half (7) of the students believed that the mentoring of their supervisors included not only academic research issues, but also engineering practice issues, and even included a certain level of work and life communication, which was richer and more multifaceted than full-time Ph.D. students. In the topic selection of the thesis, more consideration was given to students' actual needs and to solve the actual problems of enterprises. An engineering doctoral student mentioned:

There should be some differences in the contents and focus of the mentoring of the supervisors. Full-time students still prefer academic research. We have both academic and engineering practice issues, even including exchanges in life. After all, we are in different environments. We may have families, jobs, which is different from full-time students.

When regarding the ways of mentoring, students' perception varied. 5 students believed that the supervisors' mentoring modes were the same as that of the full-time Ph.D. students. The supervisors also allow the engineering doctoral students to participate in their research team. In daily learning, they also needed to participate in regular meetings and share their learning and research progress. A student mentioned in the interview:

we have a regular meeting every week, because I am at work, for a short distance from the school and the meeting time is working days, so sometimes it is difficult for me to live in, but they always had a video conference for me, so I could see what the full-time students in the research group were presenting, and I could hear what they were talking about, and in my case, I could have a video conference with them.

But at the same time, other students (6) hold a different view, they believed that the supervisors considered a lot about the cultivation characteristics of the engineering doctoral students in the mentoring process, and the supervisors usually did not force the time and frequency of attendance. The mentoring on engineering doctoral students always be more based on cooperation projects or engineering practice issues. An engineering doctoral student said in the interview:

We are already employed. The mentoring provided by my supervisor is mainly about some practical problems I encountered in my actual work. If I cannot solve it, I need to seek help from my supervisor. The guidance and help in this area are the greatest.

Conclusions

In conclusion, through the questionnaire data, it can be concluded that most of the professional engineering doctoral students (average is 87%) were highly satisfied with the mentoring of their supervisors. Analysis of qualitative data shows that the view of the professional engineering doctoral students in first-grade on mentoring is closely related to whether they participate in projects or not, and does not form a specific pattern. Qualitative data from the second-grade students show that students generally agree that the mentoring frequency, contents, and ways are sufficient for their research and learning to meet their daily needs. However, compared with full-time Ph.D. students, the mentoring frequency is slightly lower, the mentoring contents is more practical, and the way of mentoring is more diversified, as the professional engineering doctoral students are more practically oriented.

Therefore, to fully promote the positive effect of the in-school supervisors' mentoring on the learning outcomes of the engineering doctoral students: (1) It is necessary to eliminate the ambiguity of in-school supervisors' cognition of engineering doctoral students. The supervisors should make a clear distinction between the cultivation objectives and programs of the engineering doctoral students and the Ph.D. students in engineering, rather than simply supplementing the traditional cultivation programs. (2) It is also important to clarify the mentoring responsibilities of in-school supervisors for engineering doctoral students. The supervisors should consider the innovative and practical characteristics of the engineering doctoral students, and reflect in various aspects such as regular communication, academic mentoring, and thesis mentoring.

According to the preliminary work, we find that the cultivation of engineering doctoral students has distinct practical and innovative characteristics, so it is very important to consider the characteristics of the samples in relevant studies. Therefore, future research will further consider the demographic information of engineering doctoral students, including students' grades and majors, to explore the changes in the time dimension of mentoring and supervisors' roles.

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The Role of Academic Development (Research and Teaching) in Enabling Quality Teaching

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ABSTRACT

CONTEXT

Extensive research has been carried out regarding the theoretical framework of what constitutes effective teaching at higher education. Some focused on the barriers that inhibit effective teaching including limited training in teaching for research-active academics, and poor systems for academic development in terms of structure and effectiveness at the institutional level. By reviewing the literature, only limited studies focus on academics' perspectives regarding academic development, hence this is a topic for further investigation.

PURPOSE OR GOAL

There is increasing interest in how academics are supported to develop as teachers to enhance teaching practice. This study aims to build upon the current research on academic development through the lenses of academics to explore the interventions of academic development initiatives that constitute effective teaching at higher education and the impediments that prevent academics from being effective teachers. This study is framed around a central research question: How is academic development fostered amongst teaching-focused academics?

APPROACH OR METHODOLOGY/METHODS

This study proposes a method to investigate academics' conceptual understanding and experience of academic development for effective teaching, which is descriptive and interpretive. A thematic analysis approach is considered as most relevant in answering the research question. The approach is a combination of inductive and deductive techniques that allow themes to emerge from data and. A semi-structured qualitative interview is outlined in this study.

ACTUAL OR ANTICIPATED OUTCOMES

For successful implementation of quality teaching, universities must build a culture of quality research-informed teaching as a strategic direction that aligns with their policies and practices. It is encouraging to find that universities are advocating for SoTL intervention as part of their academic development initiatives to enhance quality teaching and incentivising a research-focus amongst academic staff. However, for those in teaching-only roles, there is a divergence between expectations and incentives around academic development: research is not formally required, but a research degree frequently is. To maintain their academic identity and develop as an academic, teaching-only staff are still incentivised to research. We aim to explore this divergence and how it affects teaching staff. It is imperative that institutional policies and practices position teaching as a separate but equal partner to research, and to explore how the institutional policy context shape research–teaching dynamics.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Despite the reasonably straightforward theorisation of how academic development impacts on teaching and learning, it is challenging to monitor and evaluate this complex task due the scale and range of direct and indirect influences. However, to continue improving academic development initiatives, it is essential to monitor its progress. Monitoring quality teaching is an area that needs further investigation.

KEYWORDS

Academic development, effective teaching, thematic analysis

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Introduction

Academics employed in teaching-only positions, or "Teaching Focused Academics" (TFAs) are those who have no research component in their job description. These positions may be permanent or fixed term, with fixed term employment contracts being renewed on term basis. TFAs have strengths and competencies in areas that are vital to the sustainability of their academic institution. However, they are under-recognized resources featured with no sabbatical opportunities and a high teaching workload.

Because of their teaching-only roles, TFAs realise that their academic identity is fragile and needs to be strengthened by having research roles in their job requirements. Without a strong research base and regular publications, it is almost impossible for TFAs to make any further career progression. This unfortunately can result in considerable consequences for work satisfaction and development of their academic vitae. It is well-recognised by the academic community that performance in research has become highly prized in academics' recruitment and promotion, that is to "publish or perish", but little attention is paid to the way in which that mandate still applies doctoral graduates in non-research roles.

As TFAs are a lynchpin of many faculties, enabling effective teaching of large undergraduate courses that free research-active academics' time, it is imperative to explore their perceptions of their academic development to embed them into the academic culture. Therefore, this paper presents a proposal to qualitatively collect and analyse TFAs' perceptions of their academic development needs.

Literature Review

Academics' perceptions of their development have long been a focus of interest in academia. It is well- recognised that academic development is a necessity due to rapid changes in academia, which result from changing economic and social forces, new teaching and research methods and technological updates including use of IT to mediate/facilitate instructions (Buckley & Cowap, 2013; Tamim et al., 2011). A favourable atmosphere to encourage academic excellence in higher education institutions requires a systematic career progression and structure for academics (Chen et al., 2015). Where TFAs are fresh PhD graduates in their first academic post, they can be categorized as early career academics (ECAs) for the purpose of an extensive literature search for similar topics. An appropriate career structure and preparation may help those entering academia to be ready for their roles as academics (Walker & Yoon, 2017). Amongst ECAs and TFAs, initial transitions into higher education can have considerable consequences for career development and work satisfaction (Hollywood et al., 2020).

In general, academics with teaching-only roles only are heavily involved in routine teaching with no genuine opportunities for discipline-specific research. However, as their doctoral qualifications are discipline-specific, they frequently have limited skills in curriculum development and are underequipped to deliver competent learning activities (Matthews et al., 2014). This presents challenges for career development in education of the discipline, and the lack of research in their discipline impedes successful transition into research-academic roles. The resulting fragile academic identity (Archer, 2008) can make this group particularly susceptible to negative perceptions and adverse experiences in their work. The dilemma of the academic development needs in terms of scientific research engagement has become a topic of debate over the last two decades, as shown in Figure 1 below.

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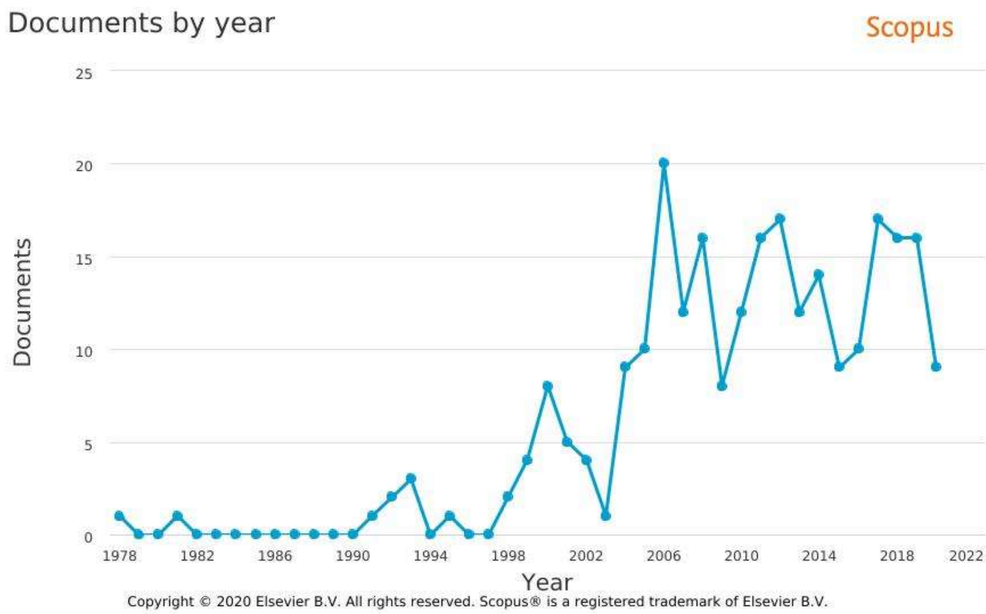

Figure 1: Literature search of academic development AND engagement in research

One of the earliest studies, by Gao et al. (2000), used qualitative interviews to investigate what research and research methods meant to academics in terms of their progression. Recently, Hollywood et al. (2020) explored academics' perceptions of their work environment along with their beliefs about their future career development through qualitative analysis. They highlighted distinct intrapersonal dimensions and experiential /situational factors, which relate to variations in the perceived potential for career development. Between these two studies, the literature is rich in reporting about academics' perceptions of their development, mainly with reported qualitative case studies. The International Journal for Academic Development (IJAD) produced two special issues, in 2009 and 2011, to discuss concerns and considerations for new academics amongst the academic development community.

Recent research has developed insights into predictors of successful career development, demonstrating different conceptions of success in various facets of academic roles. Hill et al. (2019) investigated the key elements to consider in building and sustaining academic development programs for ECAs. In their quantitative study, Matthews et al. (2014) reported ECAs' attitudes and perceptions of teaching versus research and involvement in academic development. Lai (2009) investigated the new challenges to the work-life of academics, using qualitative research methods to answer how academics should maintain their academic status. In his semi-structured interviews, he concluded that research performance has become highly prized in academics' recruitment and promotion. Furthermore, number of research publications are increasingly being used to judge on academics' performance as part of their career promotion. Among the academic community, it is widely believed that success in research, as opposed to teaching, to be a stronger predictor of career advancement (Sutherland, 2017; Bosanquet et al., 2017). Furthermore, increases in job satisfaction are perceived to predict success in research, but not teaching (Stupnisky et al., 2016).

Gap in the Literature

The unbalanced relationship of importance between the teaching and research is evident in the literature. However, there is no reported proven practices/protocols to re-balance this

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relationship up to date. Furthermore, there is no road map on how to create an appropriate career progression structure for academics of heavy teaching roles such as TFAs. It is an area that calls to enhancing TFs' academic development by including research productivity in their academic progression plan. Academic institutions need to enable ECAs, including TFAs, to access development that speaks to their current responsibilities as well as their career intentions.

Research Objectives and Questions

With this endeavour, the main objective of this proposed study is to qualitatively investigate TFAs' perceptions of their development needs. This objective should establish and conclude the importance of a research component in TFAs' job description and how it is reflected in their academic progression. The objective of this proposal aligns with a growing international interest in academics' perceptions of their development needs (for example, Castelló et al., 2017; McKay & Monk, 2017; Acker & Webber, 2017; Greer et al., 2016).

Research Questions

This proposed study is guided by two major research questions. Under the heavy teaching load and limited access to scientific research opportunities:

(1) How do TFAs perceive the value of effective teaching versus research productivity towards academic development?

(2) What motivates TFAs to engage in research given it is not a component of their role?

These main questions will pave the way for further discussion with expanded direct and non-direct sub-questions. By answering the questions above and linking them to the TFAs' academic development needs, the aims of this study will be covered entirely.

Research Design

Proposed Methodological Approach

The construct of academic development could not be easily reduced to measurable items on survey instruments, and so warrant a qualitative investigation in principle. This research follows a qualitative approach using semi-structured interviews with a group of TFAs to produce the required data. The perspectives of subjective (rather than objective) understanding, is necessary to glean TFs' perceptions of their academic development needs, so informs the methodology adopted in this research.

Theoretical Framework

For the reasons outlined above, the theoretical framework of the proposed study is one in which the TFAs' needs regarding engagement in research and their academic development are explored through their reflective observations. This theoretical framework aligns well with the interpretive epistemology by explaining career development as descriptive. The research's ontology of the qualitative approach includes human psychological perspectives. Accordingly, the research epistemology in this way of acquiring knowledge defines no single reality. This proposed study will be an example of the interpretive research paradigm that perceives no single truth among the participants' experiences, and this is why the reality needs to be interpreted. Such a paradigm has the flexibility to define academics' perceptions of their career development, in non-measurable numerical terms.

Inquiry and Data Collection

Sample Size

The participants will be selected from a pool of TFAs in different tertiary institutions. The purposeful sampling for qualitative data collection and analysis by Palinkas et al. (2015) will be consulted for criteria of sample selection. The participants will be invited to take part in the study via an email sent to all. They will not be identified explicitly in any publications about the research outcomes.

Procedure

In a series of semi-structured interviews, a systematic procedure will be followed to ensure that the trustworthiness of the collected data will not be violated. The interviews will be conducted face to face or via videoconferencing (Zoom) sessions and run for around 45 minutes each. The sessions will be audio-recorded with the participants' consent and transcribed for analysis to elicit the academics' perceptions.

Interview's Questions

The participants will be asked a series of open-ended and flexible questions. Still, the most central one is how they perceive the engagement in research to build the foundation for their academic development. The main interest will be in the participants' personal opinions about how they have developed as academics and what influenced this development. The interviews will seek to elicit participants' views, understanding and experiences on the subject of their academic development to draw these personal opinions out in conversation. Where the interviewers think it is necessary, questions on these opinions can become increasingly focused as the interviews progress. The interview questions will be specific to begin with, but the participants will be given an expanded space to voice their perceptions, opinions and personal feelings. Offering such an area of freedom is supported by literature (Creswell, 2008). Wherever possible, the interviews will run as free-flowing conversations with the agreed vital questions inserted as prompts to ensure the interviews are comparable to each other in all sets.

At this initial stage of the proposal, the interviewers have created a set of questions to guide the interviews. However, they need to be further developed and arranged purposely based on the participants' own experience of academic development.

Data Analysis Approach

Thematic Analysis

Using qualitative analysis software (NVivo), the interview transcripts will be subsequently thematically analysed to construct a coding framework following Fram (2013). It will be necessary to examine the reliability of the preliminary codes obtained at the early stage. This can be done by eliminating scattered or redundant codes, collapsing similar codes, and narrowing down the final codes to broader overarching themes. The concept of data saturation that refers to the quality and quantity of information will be carefully applied. Data saturation can be defined as the point when "no new information or themes are observed in the data" (Guest et al., 2006, p. 59).

Data Mapping

Once the main themes are identified, the sub-themes will be further refined and linked to each other for coherence and further adjustments. Each coded excerpt will be condensed

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into a short title that summarises its actual content. Every title will then be added to a concept map by locating it to related titles and linking them with explanatory labels as needed. As part of this process, a few titles will be relocated and relinked as new relationships emerge. After completing excerpts' processing, major themes, each with several sub-themes, will be evident. NVivo's codes, nodes architecture, word clouds/ frequency, and concept and project maps will be created.

Data Analysis

To identify and analyse the overarching themes, a common approach to qualitative reporting will be followed to explain the descriptive accounts of the themes with support of illustrative direct quotations.

Research Limitations and Challenges

Trustworthiness

The technique of semi-structured interviews for data collection can alter the data in subtle ways with some limitations, as per the following.

- The personal knowledge, experience of the participants may influence findings and conclusions. Therefore, a high level of interview management is required.
- Due to the presence of open-ended questions, the conversations may delve into psychological interactions for data collection. Therefore, the discussions often tend to deviate from the main issue to be studied.
- The interpretation of the results can be biased because the interviewer's perspectives somehow influence it.
- The limits in sample size and identical engineering background may not represent a general understanding of how the TFs perceive themselves in the context of academic development.

For this study to be accepted as trustworthy, the researchers are keen to demonstrate that data analysis will follow an exhaustive manner through recording, thematizing the transcripts, and disclosing the methods of analysis with enough detail to ensure that the process is credible, transferable, and confirmable (Daniel & Harland, 2018).

While conducting this research of semi-structured interviews, it will be important to cross-reference the data obtained with related quantitative data. Unfortunately, this may not be achieved in this study due to its perspective-based method of research that is based more on personal opinions/experiences rather than objective results. Thus, the responses given will not be measured, and this study will not be statistically representative. In other words, the concept of triangulation will not be applied in this study. Triangulation is a "method of cross-checking data from multiple sources to search for regularities in the research data" (O'Donoghue & Punch, 2003, p. 78). The purpose of triangulation in qualitative research, in general, is to increase the credibility and validity of the results.

Research Formalities and Considerations

Ethical Approval

Ethical Approval is a requirement as the research is to be conducted/facilitated with human participants. The outcome of this research will be included in a research paper for conference/journal publication. The participants (TFAs) are free to consent to their participation (opt-in approach) in the research. A consent form with relevant information will be sent to the participants to sign and submit prior to every interview session.

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The participants have the right to withdraw, without giving reason. They have the right to not answer any questions during the interview, and can also withdraw fully at any time during the interview without providing a reason. Participants can withdraw their interview responses at any time for three months following the interview, without providing a reason.

It is expected that participating in this research can be of direct benefit to TFAs groups and/or the wider community of ECAs as an opportunity to reflect on their role, and because the results of this research can potentially inform improvements to that role. Additionally, it is not expected that any harm would arise to participants from participating, and no aspects of this research are considered to raise any specific cultural issues.

There will be fair treatment in the selection of the participants. The invitation will be sent to a cohort of TFAs. The participants will be treated equally regardless of their opinions.

Research Significance & Contribution to Practice

There is a common understanding that TFAs should be permitted to be engaged in research on their practice. However, this understanding should be translated to practical steps. As TFAs are a key element to the delivery of higher education, universities must explore TFAs' perceptions of their professional development to include them more effectively into academic culture. This study will work as a formal submission on how to implement academic development for TFAs for better work satisfaction, staff retention, and students' engagement that should be reflected in greater financial benefits at the end.

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Development of an online teaching-focused professional development program for junior teaching staff

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ABSTRACT

CONTEXT
The ongoing coronavirus pandemic required us to quickly adapt and familiarise ourselves with new skills and technologies in the shift to online teaching. Irregular communication due to extended lockdowns has meant that while knowledge on effective online teaching has been developed, this knowledge has not been properly disseminated to our junior teaching staff. As they operate predominantly in student-facing positions, it is essential that our junior staff be equipped with information on best practice in online teaching as well as with an awareness of the resources available to support them.

PURPOSE OR GOAL
To address the gap outlined above, we developed a new professional development program for our junior teaching staff, focusing mainly on online teaching. The goal was to share our collective knowledge on best practice in online teaching, and to demonstrate how various technologies could aid in promoting active learning in an online setting. The program also aimed to initiate a community of practice around teaching and the online teaching space.

APPROACH OR METHODOLOGY/METHODS
In designing our program, we considered student feedback from previous semesters, and more recent feedback on the online teaching experience from 2020. The final program covered the following topics: general advice, navigating Zoom and physical setup for online teaching, online tools for active learning, engagement within teaching teams, online feedback, and blended synchronous learning. Tools and technologies showcased in the program were embedded in the delivery to allow first-hand experience.

ACTUAL OR ANTICIPATED OUTCOMES
An exit survey indicated that in general, participants found the program useful, with an average rating of 8.27 (out of 10). The top areas that participants indicated that they would like more assistance were quizzes and tools for active learning (31%), providing feedback to students (22%), and blended synchronous learning (20%). Zoom (12%) and the physical setup for online teaching (15%) did not rank highly, in line with our observation that a large percentage of participants had some prior experience with online teaching in 2020.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
In summary, we piloted a professional development focused mainly on online-teaching for junior staff. The program was well-received, and the collected feedback will used for implementation and improvement of future run.

KEYWORDS
Professional development, mentorship, training, online teaching.

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Introduction

The ongoing coronavirus pandemic has required university academics to shift rapidly to online teaching (Ali, 2020). This has meant that academics have had to equip themselves with new skills and specific technological capabilities required to navigate virtual learning (Simamora et al., 2020). While this has meant that a sizeable body of experiential knowledge on effective online teaching has been developed, this knowledge has not been properly disseminated to our junior teaching staff. As it is our junior teaching staff that operate predominantly in student-facing positions (tutorials and workshops), it is important that they be equipped with information on good practices in online teaching, as well as with an awareness of the resources available to support them.

Having identified this issue, we developed a new professional development program (focused on online teaching) to support our junior teaching staff within the Faculty of Engineering and Information Technology at the University of Melbourne. The primary goal of our program was to share our collective knowledge on good practices in online teaching, and to encourage the implementation of various digital technologies to support active learning in online settings. The program also allowed us to promote our team members as points of contact for future support, guidance, and mentorship, initiating a community of practice around navigating the online teaching space.

In this paper, we describe the approach taken to design our program and identify the areas flagged as requiring more support in future iterations. The role of our program in initiating the formation of a community of practice around effective teaching is also discussed using the conceptual framework for social learning systems (Wenger 2000).

Background

Online Learning

Online learning, including blended and fully online courses, has become a common aspect of adult education in the last two decades (Allen & Seaman, 2013). However, not all is perfect in the online landscape. Educators continue to report many challenges involving content creation and delivery, which can take more time and effort than when compared to traditional face-to-face approaches (Oliveira et al, 2021; de Barba et al, 2020; Allen & Seaman, 2015).

In this context, Dunlap and Lowenthal (2018) identified and recommended four themes to promote more effective online course design and facilitation: (a) supporting student success, (b) providing clarity and relevance through content structure and presentation, (c) establishing presence to encourage a supportive learning community, and (d) being better prepared and more agile as an educator. After analysing their themes with experienced online educators, the authors highlighted that the highest number of recommendations in their study aligned with the "presence" theme. Online educators commented on the importance of connecting with students, helping students connect with each other, and helping students feel they are members of a supportive learning community. Garrison, Anderson, and Archer (2000) developed the Community of Inquiry (CoI) model, which significantly influenced the themes identified by Dunlap and Lowenthal (2018), to describe how the interplay between teaching presence, social presence, and cognitive presence are foundational to the development of deep and meaningful educational experiences in online courses. The CoI model emphasizes balanced instructional attention to teaching, social, and cognitive presence in order to cultivate an engaged online learning community (Lowenthal & Dunlap, 2014).

The disruptive effects of the ongoing COVID-19 pandemic have impacted almost all sectors of our society. Higher education is no exception, and the paradigm has shifted from one characterised by on-campus face-to-face learning to one involving almost entirely online

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learning. Students face an increasingly uncertain environment, where financial and health shocks (for example, lack of resources to complete their studies or fear of becoming seriously sick), along with the transition to online learning may have affected their academic performance, educational plans, current labour market participation, and expectations about future employment (Aucejo et al., 2020). Educators have also had to quickly transition to online teaching, which meant learning to use digital tools to promote interaction and collaboration, nurturing a sense of community by redesigning their curriculums and activities, and making use of asynchronous tools to allow communication with offshore students (Oliveira et al, 2021). The "presence" theme identified and discussed by Dunlap and Lowenthal (2018) has become even more necessary and urgent due to this rapid and large-scale shift to online delivery.

To address the challenges identified above and to support new/junior teaching staff within the Faculty of Engineering and Information Technology at the University of Melbourne in this transition to online learning, we developed a professional development program focused on the use of digital tools, active learning, and ways of establishing presence to encourage a supportive learning community.

Social Learning Systems & Communities of Practice

We aligned our program with the conceptual framework for social learning systems proposed by Wenger (2000) and with the presence theme identified by Dunlap and Lowenthal (2018). Within social learning systems, expected boundaries of knowledge and competencies are established over time by relevant communities of practice. Communities of practice here have previously been defined (Wenger et al., 2002) as "groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis". Wenger (2000) proceeds to describe these communities as being characterised by two components: competence and experience. In our context, "competence" might refer to the practical online teaching knowledge that more senior academics have accumulated via experimentation over the course of the pandemic thus far. "Experience" then might refer to the transfer of this knowledge to our junior teaching staff members. In line with this framework, one of our program's long-term goals was to help foster a stronger culture and community dedicated to the discussion and exchange of effective online teaching practice – one that includes junior teaching staff.

Approach

Program Design

In designing our program, we considered student feedback from both department-based tutor/demonstrator surveys and formal University-level subject evaluation surveys conducted in previous semesters. In line with our program's focus on online teaching, we also considered the findings of a report published by the University on the common problems encountered by students during the initial shift to online teaching in Semester 1, 2020 (the main goal of this report was to identify areas where improvement was needed in Semester 2, 2020). From this report, student interaction and engagement, academic staff presence, and clarity of information and communication were identified as key areas that required attention. Here, interaction and engagement include not only interactions with teaching staff, but also interactions between students. It was recognised that the shift of teaching to an online environment had changed the nature of these interactions, and that efforts had to be taken to properly nurture and support students. In a separate panel discussion with students, they noted, for example, that they did not have as many opportunities to study together in the shift to online teaching. Academic staff presence here relates to the availability of teaching staff, but also encompasses the quantity and quality of feedback provided to students to help them gauge their progress through their subjects. Finally, clarity of information and communication refers both to the structure of the content being taught in an online setting, as well as guidance to students on how to engage with the available online materials and tools.

As an outcome of our analysis of the aforementioned surveys and reports, we designed a two-hour program agenda around the following topics: an introductory icebreaker session, general advice for teaching in an online context, navigating Zoom and its features, the optimisation of physical setups for effective online teaching, digital tools to support active learning, engagement and initiative within teaching teams, online feedback mechanisms, and blended synchronous learning. Various digital tools and technologies showcased in the program (breakout rooms, Padlets, PollEV, Kahoot) were embedded in the delivery of the program, allowing attendees to experience their functionality first-hand. Brief descriptions of each of these areas of focus are included as follows.

Introductory icebreaker session

The first ten minutes of the program was used to conduct an icebreaker session. Participants were assigned into breakout rooms where they introduced themselves to each other. To provide structure, we recommended that each person mention their name, department, past teaching experience (if any), subjects they would be teaching into, and favourite food. We felt that this icebreaker session was necessary to help initiate a sense of community and camaraderie amongst our junior teaching staff members, many of whom are used to performing their teaching duties in relative isolation from the wider teaching community. The second benefit was to demonstrate how such an activity can be used to foster interactions between students in an online environment.

General advice for teaching in an online context

Our program was pitched at junior staff members with a wide range of teaching experience, from those about to teach for the first time, to those with several years of experience. While this section was primarily targeted towards newer staff members, we hoped that its inclusion would also prompt more-experienced attendees to reflect on their current teaching practices and to consider how small-group teaching might translate from face-to-face teaching in the transition to an online environment.

Areas covered included providing students with a supportive learning environment, how class preparedness is more important than having answers to everything, and methods of promoting both teacher-student and student-student interactions in an online environment. Attendees were split into breakout rooms and were encouraged to use Padlet to document how they have – or plan to – foster supportive and active learning environments in their subjects.

Navigating Zoom and its features

Due to the global pandemic and subsequent lockdowns, many classes that were previously held face-to-face were held over Zoom, such as tutorials and workshops. Zoom has many useful features that can be leveraged for a valuable online classroom experience. While most attendees had some experience participating in Zoom meetings, many had limited experience when it came to managing a class in such a setting and maximizing the value of Zoom's features. Various features of Zoom were discussed, including how to schedule meetings, waiting rooms, recording capability, muting participants, breakout rooms, polls, whiteboards, and screen sharing. Further resources with greater details on particular processes were also made available to the participants.

Optimisation of physical setups for effective online teaching

Online teaching requires a different physical setup from that of face-to-face teaching. It is important that the tools and setup to be used are properly considered and optimised, from both the perspective of effective student learning, as well as the perspective of staff health, wellbeing, and safety.

Topics discussed included effective communication of materials, microphones, cameras, iPads/Tablets, and the use of webcams as document cameras. Attendees were also directed

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to resources for booking teaching pods containing all the equipment required for effective online teaching. Attendees were then split into breakout rooms, where they took turns testing their microphones and cameras, sharing their screens, and switching between their devices.

Digital tools to support active learning

There are many digital tools available that can help engage students and aid active learning in an online environment. They can be used to facilitate students interacting with both the teaching staff and with each other in different ways. In addition to the various features of Zoom, there are tools that can be used both in conjunction with synchronous online classes as well as asynchronous activities. Tools discussed included Kahoot!, Poll Everywhere and Padlet, as well as those available within the Canvas Learning Management System, such as quizzes and H5P interactive videos.

Engagement and initiative within teaching teams

Our junior teaching staff cohort consists largely of PhD candidates and high achieving Master's students. As many of them have plans to pursue academic careers, it is important for them to gain hands-on teaching experience. While this is the case when it comes to content delivery, many of them get minimal exposure to the behind-the-scenes aspects of teaching, for example curriculum design, content creation, and the exploration and setup of new digital learning platforms.

In this section, junior teaching staff were recognised as important bridges connecting students with lecturers, and vice-versa. They were encouraged to not merely deliver content, but to engage in proactive teaching. This might involve improving on existing teaching resources, developing new resources, and alerting subject coordinators of issue areas – and offering viable solutions. Several examples of such initiatives by past tutors/demonstrators were showcased, including projects revolving around the production of short concept-based video tutorials, question bank expansion, and the introduction of new programming-based workshops revolving around MATLAB Grader.

Towards the end of this section, attendees were encouraged to think beyond just content delivery, and to consider themselves as active contributors to the continuous improvement of their subjects. In many cases, internal teaching grants are available for subject development, and when working together with the subject coordinator, junior teaching staff members can make a large impact on subject delivery and materials, and ultimately the student learning experience.

Online feedback mechanisms

Feedback is a very important influence on student learning (Hattie and Timperley, 2007) but students report that it is often done poorly in higher education (Dawson, Henderson et al. 2019). While some student feedback comes via the lecturer, much of it is delivered via the junior teaching staff (written comments on assignments or verbally in class) or quizzes and online activities that the junior teaching staff may assist in building. As such, it is vital that we nurture a vigorous enthusiasm for clear, useful, and timely feedback in all our teaching staff. The concepts of feed-up, feedback and feed-forward were discussed, as well as logistical considerations, such as calibration of marks, and tools such as rubrics.

Blended synchronous learning

After the initial shift to purely online teaching, a new teaching mode was adopted by the University: dual-delivery mode. Dual-delivery is used here to describe any teaching mode that allows both on-campus and off-campus students to attend a given teaching session. Possible ways of dual-delivery include a split-cohort approach, with separated sessions for online and on-campus students, or mixed-cohort approach, where all students join the same session synchronously. In this paper, we refer to the latter as "blended synchronous learning". Our teaching staff were familiar with on-campus activities and had some experience with online-only sessions due to the initial shift to online teaching, which enabled them to have classes in

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a split-cohort mode. Blended synchronous learning, however, was an entirely new approach and so an introduction to this mode was recommended.

In this session, junior teaching staff were introduced to some of the expected challenges, both technical and cognitive, associated with blended synchronous learning. Strategies to manage and engage both online and on-campus cohorts in blended synchronous teaching sessions were also covered. On the technical side, they were encouraged to consider sharing content and adopting online tools that could be used by both cohorts for equity reasons. They were also introduced to types of activities and distribution of activities between students that might encourage cross-cohort interactions and help foster an equitable learning experience for both cohorts as well as promote student-student interaction.

Evaluation

To evaluate the usefulness of our pilot professional development program, the following exit survey was conducted using Qualtrics:

1. What is your department?
2. Overall, how would you rate this training session? *(Likert scale from 0: Not at all useful, to 10: Extremely useful)*
3. What would you like more help on? *(multiple options selectable)*
    - Zoom
    - Physical setup for online teaching
    - Quizzes and tools for active learning
    - Providing feedback to students
    - Blended synchronous learning
4. What was one thing you learned? *(free text response)*
5. What could be improved? *(free text response)*
6. Any other feedback? *(free text response)*

All responses were collected anonymously. The first question was included as an internal gauge for departmental engagement with the program. The remaining questions aimed to collect feedback to help us improve future runs of the program.

Outcomes & Discussion

215 people registered and attended our professional development program. 86 answered the exit survey. The results of the survey indicated that in general, participants found the program useful, with Question 2 registering an average rating of 8.27 (out of 10) with a standard deviation of 1.40 (n=86).

Figure 1 displays a pie chart visualising the areas that participants indicated that they would like more assistance (Question 3). The top three areas were quizzes and tools for active learning (31%), providing feedback to students (22%), and blended synchronous learning (20%). As expected, Zoom (12%) and the physical setup for online teaching (15%) did not rank highly, in line with our observation that a large percentage of participants had some prior experience with online teaching in Semester 1, 2020. We anticipate that blended synchronous learning will emerge as a major focus area in future runs of our program, in line with the University's recent transition to a strategy of actively promoting teaching in blended synchronous mode (as opposed to a split-cohort approach) where possible.

Figure 2 display word clouds visualising the free text responses to Questions 4, 5, and 6 of the survey, respectively. Taken together, the data displayed in Figures 1 and 2 (Question 4) suggest that while our participants were generally familiar with the infrastructure associated with online teaching (Zoom, physical setup for online teaching), most were not aware of the specific tools and platforms available to promote active learning and student interactions in online settings ("Tools", "Padlet", and "Kahoot" feature prominently in Figure 2, Question 4). While this program might have introduced them to some specific examples of active learning

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tools, the data for Question 3 (Figure 1) suggests that this area should be further expanded and emphasised in future runs of our program.

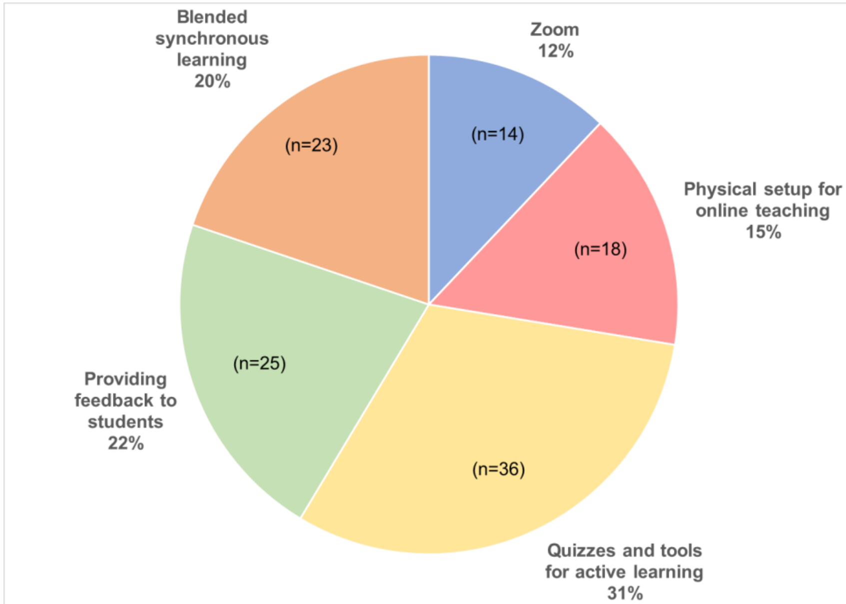

Figure 1: Areas in which participants indicated that they would like more assistance.

The word cloud in Figure 2 (Question 5) suggests that participants require more time to properly engage in discussions within their breakout rooms. More opportunities for discussion can not only result in more effective exchange of ideas but can also contribute to forming stronger connections and networks within this community of practice. One way of addressing this might be to extend the duration of our program from two to three hours in future runs – this might have the added benefit of providing participants with more time to digest the wide range of information being covered. Finally, the word cloud in Figure 2 (Question 6) aligns well with the quantitative data recorded for Question 2 in the survey: most participants found the program helpful in providing information relevant to navigating teaching in online environments.

Reflecting on the long-term trajectory of our program, we envision this program evolving from one characterised by unidirectional information flow from our team of more senior teaching-focused academics to junior teaching staff, to one where information flow is bidirectional. In the context of the framework for social learning systems, the previously described hallmarks of communities of practice – "competence" and "experience" – might effectively be flipped. Here, more senior academics will also have important lessons to learn from junior teaching staff. After all, the bulk of teacher-student interactions involve junior teaching staff members in tutorial/workshop settings, and they are therefore more well-poised to understand and relay the specific problems and challenges that students face. It is in tackling these problems and challenges that practical opportunities to experiment with new teaching-related tools and platforms organically arise. This ideal version of our program – one characterised by active discussions, debate, fluid exchange of ideas, and continuous improvement – aligns well with the key elements of communities of practice: engagement, mutuality, and repertoire (Wenger, 2000).

This study has 2 main limitations. First, it was conducted only in the Faculty of Engineering and Information Technology. Replication considering other faculties could contribute to a better understanding of the different contextual influences on the delivery of online teaching and learning and use of digital tools. Second, student results and performance were not examined

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in this study so we could not measure how students benefited from our program. This analysis was beyond the scope of this training, but future studies might focus on further examining the impact of professional development programs on student performance.

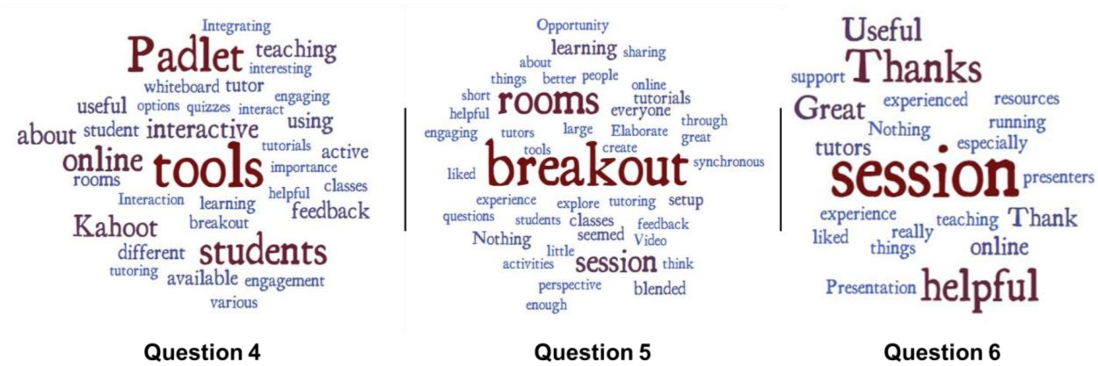

Figure 2. Word clouds corresponding to Questions 4, 5 and 6.

Conclusion

The ongoing coronavirus pandemic has resulted in the accumulation of a wealth of experiential knowledge on how best to navigate online teaching. However, due to circumstances associated with the pandemic, as well as the lack of a strong underlying sense of community revolving around effective teaching practice, this knowledge has not been properly transmitted to junior teaching staff. To address this issue, and to initiate the building of a more robust community of practice, we developed and piloted an online teaching-focused professional development program. This pilot run of our program was well-received, with feedback collected for implementation in future runs. Moving forward with this program, we envision it shifting from one involving unidirectional information transfer to one characterised by a more fluid exchange of ideas and best practices in online teaching.

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Navigating Remote Delivery of Capstone Project(s) to Achieve Equitable Learning Outcomes Within Higher Education

Sarah Grundy[a], Wesley Moss[b], Dilusha Silva[b], Daniel Eggler[a], Pierre Le-Clech[a] and Andrew Guzzomi[b]
The University of New South Wales, Sydney[a], University of Western Australia[b]
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WORKSHOP MODE

Hybrid mode during Perth business hours

OVERVIEW OF WORKSHOP

The final year capstone project is a major milestone for any student completing an engineering degree irrespective of discipline. With the disruption of the Covid-19 pandemic, all design project(s) courses since 2020 have resulted in innovative additions and modifications to existing course activities to be inclusive of the diverse learning environment of the cohort. This includes the capability of running industry-linked projects on-line to cater for both face-to-face and remote distance students and industry sponsors, restricted by border closures and time zones.

The significant number of students, staff and industry impacted by the Covid-19 imposed restrictions necessitated course adjustment and in some redesign of final capstone project courses. This was a common challenge amongst all Engineering disciplines across Australasia. The purpose of the proposed workshop is to share and collaborate learnings based on the capstone project(s) or similar courses to improve engagement, student experience and learning outcomes moving forward.

ACTIVITIES

Group facilitated discussion will be conducted based on various capstone project courses experienced during the Covid-19 era across institutions. Case studies will be provided by workshop facilitators and followed by semi-structured group facilitated discussions.

TARGET AUDIENCE

Education collaborators who are involved or interested in project-based learning, work-integrated learning, authentic assessment, team-based learning, and design to capstone projects. No prior knowledge is needed to participate.

OUTCOMES

Participants will:

1. Gain an understanding of the key capstone design learning outcomes
2. Share examples of design project implementation based on first-hand experience
3. Identify commonalities, pros, cons, sticking points and resolutions
4. Discuss lessons learned from remote distance involvement of students and industry sponsors
5. Establish best practice design project framework for various teaching modes

KEYWORDS

Capstone project, design project, project-based learning, authentic assessment

PRESENTERS' BACKGROUNDS

Dr Sarah Grundy leads design courses at the School of Chemical Engineering (CHEM), UNSW.

Mr Wesley Moss is a doctoral candidate and educator, who has facilitated capstone engineering design units at UWA for a number of years. He has experience engaging with students and industry sponsors both remotely and face-to-face.

Dr Daniel Eggler is an education focused academic at UNSW Sydney. He teaches mechanical design from 1st year to 4th year and loves how empowered students feel after prototype testing.

Professor Dilusha Silva leads capstone projects at the School of Electrical Engineering, UWA.

Associate Professor Pierre Le-Clech leads capstone projects at School of CHEM, UNSW.

Dr Andrew Guzzomi is the unit coordinator of the capstone projects within the Department of Mechanical Engineering at UWA and was awarded an AAUT citation in 2020.

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Reviewing The Engineers Australia Competencies

Prue Howard[a], Bernadette Foley[b],
Australasian Engineering Accreditation Centre[a], Engineers Australia)[b] ,
Corresponding Facilitator's Email: prueandpointo@gmail.com

WORKSHOP MODE

Hybrid mode during Perth business hours

OVERVIEW OF WORKSHOP

It is eight years since the Engineers Australia Competencies (Stage 1, Stage 2) have been reviewed. As the IEA approved changes to their Graduate Attributes and Professional Competencies in June 2021, it is timely that Engineers Australia reviews their competencies for the three occupational categories of Professional Engineer, Technologist and Associate. This workshop will give Australian educators the opportunity to contribute to that review, and the outcomes of future education programs.

ACTIVITIES

Activities will include an introduction to the new IEA competencies, and group based discussion of what Australia's competencies should look like for the next seven years. The workshop will conclude with participant groups sharing their views.

TARGET AUDIENCE

The target audience is Australian Engineering Educators, and any other Engineering Education stakeholders. No prior knowledge is needed, but an awareness of the current competencies would help.

OUTCOMES

The outcomes for those participating in the workshop is an increased knowledge and understanding of the Engineers Australia's current competencies, and hence their own program learning outcomes. Additionally, participants have the opportunity to contribute to redefining the Australian competencies going forward. The redefined competencies will help to develop the engineers of the future, through future program learning outcomes. Participants improved knowledge and understanding of the competencies will in turn equip them with the knowledge to effectively review and develop their own units.

KEYWORDS

Competencies, Accreditation Graduate attributes.

PRESENTERS' BACKGROUNDS

Dr Prue Howard is the Project manager for the EA Competency Review Project. She is also an AEAC Visit Manager, and has 30 years experience as an engineering educator. Bernadette Foley is the General Manager, Professional Standards for Engineers Australia, with a mix of industry, education experience.

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WORKSHOP

Aboriginal Perspectives in Engineering Education Practice and Research – Understanding and Appreciating Relationships

Juliana Kaya Prpic[a], Tom Goldfinch[b]
The University of Melbourne[a], The University of Sydney[b]
Corresponding Facilitator's Email: tom.goldfinch@sydney.edu.au:

WORKSHOP MODE

Hybrid during Perth business hours

OVERVIEW OF WORKSHOP

The Indigenous Perspectives space has drawn much interest from students, staff and faculty leaders alike. The Australian Council of Engineering Deans have recognised the importance of this in their position statement on Indigenous Perspectives in Engineering Education (ACED, 2018). Capacity in the engineering education community is slowly building around this topic (Kennedy, 2016, Prpic, 2018), but the fact remains that there are many more 'interested' people than there are 'experienced' people (Goldfinch, 2017). This creates the challenge for those who are experienced to provide support and advice to others. There is much good will, but converting good will into impact is an ongoing challenge. Frustrations often appear between the 'experienced' and the 'inexperienced', particularly around the issue of existing relationships others have built.

ACTIVITIES

We will explore the following topics, each from 'experienced' and 'inexperienced' perspectives:

1. The criticality of relationships with Aboriginal people and communities

2. The nature of relationships – different types, purposes, intents and what this enables in education and research

3. Scale and focus – Understanding what types of relationships can support large educational experiences, small immersive experiences, and research.

4. What are you are asking for when you want to collaborate or initiate relationships?

TARGET AUDIENCE

Those who have experience running on country learning experiences and community driven student projects in engineering curricula, and those who are interested in doing so themselves.

OUTCOMES

Clearer perspective on the importance of relationships in this space and the range of types of engagement possible through different types of relationships. Participants will leave with an improved familiarity with the individuals working this space and how they can be supported in forming new relationships.

REFERENCES (OPTIONAL)

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https://doi.org/10.52202/066488-0125

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KEYWORDS

Indigenous Perspectives, team building, communities of practice.

PRESENTERS' BACKGROUNDS

A/Professor Juliana Kaya Prpic is an educator and researcher at the University of Melbourne. Her work is exclusively focused on engaging with Aboriginal communities around Australia to collaboratively explore western engineering knowledge and Indigenous knowledge systems, and integrating Indigenous perspectives and ways of knowing into the engineering curriculum.

https://findanexpert.unimelb.edu.au/profile/189827-juliana-prpic

Dr Tom Goldfinch is Associate Dean (Teaching and Learning) at the University of Sydney, and was President of the Australasian Association for Engineering Education from 2016-2018. His research interests are around preparing graduates for engineering practice with a focus on qualitative studies of the social and cultural aspects of engineering education and practice. Tom has published numerous papers and led several projects on the topic of Australian Indigenous Perspectives and Knowledges in engineering education and practice.

https://sydney.edu.au/engineering/people/tom.goldfinch.php

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Developing intersectional inclusion capability in engineering students

Nick Brown[a], Eva Cheng[b], and Karen Whelan[c]
RMIT University[a], University of Technology Sydney[b], Queensland University of Technology[c]
Corresponding Facilitator's Email: nick.brown@rmit.edu.au

WORKSHOP MODE

In hybrid mode during Perth business hours

OVERVIEW OF WORKSHOP

To tackle the world's biggest challenges, the engineering profession needs to reflect the diverse make up of society. This workshop won't debate the need for intersectional inclusion (the why), but will share practice to enable an inclusive learning environment (the how). Few existing Australasian university student initiatives address inclusion at the classroom level or address a minority in the room rather than the cohort as a whole. The facilitators are developing an approach where engineering students develop 'inclusion capability' through participation in learning experiences which both model inclusion best practice and integrate intersectional inclusion capability building. This project has received a 2021 Engineering Education Grant from AAEE. The workshop will use a co-design approach to share and strengthen the preliminary inclusion model developed, with open discussions around challenges faced by participants in the classroom and developing improved practices to address these challenges.

ACTIVITIES

The facilitators will create a safe and respectful space where all backgrounds, experiences, and opinions are welcomed. The workshop will be an opportunity for participants to:

- Hear a short overview of the inclusion project to date along with the inclusion concepts that inform the model
- Reflect on the inclusion concepts and share insights and feedback using their experiences
- Identify diversity and inclusion challenges and successes they experience
- In facilitated small groups, work through the inclusion model to case studies, with a view to creating new designs for classroom practices that address intersectional inclusion

TARGET AUDIENCE

No prior knowledge is needed to participate in the proposed activities. Whilst relevant to all with an active interest in strengthening the engineering profession through inclusive practices, this workshop will most benefit academics researching or actively teaching in problem-based learning or large groupwork courses, as these match the pilot courses under study for the parent research project.

OUTCOMES

Those participating in the workshop will come away with ideas and a preliminary inclusion model for enhancing inclusion in their courses. Additionally, participants will be contributing to a collaborative project to develop inclusion best practice in engineering education.

KEYWORDS

Inclusion; diversity; equity; intersectionality

PRESENTERS' BACKGROUNDS

Karen Whelan (she/her), is the Associate Dean Learning and Teaching at QUT and a member of the AAEE Executive whose research focusses on inclusion. Eva Cheng (she/her) is a Senior Lecturer and Director of Women in Engineering and IT at UTS with expertise in gender equity and building inclusive communities. Nick Brown (he/him) coordinates large courses at RMIT on professional practice and social justice whose research covers diversity and inclusion in engineering education.

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Engineering Ethics Case Study

Bouchra Senadji [a], Elisa Martinez-Marroquin [b], Lincoln Wood [c]

Professor, Faculty of Engineering, Queensland University of Technology [a], Professor, Chair of Academic Board, University of Canberra [b], Lincoln Wood, retired [c]

Corresponding Facilitator's Email: b.senadji@qut.edu.au

WORKSHOP MODE

Hybrid mode during Perth business hours

OVERVIEW OF WORKSHOP

This workshop will involve participants in the evaluation of a case study of ignition switch failures on some US automobiles in the early 2000's. It explores how a failure of professional judgment progressed to a failure of professional ethics, resulting in avoidable deaths. Other factors magnified the extent of harm caused by these failures, but this case study is limited primarily to the root cause: decisions concerning the early engineering design of the ignition switch, and subsequent decisions in relation to that design. The case aims to show, amongst other things, how an ethical failure does not always start with bad intentions. The ethical dimension may develop gradually, and consequently evolve into a continuing intention to deceive.

ACTIVITIES

The case study (about five pages of reading) will be provided to registered participants in advance. Written questions will be provided with the case study. Groups of 3 – 5 participants (virtual if necessary) will work together to respond to the questions, following a ten-minute introduction from a Lead Facilitator. Groups will briefly report at the end of the session.

TARGET AUDIENCE

The target audience of the workshop is all staff who are engaged in L&T activities for professional practice and engineering design (all disciplines), although it is open to all who may be interested. The case is sufficiently non-technical and generic to provide valuable learnings for all engineering disciplines. A working knowledge of the EA professional Code of Ethics is highly recommended.

OUTCOMES

Appreciation of metacognition in professional judgment and decision; an understanding of the gradual nature of many ethical failures; case study materials for teaching professional ethics.

REFERENCES

Engineers Australia Code of Ethics 2019
https://www.engineersaustralia.org.au/sites/default/files/resource-files/2020-02/828145%20Code%20of%20Ethics%202020%20D.pdf (accessed 25 July 2021)

KEYWORDS

Professional judgment and decision, professional ethics, engineering design

PRESENTERS' BACKGROUNDS

Bouchra Senadji, Professor, Faculty of Engineering, Queensland University of Technology
Elisa Martinez-Marroquin, Professor, Chair of Academic Board, University of Canberra
Lincoln Wood, industry (retired)

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

What is the ideal engineer and how do we get there?

Conrad Drake, Stuart Payne, and Shawn Fernando
EA CLM (WA), EA CLM (WA), EA CLM (WA)
Corresponding Facilitator's Email: conrad.drake@ieee.org

WORKSHOP MODE

In-person in Perth

OVERVIEW OF WORKSHOP

Recent work, by both industry and academia, has highlighted the lack of understanding of the characteristics of a "good experienced engineer", particularly in linking work decisions to value, in the broadest sense. While the mechanics of engineering practice has been studied, how engineers can visualise, communicate and achieve "best value" outcomes for their stakeholders is recognised as a gap in our knowledge.

This is reflected in the paucity of education (beyond MBA or PhD) and criteria (between CPEng and EngExec) targeting the mid-career engineer.

This workshop extends an informed discussion on what the ideal mid-career engineer might look like; what development options there might be; and what challenges or contradictions can be seen.

ACTIVITIES

The activity will be in a "world café" format: an introduction outlining the problem and process; then group discussions on each of the three questions in sequence, with groups reporting back on their discussions between each one.

TARGET AUDIENCE

The target audience (participant types) are practicing engineers; engineering educators; engineering regulators; and the consumers of engineering services.

OUTCOMES

The primary outcome will be broader awareness of this problem in the target audiences. Specifically, it will help EA progress the definition of a mid-career engineer role and associated development path options.

REFERENCES

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https://theconversation.com/why-we-need-engineers-who-study-ethics-as-much-as-maths-161356

KEYWORDS

Engineering Value Sustainability

PRESENTERS' BACKGROUNDS

The three presenters are members of WA committee of the College of Leadership and Management of Engineers Australia (EA CLM (WA)). The current topic is a result of cooperation on sustainable engineering between the EA CLM (WA) and UWA's Public Policy Institute (PPI) last year. Each of the presenters is a senior engineer currently practicing in Western Australia.

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

First People's Engineering – implementing cases and experiences

Dr. Elyssebeth Leigh[a], Dr Cat Kutay[b], Lyndon Ormond-Parker[c] and Kaya Prpic[d]
University of Technology Sydney[a], Charles Darwin University[b], Australian National University[c], University of Melbourne[d]
Corresponding Facilitator's Email: elyssebeth.leigh@icloud.com

WORKSHOP MODE

Hybrid during Perth business hours

OVERVIEW OF WORKSHOP

This workshop builds on research and writing which is developing and extending new and updated contextual information about integrating First Peoples' engineering and practices. The workshop will employ aspects of the Cynefin Domains of knowledge to help participants explore their own plans for incorporating First Peoples' knowledges into future units of study.

ACTIVITIES

1. We will introduce participants to a method of graphically representing a current or pending course/unit of study and employ the process to guide an exploration of how to appropriately incorporate First Peoples' engineering knowledges into their work. This will be done in groups from the same location or unit theme, who may collaborate on creating the image.
2. Images are rotated around the group for a different person to complete the next stage
3. Knowledge management concepts (e.g. Cynefin, and Tex Skuthorpe) are introduced – with a focus on complexity and this is applied to making additions to the initial drawing
    a. This is for many a new knowledge domain and there will be some predictable uncertainty and confusion to be explored during the debriefing
    b. The task is to add challenges and ideas that can prompt the course owners to consider new/different approaches to teaching the course.
    c. Special consideration is given to listing observations about where First Peoples' engineering knowledge is relevant – new ideas, gaps and questions are added
4. The worksheets are then passed on once more to a new individual/group for the task of -
    a. critiquing the whole document
    b. offering ideas about how to manage the complexity of what is emerging
5. The amended document returns to its owners who review its amended condition and develop answers to these questions: a) *What do we need to do to implement these suggestions? B) Where might we look for support? C) What will change in our teaching/student learning because we can do this in future?*

TARGET AUDIENCE

The target audience is engineering educators interested in including First Peoples' engineering knowledges into courses/units off study. No prior knowledge is needed to participate in the activities.

OUTCOMES

1 A process of critically friendly review by peers outside the designer's sphere, will provide insights into opportunities for adding to/adapting work in new and creative ways

2 Critiquing another's work provides insights into one's own design and plans for teaching, and into ways of adding First Peoples' engineering knowledge into standard teaching practices

3 everyone will have an increased understanding of First Peoples' engineering knowledges and tacit insights into how engineering concepts can be similar in intent and different in execution.

KEYWORDS
First Peoples' engineering knowledge; Cynefin domains of knowledge; learning design

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PRESENTERS' BACKGROUNDS

Dr Leigh has an extensive record of tertiary education and has contributed to several academic projects on developing and extending awareness of First Peoples' engineering knowledge. Dr Kutay has worked in the arena of First Peoples' engineering knowledge for many years. Together they are 2 of the 4 co-editors of a new book on *First Peoples' Engineering for an Enduring* Culture to be published at the beginning of 2022.

Dr Cat Kutay is an electrical and computer engineer who has worked on Aboriginal Engineering and Information Technology projects for over 30 years and is researching how to improve two-way learning in our universities.

Dr Lyndon Ormond-Parker is of Alawarra descent, from the Barkly Tablelands of NT. He is a cultural heritage expert working in repatriation, archives, information technologies, heritage, and policy. He has coordinated and lectured in various tertiary level subjects and developed and delivered 'on country' learning.

A/Professor Juliana Kaya Prpic is an educator and researcher at the University of Melbourne. Her work is exclusively focused on engaging with Aboriginal communities around Australia to collaboratively explore western engineering knowledge and Indigenous knowledge systems, and integrating Indigenous perspectives and ways of knowing into the engineering curriculum.

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Current best practice, support mechanisms and experiences of project-based learning

Sarah Grundy[a], Guien Miao[b], Nick Brown[c], Marina Belkina[d], Tom Goldfinch[b]
The University of New South Wales[a], The University of Sydney[b], RMIT University[c], Western Sydney University
Corresponding Facilitator's Email: guien.miao@sydney.edu.au

WORKSHOP MODE

Hybrid during Perth business hours

OVERVIEW OF WORKSHOP

The importance of integrating tasks that are relevant to graduate practice into the engineering curriculum has been widely recognised. One key approach is project-based learning; however, there are significant barriers to improvement and wider adoption of practice-based approaches—including (but not limited to) the cost of scaling up projects for large cohorts, appropriately qualified teaching staff, organisational structures—which can lead to inauthentic approaches and staff attrition.

The team has received an AAEE engineering education grant to identify current best practice and support mechanisms for project-based learning. The project will provide greater clarity to teaching staff on what best practice in project-based learning is and what support they ought to seek from their T&L leadership for their project-based learning courses. The purpose of the workshop is to share and discuss preliminary data from the team's project and provide an opportunity to share experiences of running project-based learning.

ACTIVITIES

Group-facilitated discussion around experiences of teaching via project-based learning will be conducted. Exemplars of project-based learning practice and support mechanisms for successful project-based learning will be provided by workshop facilitators and followed by semi-structured group facilitated discussions.

TARGET AUDIENCE

Australasian collaborators who are involved or interested in project-based learning. No prior knowledge is needed to participate. Please note that artefacts generated from discussions will be used toward our study and, because of the way in which the workshop artefacts will be generated, the research team will not be able to withdraw or destroy individual participant responses. Our Participant Information Statement with further information on the study and Consent Form for participation are available at:

https://unsw-my.sharepoint.com/:f:/g/personal/z3519343_ad_unsw_edu_au/Eho0uIdwDj9ElfXuDRwXtyABM4-8--TYU6lzY33Ba9Q8yw

OUTCOMES

Participants will:

- Gain a wider understanding of exemplar practice in Australasian project-based learning
- Discuss support mechanisms required for successful, authentic project-based learning
- Share experiences of running project-based learning

KEYWORDS

Project based learning, support, academic capacity

PRESENTERS' BACKGROUNDS

All presenters have experience in teaching project-based learning units and thus have a clear understanding of the variability of experiences and support, as well as the challenges associated with running PjBL units. Dr Sarah Grundy teaches design units across first-fourth year in chemical engineering at UNSW. Dr Guien Miao has taught a project-based first-year unit at the University of Sydney. Dr Nick Brown teaches engineering practice through project-based learning at RMIT University. Dr Marina Belkina is a member of a project-based learning working group at WSU. Dr Tom Goldfinch teaches project-based units across first-fourth year at the University of Sydney.

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

How do Teachers Respond to Sustained Change?

Roger Hadgraft [a], Franziska Trede [a] and Monika Rummler [b]
[a] University of Technology Sydney, [b] Technische Universität Berlin
Corresponding Facilitator's Email: Roger.Hadgraft@uts.edu.au

OVERVIEW OF WORKSHOP

Higher Education is facing profound shifts: employers seek graduates who can work effectively with others in rapidly changing, transdisciplinary contexts, defined by globalisation, digitalisation, sustainability, complexity and, most recently, a global pandemic. COVID caused an instantaneous acceleration to online learning, where academics were forced to conduct their normally face to face classes through video conferencing tools. The calls for sustained change are challenging academics to rethink their traditional teaching role.

This workshop seeks to understand how academics have responded to these challenges, both short term (emergency remote teaching) and the longer-term shift to transdisciplinary teaching, where problems in the world have become more complex and where graduates need to be prepared for transdisciplinary learning, working with diverse communities on their solutions. The workshop will build upon a matching workshop held at SEFI in September 2021, to enable comparison of results between Australia and Europe.

ACTIVITIES

Participants will work in small groups to discuss three big domains:

1. Teaching changes due to COVID: What have been the **positive and negative changes in your teaching practices** in the last 18 months due to COVID? How have these changes **affected you and your colleagues** as teachers? What have you observed about **student reactions** to this new form of completely online teaching and learning? **What are we learning** for the future of learning and teaching?
2. Preparing graduates for their professional future: What do you see as some of the **big challenges** facing your graduates, in their lifetime? How do you see the **academic role changing** to prepare graduates for this increasingly complex world?
3. Supporting teachers for their changing role: What formats, topics, and methods of **continuing education** would prepare you to become a more future-focussed academic teacher to prepare graduates for their professional engineering future in this constantly changing, increasingly more complex and uncertain world?

TARGET AUDIENCE

All conference attendees will be welcome. Teaching academics will be the main focus.

OUTCOMES

At the conclusion of this workshop, participants will have explored future trends in teaching engineering, with the intent of defining continuing education needs for those future skills. They will personally benefit from exchanging points of view and collectively developing didactic strategies for future transdisciplinary teaching. The workshop will generate useful data for the implementation phase of the Engineer 2035 project, for ACED, AAEE, and the ADLT Network.

The anonymous data gathered at the workshop will also help the workshop facilitators to shape an ongoing research project: *Developing the Deliberate Teacher's Voice in the Age of Complexity, Sustainability, Globalisation, Digitalisation and Transdisciplinarity – how do Continuing Education Programs for Academics need to Change to Enhance Teaching Competence at University?*

KEYWORDS

globalisation, digitalisation, sustainability, complexity, COVID, transformation

https://doi.org/10.52202/066488-0131

PRESENTERS' BACKGROUNDS

Roger Hadgraft has 30 years' experience in transforming and researching engineering education, with a focus on project-based learning. This current research builds on research in the last 10 years on student outcomes and curriculum design.

Franziska Trede has dedicated her research career to professional practice exploring agency, identity, and professional responsibility. This current project builds on her concept of educating the deliberate professional.

Monika Rummler is the Deputy Director of TU Berlin's Centre for Scientific Continuing Education and Cooperation, where she is responsible for the continuing education program for the scientific staff of TUB with the focus on teaching and learning to improve academic teachers' teaching and learning competencies.

This research will compare academic development needs between Australia and Europe, through a matching workshop held at SEFI in September 2021.

ETHICS STATEMENT

We have received Ethics approval through the University of Technology Sydney's Human Research Ethics Committee Approval No. IML 202103 for this workshop. This workshop is part of a wider study to explore teaching experiences during COVID pandemic and the future higher education challenges to gain insights into the future directions of higher education, and engineering education in particular; see information and consent sheet in the appendix below.

You are invited to participate because you are a university teacher. We will audio record this session and use contributions into the chat function and a shared digital document from small group activities as our research data. All data will be de-identified and stored in a password protected secure space. Only the facilitators of this workshop have access to this data which will be kept for 5 years. Participation in this workshop will be assumed as consent for the anonymous and ethically responsible use of the ideas generated.

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Academic perspectives of student professional identity development

Amy Young, Les Dawes, Bouchra Senadji
Queensland University of Technology
Corresponding Facilitator's Email: a41.young@hdr.qut.edu.au

WORKSHOP MODE

Online only.

OVERVIEW OF WORKSHOP

Professional identity encompasses the holistic development of engineers including aspects of personal values and ethics, technical competency, academic success, leadership skills, experiences, and many others (Trede, Macklin, & Bridges, 2012). A strong professional identity has been linked to professional effectiveness and it has been found that the strength of students' professional identity is likely to affect their consequent success and retention as professional engineers (Crosthwaite, 2019; Sachs, 2001). Numerous influences to professional identity development have been previously identified as being intertwined with university experiences and learning. These primarily focused on theoretical content and classroom experiences through industry experience, consultations with project supervisors, autoethnographic reflections and the completion of the independent design project. As professional identity is a qualitative learning outcome, embedding it cohesively across undergraduate courses is challenging (Donnison & Marshman, 2013). This workshop seeks to explore academic understanding of student professional identity development through three short activities described below.

ACTIVITIES

This 90-minute workshop will involve group discussion, collaboration and three short activities related to understanding academic perspectives of student professional identity development. Participants will be invited to share thoughts and opinions based on given prompts through JamBoards, breakout rooms and discussions. These activities will be based around defining professional identity, identifying how students develop their professional identity and methods for facilitating professional identity development through curriculum and classroom activities.

TARGET AUDIENCE

Engineering academics with any level of teaching experience are the ideal participants for this workshop.

OUTCOMES

Outcomes from these groups will reveal professional identity influencers which are constructive or detractive to professional identity development, from the perspectives of current engineering educators. This will allow exploration between student self-identified influences and academia identified influences and thus allow universities to better facilitate student development and support within curriculum and co-curriculum engagement.

https://doi.org/10.52202/066488-0132

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KEYWORDS

Professional identity, engineering identity, undergraduate engineers

PRESENTERS' BACKGROUNDS

Amy Young

Amy Young is a PhD Candidate at the Queensland University of Technology with a research focus on engineering education and professional identity, currently in her second year of her PhD. Her professional and research interests are centred around education, diversity within engineering and environmental sustainability. Amy is also an experienced sessional academic at QUT, responsible for the delivery of undergraduate engineering courses to approximately 500 students.

Professor Les Dawes

As the Head of the School of Civil and Environmental Engineering at the Queensland University of Technology (QUT), Professor Dr Les Dawes has a keen interest in the education of STEM professionals and engineering education. His research and professional interests are centred around water resources, environmental sustainability and education. Les has received peer, community and national recognition for his commitment to furthering the quality of engineering education. Les has been the president of the Australasian Association of Engineering Education and a journal editor of the Australasian Journal of Engineering Education. He has also supervised numerous postgraduate research candidates.

Professor Bouchra Senadji

Professor Bouchra Senadji holds a Bachelor of Engineering in Electronics from ENSEEIHT, Toulouse, France, a Master of Engineering from University Paul Sabatier, Toulouse, and a PhD in Signal Processing from Ecole Nationale Superieure des Telecommunications, Paris. She has worked as a Telecommunications Engineer in Paris before joining Queensland University of Technology. She holds an Honours degree in Psychology from QUT. She has held the position of Academic Program Director for Engineering at QUT between 2012 and 2019, and a strong knowledge of the Engineering discipline. She led the design of the current Bachelor of Engineering and Master of Professional Engineering at QUT and has been involved in many Engineers Australia accreditations. Her support for students' learning has led to a number of awards, including a Commendation for Excellence in Engineering Education by the Australasian Association in Engineering Education and a national ALTC Citation. She is a Senior Fellow of the Higher Education Academy. She is also passionate about gender diversity and has been involved in many programs to improve gender diversity in STEM disciplines, including the SAGE Athena SWAN program.

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Culturally Relevant Pedagogy in Engineering: Examining How Who We Are Informs How We Teach

James Holly, Jr. [a], Avneet Hira[b], Homero Murzi[c], and Brooke C. Coley[d]
University of Michigan[a], Boston College[b] , Virginia Polytechnic Institute and State University[c], Arizona State University[d]
Corresponding Facilitator's Email: avneet.hira@bc.edu

ABSTRACT
Engineering educators should consider how cultural identity mediates the formation of engineering identity. This workshop will help engineering educators examine their instructional practices and how their teaching is informed by their cultural identity. This self-reflection will help instructors better utilize the cultural capital students possess to enhance engineering learning and identity.

WORKSHOP MODE
Online only out of Perth business hours

OVERVIEW OF WORKSHOP
This workshop is designed to formulate a community of practice by bringing engineering educators together that aspire to improve their teaching by acknowledging and supporting the cultural knowledge students possess. At the conclusion of this workshop, participants will be able to: 1) Apply principles of critical self-reflection to their pedagogy, 2) Identify the tenets of Culturally Relevant Pedagogy (CRP), and 3) Locate socio-political considerations embedded in their course content and assessment procedures

ACTIVITIES
The first part of this workshop will consist of participants being guided through exercises that will help them think about their cultural identity, and the ways in which their identity shapes their teaching. Participants will have the opportunity to share their responses to the exercises with the entire group of workshop participants, and participate in collective and individual sensemaking activities. Next, we will present the tenets of CRP as defined by Dr. Gloria Ladson-Billings. Participants will be provided with time to share their initial reactions and perceptions of these tenets with a partner to process their thinking. Lastly, participants will be given time to think about where there are opportunities to implement CRP in their instructional practices for a particular course they currently teach or would like to teach. Participants will do this by identifying the social and political aspects of their curricular materials, learning objectives, teaching strategies, and/or methods of assessment for student learning.

TARGET AUDIENCE
Academics and graduate students (higher degree) who teach engineering students and are interested in learning about CRP.

OUTCOMES
This short workshop will serve as an initiation for further workshops, discussions, and inquiries on how our cultural identities shape our teaching, and the impact of supporting students' cultural knowledge and ways of being on engineering learning experiences.

KEYWORDS
Culturally relevant pedagogy, faculty development, undergraduate engineering education

PRESENTERS' BACKGROUNDS
Dr. Holly, Jr. is a Detroiter, educator, and researcher focused on counteracting anti-Black racism in Science, Technology, Engineering, and Mathematics (STEM) education. Dr. Hira's scholarship is motivated by the fundamental question of how engineering and technology can support people in living

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well in an increasingly engineered world. Dr. Murzi's research is on inclusive pedagogical practices, industry-driven competency development, global engineering education, and understanding barriers Latinx and Native Americans have in engineering. Dr. Coley's work aspires to elevate the experiences of marginalized populations, dismantle systemic injustices, and transform the way inclusion is cultivated in engineering through the implementation of novel technologies and methodologies in engineering education.

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Research in Engineering Education Symposium &
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WORKSHOP

Curricular Innovation through Design-Based Research

Bart Johnson, Ron Ulseth
Iron Range Engineering
bart.johnson@itascacc.edu

WORKSHOP MODE

Online only

OVERVIEW OF WORKSHOP

When starting up new engineering education programs or creating significant change within current programs, there is both a need and an opportunity. The need is for the program to have continuous inputs for improvement. The opportunity is to harvest knowledge being created during the process to be shared widely. The dual cycles in a Design Based Research (DBR) study serve both. The purpose of this workshop is to share the DBR methodology and inspire participants to consider an adaptation of DBR in their next change process.

The workshop presents the utilization of DBR as an action research approach for innovation in an engineering program that provides a systematic and flexible methodology to improve the curriculum through iterative analysis, design, development, and implementation. The methodology can be instrumental to curricular innovation as it both guides the innovation and identifies the strengths and weaknesses of the curriculum at each iteration of development. Of greatest value to the broader engineering education audience is the increased understanding of how the methodology can be utilized to develop engineering curriculum in a rapidly evolving world, vital to engineering education staying relevant.

ACTIVITIES

The workshop will begin with a brief overview of DBR, with examples, followed by participants reflecting on past research experiences. The focus, for most of the workshop, will then center on participants developing DBR plans for a research question and application relevant to them utilizing a structured and shared learning experience. In-person participants are encouraged to bring a laptop.

TARGET AUDIENCE

Since DBR is a form of action research, participants should be interested in implementing a research study in a program where they are a participant in the program and seeking information that can be used to make programmatic improvements in the future.

OUTCOMES

The outcomes from the implementation of DBR are both inputs to the next iteration of the curricular or programmatic change process and research results to be published and shared with the greater engineering education community.

The outcomes of the workshop are a working knowledge of the DBR process and the beginnings of a personalized plan for future implementation of a DBR method at the participant's home institution.

KEYWORDS

action research, change process, curricular innovation

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PRESENTERS' BACKGROUNDS

The authors have recently started a new engineering program. They adopted DBR at the beginning and have formally published six iterations at international engineering education conferences. Bart Johnson and Ron Ulseth are the founders of the Iron Range Engineering and Bell programs in Minnesota in the United States. They adapted the Aalborg University model of PBL to create those programs. Johnson is the Vice-President of Academic and Student Affairs in the new Minnesota North College and Ulseth is the Director of the Iron Range Bell program. Both are affiliated with the Aalborg UNESCO Center for Problem Based Learning.

Workshop timeline:

0-15 Minutes: Introductions and DBR Overview with examples

15-30 Minutes: Breakout room, describe previous work that could have fit in a DBR model and what would have been the benefit

30-45 Minutes: Individuals develop research question and plan for DBR

45-60 Minutes: Q&A and additional DBR scaffolding discussion

60-90 Minutes: Participant development of PowerPoint slide for initial two cycles of DBR application

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Research in Engineering Education Symposium &
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5 – 8 December, 2021 - Perth, WA

WORKSHOP

Engineering Futures 2035: Implementing the Vision

Carl Reidsema [a], Roger Hadgraft [b], and Sally Male [c]
University of Queensland [a], University of Technology Sydney [b], The University of Melbourne [c]
Corresponding Facilitator's Email: c.reidsema@uq.edu.au

WORKSHOP MODE

Hybrid during Perth business hours.

OVERVIEW OF WORKSHOP

This workshop will explore the development of pilot curriculum projects aligned to key recommendations from the recently completed Australian Council of Engineering Deans (ACED) led review of Engineering Education: Engineering Futures 2035. These recommendations (represented by eight Work Packages) aim to significantly increase students' professional practice experiences and learning outcomes through enhanced collaboration with other universities, industry and the community.

ACTIVITIES

A brief overview of the main recommendations of the report will be presented (5-10 minutes). Participants will then work in breakout rooms, and at the conference venue, to refine and scope the current draft Work Packages, and then prioritise and plan potentially feasible pilot projects aligned to these work packages. Main outcomes will be shared in a plenary session.

TARGET AUDIENCE

All conference attendees are welcome. We are particularly keen to see those who have an interest in an aspect of the 2035 report and who are keen to engage in the conversation on how outcomes might be delivered by working collaboratively across universities.

OUTCOMES

Participants will gain an enhanced understanding of the 2035 report's recommendations as well as insight and opportunities to collaborate in the processes that ACED and the ACED Associate Dean Learning and Teaching Network (ADLTN) are proposing to assist Engineering Schools in achieving the Engineering Futures 2035 vision. Participants will have opportunities to collaborate and make significant contributions to the operational planning and future activities of ACED and the ADLTN towards identifying curriculum exemplar projects for funding in 2022-23.

REFERENCES

Engineering 2035 website: https://aced.edu.au/index.php/engineering-2035

KEYWORDS

Engineering 2035, curriculum change, industry collaboration, social impact, digital engineering

PRESENTERS' BACKGROUNDS

Carl Reidsema is a mechanical engineer known widely for his work in advancing professional practice in engineering education through large scale hands-on active learning through design and the flipped classroom.

Roger Hadgraft is a civil engineer with more than 25 years of experience in improving engineering education. He has published many papers on problem- and project-based learning (PBL), and the use of online technology to support student-centred learning.

Sally Male is Director of the Teaching and Learning Laboratory, Faculty of Engineering and IT, The University of Melbourne, and Editor-in-Chief of the *Australasian Journal of Engineering Education*

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

EA Accreditation as an evidence-based evaluation process

Bernadette Foley[a], Alan Bradley[a] and Bill McBride[b]
Engineers Australia[a] University of Newcastle[b]
Corresponding Facilitator's Email: bfoley@engineersaustralia.org.au

WORKSHOP MODE

The workshop will be facilitated in hybrid mode during Perth business hours.

OVERVIEW OF WORKSHOP

Program accreditation is an evidence-based evaluation process to determine if educational programs meet defined outcomes: the Engineers Australia (EA) Stage 1 Competency Standards for the three different occupational categories. Part of this process is the mapping of Program learning outcomes to EA Stage 1 Competencies, as well as the mapping of Unit learning outcomes to Program learning outcomes. A revised Accreditation Management System, to streamline accreditation criteria and consolidate documentation was introduced in 2019. While this has not fundamentally changed requirements, it has resulted in some changes to expectations for submissions.

This workshop aims to demystify the accreditation process and provide participants with practical tools to assist in the preparation of their next accreditation review. While structured for a 5-year general accreditation review, the workshop will also be applicable to special reviews including new programs.

ACTIVITIES

Participants will be able to explore accreditation requirements, map out key questions/tasks and develop an accreditation preparation plan for their next accreditation review. Participants will also be given the opportunity to understand how their activities relate to emerging accreditation trends, issues and concerns.

TARGET AUDIENCE

The workshop is specifically designed for academic and professional support staff likely to be involved in the accreditation of engineering programs at their institution over the next 12-24 months. This includes: Program Coordinators/Directors; Associate Deans; and accreditation or work integrated learning (WIL) support staff. While targeted at those with upcoming accreditation reviews, it is open to all with an interest in increasing their understanding of accreditation.

OUTCOMES

Participants will understand current accreditation requirements, particularly with respect to preparing for upcoming accreditation reviews.

KEYWORDS

Accreditation, constructive alignment, outcomes-based, Stage 1 competency standard, Mapping

PRESENTERS' BACKGROUNDS

Bernadette Foley is the General Manager, Professional Standards for Engineers Australia and has responsibility for all accreditation activities undertaken in Australia. She also manages and reports on Engineers Australia's obligations as a signatory to the Washington, Sydney and Dublin Accords. Bernie has a mix of industry and academic experience, including overseeing accreditation activities from the providers perspective, as an Associate Dean (Education).

Co-facilitators will include an Alan Bradley as in his role as EA Visit Manager and Professor Bill McBride to provide recent accreditation review experience from the academic perspective. These facilitators will be able to provide on the ground experience and tips for successful accreditation.

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Research in Engineering Education Symposium &
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5 – 8 December, 2021 - Perth, WA

WORKSHOP

Aboriginal Perspectives in Engineering Education Practice and Research: Barriers and Enablers for Building Student Understanding and Cultural Intelligence through Remote Project-Based Learning

George Goddard[a], Juliana Kaya Prpic[b] ,Grace Roberts[c]
Engineers Without Borders Australia[a,c], University of Melbourne[b]
Corresponding Facilitator's Email: g.goddard@ewb.org.au

WORKSHOP MODE

Hybrid mode during Perth business hours

OVERVIEW OF WORKSHOP

Increasingly Australian Universities are seeking to embed a consideration of Aboriginal and Torres Strait Islander perspectives across curricula for all degrees and disciplines. This is an encouraging move, one recognised as important by the Australian Council of Engineering Deans (ACED, 2018). However not all engineering educators necessarily have the skills and relationships required to engage with Aboriginal and Torres Strait Islander communities and perspectives appropriately nor meaningfully in their teaching. Building on the other workshop in this series, Aboriginal Perspectives in Engineering Education Practice and Research – Understanding and Appreciating Relationships, this workshop explores how engineering educators can and have been leveraging remote project-based learning content, like the EWB Challenge which has had an explicit focus on remote Indigenous homelands in 2020 and 2021, and publicly available content to build safe spaces where students can build their cultural intelligence and learn from Aboriginal and Torres Strait Islander perspectives.

ACTIVITIES

With a strong focus on participant knowledge sharing we will:

- Understand what materials and strategies participants are using to meaningfully bring Aboriginal and Torres Strait Islander Perspectives into the classroom
- Map the barriers to doing this in curricula
- Co-create/share strategies for overcoming these barriers
- Establish next steps for ongoing mutual learning

TARGET AUDIENCE

- Teaching staff who already engage with EWB project-based learning resources, specifically the EWB Challenge
- Teaching staff interested in introducing Aboriginal and Torres Strait Islander perspectives in engineering curricula but who don't necessarily hold the relationships to support this

OUTCOMES

Participants will have a better understanding of how they can use existing content to support safe spaces where students can understand and celebrate Aboriginal and Torres Strait Islander perspectives, building cultural competence while managing risk to communities.

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REFERENCES (OPTIONAL)

Include any relevant references for the workshop. If references are included please use APA referencing style.

KEYWORDS

Indigenous Perspectives, project-based learning, communities of practice.

PRESENTERS' BACKGROUNDS

George Goddard is a development practitioner, educator and researcher with 13 years of experience in the International Development and Environmental sectors. In his current role as Research, Learning and Influence Specialist at EWB George has a focus on supporting engineering students and the professional sector to adopt approaches which will enable the creation and application of technologies that benefit All. He believes Reconciliation, celebrating and learning from Australia's First Engineers are critical to this mission.

https://ewb.org.au/team-showcase/george-goddard/

A/Professor Juliana Kaya Prpic is an educator and researcher at the University of Melbourne. She is exclusively focused on engaging with Aboriginal communities around Australia to collaboratively explore western engineering knowledge and Indigenous knowledge systems, and integrating Indigenous perspectives and ways of knowing into the engineering curriculum.

https://findanexpert.unimelb.edu.au/profile/189827-juliana-prpic

Grace Roberts is a development practitioner and education facilitator with 7 years of experience in not-for-profits supporting meaningful inclusion of marginalised communities through education initiatives. Grace currently coordinates the EWB Challenge across Australia and New Zealand. She is interested in participatory approaches and helping engineers recognise and navigate the complex social world they influence through technology. She believes this starts with actively learning from deep knowledge and perspectives shared by First Nations peoples.

https://ewb.org.au/team-showcase/grace-roberts-2/

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Teaching engineering for complex contexts

Nick Brown[a], Jeremy Smith[b], Scott Daniel[c], Tanja Rosenqvist[a] and Cris Birzer[d]
RMIT University[a], Australian National University[b] , University of Technology Sydney[c] , University of Adelaide[d],
Corresponding Facilitator's Email: nick.brown@rmit.edu.au

WORKSHOP MODE

In hybrid mode during Perth business hours

OVERVIEW OF WORKSHOP

Humanitarian engineering is a field that addresses poverty, marginalisation and disadvantage (the why), using design thinking (the how), by developing essential service innovations (the what), for complex contexts (the where). With increasing interest from students, universities (including degree programs, majors and minors) and organisations and greater demand through the number and complexity of disasters, responses, and vulnerabilities, the humanitarian engineering field must consider how to ensure appropriate and quality teaching practice. This is critical when graduates will be working with marginalised and vulnerable individuals and communities in high-risk environments with significant consequences from decisions and actions. An ongoing project being led by the humanitarian engineering community of practice within Engineers Australia is determining what humanitarian engineering competencies are critical for practice and how they align to the Engineers Australia Stage 1 framework.

This workshop will unpack leading practice with regards to preparing students to work with marginalised communities, touching on risk, ethics, cross cultural communication, and power dynamics. It will contribute to the development of approaches and frameworks that can be used to review formal university programs to ensure appropriate education and preparation of graduates.

ACTIVITIES

A review of humanitarian engineering education in Australia, its relationship to the EA Stage 1 Competencies, and the ongoing project of "Professional Humanitarian Engineering" will be briefly introduced. Different aspects of the curriculum related to the application of engineering in complex scenarios will be identified, and then in a World Café format participants will share and develop ideas about how best to prepare students to deal with that complexity.

TARGET AUDIENCE

No prior knowledge needed to participate in this workshop. The session will be most relevant to educators looking to prepare students to deal with complexity and the application of engineering in complex scenarios. The workshop will be delivered from an Australasian perspective.

OUTCOMES

Participants will leave the workshop with new strategies to prepare students to deal with complexity and identify how this links to degree learning outcomes. Participants will also have built their networks with other academics interested in engineering in complexity and will have contributed to the professionalisation of humanitarian engineering.

KEYWORDS

Humanitarian Engineering; Complex Contexts

PRESENTERS' BACKGROUNDS

All presenters are involved with humanitarian engineering education at their home institutions and beyond and have track records delivering workshops at previous AAEE conferences. They are all members of the humanitarian engineering community of practice within Engineers Australia.

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Supporting international student learning in an online environment

Siva Krishnan[a], Jayashri Ravishankar[b], and Chamith Wijeyanayake[c]
Deakin University[a], University of New South Wales[b], University of Queensland[c]
Corresponding Facilitator's Email: Siva.Krishnan@deakin.edu.au

WORKSHOP MODE

Hybrid during Perth business hours

OVERVIEW OF WORKSHOP

This workshop will focus on the support for international students in an online environment. International students are under considerable pressure as they are far from home and may only have superficial acquaintances with local people and other students in similar situations. It is likely that onshore international students as well as those international students studying their degrees from overseas destinations may live in sub-optimal conditions for online learning. The intent of this workshop will be to unpack the challenges faced by international students studying engineering degrees in an online environment, and to understand what it means to support their learning and development during the COVID-19 pandemic situation and beyond.

ACTIVITIES

This 90-minute workshop will involve interactive discussions between conference delegates, a panel of students, academic staff and industry practitioners. The facilitators will guide the interaction by setting the scene, posing initial questions to draw responses from panel members and allowing time for workshop participants to engage in interactive discussion through questions and comments. The workshop will be delivered in a fully online mode and will require participants to bring their own device for participation in a Zoom session.

TARGET AUDIENCE

Academic staff in Australian Engineering departments are the target audience for this workshop. Participants are not expected to have prior teaching interactions with international students.

OUTCOMES

At the end of this workshop, participants will be able to:

- promote a deeper understanding of the needs of international engineering students studying engineering degrees online
- influence engagement of staff in engineering units across the sector to collaboratively address challenges international students face
- evaluate the delivery of learning experiences online during and beyond the COVID-19 pandemic situation.

KEYWORDS

International student experience, support for learning online, support for teaching online, engineering education.

PRESENTERS' BACKGROUNDS

Siva Krishnan is a Associate Professor in Engineering and Director of Postgraduate Studies at Deakin University. In this role, he oversees the design, delivery and performance of postgraduate coursework degrees, with a particular focus on enriching students' learning experiences.

Jayashri Ravishankar is Associate Professor and Deputy Head of School (Education), at the UNSW School of Electrical Engineering and Telecommunications. Serving as the Postgraduate

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coursework coordinator for the School 2013-19, she has immense experience dealing with the needs of international postgraduate students. She currently plays a major role within the Faculty of Engineering International Committee helping to enrich the experience of international students at UNSW Engineering.

Chamith Wijenayake is a Senior Lecturer in the School of Information Technology and Electrical Engineering, University of Queensland. He has been contributing towards innovative learning and teaching activities since 2010 including the development of blended and flipped mode classes.

Research in Engineering Education Symposium &
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5 – 8 December, 2021 - Perth, WA

WORKSHOP

What to do with late online exams?

Christopher Honig[a]
[a]*University of Melbourne*
christopher.honig@unimelb.edu.au

WORKSHOP MODE

Hybrid during Perth business hours

OVERVIEW OF WORKSHOP

Online exams allow for the assessment of remote students, they offer lower cost overheads (than in-person exams) and facilitate the use of advanced software packages in examination. So during COVID they have become much more normalized in engineering education.

But unlike in-person exams, there is no easy way to enforce the end of the exam. And unlike assignments, an extra ten minutes of working time can offer significant student advantages. So what should happen when students submit their online exam late?

Some Universities have automatic fail policies for late submission. Some impose a pro-rata late penalty. Some offer a grace period for late submission before imposing a penalty. Some have no penalty. Often there is no consistent policy within the same institution (instead local divisions or individual lecturers impose different rules).

This workshop will review the diversity of practices from the workshop participant's host institution and facilitate a guided discussion of what consequences should exist for late submissions and why. The workshop will be scaffolded with preliminary results from an analysis at the University of Melbourne.

ACTIVITIES

The workshop will use a series of games and interactive activities on a Miro board to facilitate a discussion of what policies currently exist (in each participant's own institution) and what policies they believe *should* exist and *why*.

TARGET AUDIENCE

Subject coordinators, people involved in teaching or engineering education academics. Prior knowledge of assessment policies is not required for participation in the workshop.

OUTCOMES

With the rapid transition due to COVID, many online teaching and assessment designs have been created ad hoc; there is now an opportunity to critically reflect and optimize online teaching models and assessment. The workshop will facilitate a conversation that academics can bring back to their own institutions, with a document summarizing the key findings from the workshop.

KEYWORDS

Online exams; automatic fail; timed assessment

PRESENTERS' BACKGROUNDS

I am an early career teaching specialist in the Department of Chemical Engineering at the University of Melbourne. In 2021, I accepted 2 new roles as Assistant Dean (Student Life) in the Faculty of Engineering and Information Technology (FEIT) and as Deputy Chair of the Teaching and Learning Quality Assurance Committee (TALQAC) a sub-committee of Academic Board at the University of Melbourne, focusing on teaching policy and compliance.

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Transforming Engineering Education through Critical Reflection

Grace Roberts [a], Luke Smith [b], Mark Abbott [c] and Irshaad Vawda [d]
Engineers Without Borders Australia [a], Engineers Without Borders UK [b], Engineering Change Lab Canada [c]
Engineers Without Borders South Africa/ International [d] Corresponding Facilitator's Email: challenge@ewb-uk.org

WORKSHOP MODE

Hybrid session during Perth business hours, and an additional online session out of Perth business hours.

OVERVIEW OF WORKSHOP

Engineers Without Borders is a global movement of over 60 organisations, advocating for a stronger focus on the ethical, social, environmental and cultural aspects of engineering. Over the last decade 150,000 students have participated in an Engineers Without Borders' design challenge as part of their degree course. These design challenges enable university academics to respond meaningfully to best-practice engineering education trends and develop future-fit engineering competencies within graduates at scale. In 2020, a group of Engineers Without Borders International and Engineers Without Borders organisations from Australia, Brazil, Canada, India, the Netherlands, the Philippines, UK and USA, consulted on an open letter (see: http://www.ewb-international.org/activities/engineering-education-wfeo/) to influence changes to the international Graduate Attributes and Professional Competencies (GAPC) Framework. The updated GAPC framework has the potential to further transform the engineering profession, with graduates who are critical thinkers, thoughtful about the impact and outcomes of their work, capable of working in diverse and inclusive teams and are committed to lifelong learning. In this workshop we engage in the process of critical reflection on the role of engineers that we argue is required to meaningfully build the competencies that will ensure a sustainable future for all people and the planet.

ACTIVITIES

Discussion based presentation with breakout groups, guided plenary and Q&A. Mural or other digital platforms will be used to consolidate input and sharing learning experience.

TARGET AUDIENCE

Engineering researchers and educators. No prior knowledge needed.

OUTCOMES

Learning outcomes are to practice critical reflection of engineering and its impacts, reflect on the current views of engineering that underpin engineering education and practice and connect with the call for transformative GAPC's that form the bases of engineering education and practice.

KEYWORDS

transforming, responsible, universities, engineering, competencies, critical reflection

PRESENTERS' BACKGROUNDS

Grace Roberts and Luke Smith coordinate the EWB Challenge programme, and the Engineering for People Design Challenge/ Efficiency for Access Design Challenge respectively. These deliver real-world project contexts to the classroom and inspire students to act responsibly. Irshaad Vawda and Mark Abbott have worked in the executive team at Engineers Without Borders South Africa and Canada respectively. Mark now leads the Engineering Change Lab in Canada and Irshaad is on the board of Engineers Without Borders International.

Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Industry Field Trips: Educator and Student Perspectives

Beverly Coulter, Tony Heynen and Shaun Chen
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WORKSHOP MODE

Hybrid

OVERVIEW OF WORKSHOP

The School of Chemical Engineering at the University of Queensland (UQ) has been successfully running industry field trips for students for over 40 years. This workshop aims to explore the success factors, challenges, and the value of running industry field trips for engineering undergraduate and postgraduate students. We will explore these concepts in the context of three main themes - enhancing student learning and motivation; developing an early sense of professional identity; and building friendships and a sense of cohort through participation in industry field trips.

ACTIVITIES

The expected format of the workshop will be:

- Introduction to UQ Chemical Engineering industrial field trip programs, including a short photo display,
- Presentation of UQ undergraduate and postgraduate student responses to recent surveys following industry field trips in 2021,
- Interactive survey of workshop participants to gauge the range of field trip participation and perceived value across Australia and New Zealand engineering Schools,
- Open participant discussion of teaching themes including student motivation and learning, early professional identity, and cohort and friendship building through industry field trips.

TARGET AUDIENCE

The target audience for this workshop will be engineering educators who are interested in learning about and incorporating industry field trips into their engineering programs. No prior knowledge of field trips is required.

OUTCOMES

Workshop attendees can expect to learn how engineering schools can incorporate industry field trips into their programs to enhance student learning, motivation, and experience.

KEYWORDS

Industry field trips, Professional identity, Student experience

PRESENTERS' BACKGROUNDS

All three presenters are Teaching-Focussed academic staff in the School of Chemical Engineering at UQ. Bev Coulter is Lecturer and Course Coordinator for a 2nd year foundation chemical engineering course and runs the annual 2nd year industry field trip to Gladstone. Tony Heynen is Program Lead for the Masters of Sustainable Energy (MSE) program and runs the annual MSE Field trip. Shaun Chen is a postdoc researcher in the area of student learning and student experience.

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Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

WORKSHOP

Publishing in the *Australasian Journal of Engineering Education*

Sally Male[a], Scott Daniel[b], Kacey Beddoes[c], Ray Eaton[d], Rosalie Goldsmith[b], Julia Lamborn[e], Sasha Nikolic[f]

University of Melbourne[a], University of Technology Sydney[b], San José State University[c], Macquarie University[d], Monash University[e], University of Wollongong[f]

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The Australasian Journal of Engineering Education (AJEE) is the peak research journal in our region. The journal is offered as a means of exchanging current work and ideas, predominantly from Australasian engineering education faculties and as a resource for Continuing Professional Development for our community. The journal is open to members and non-members of Engineers Australia.

WORKSHOP MODE

Hybrid mode during Perth business hours

OVERVIEW OF WORKSHOP

In this workshop, the Editorial Board Team of the AJEE will review the journal's Aim and Scope, the submission and review process, and facilitate discussions on publishing.

ACTIVITIES

In this interactive session, participants will be led in a discussion about the AJEE, the review process, and how to write for publication, including responding to reviewers' comments. Participants will have the opportunity for Q&A with the AJEE Editorial Board.

TARGET AUDIENCE

Researchers in engineering education who are considering publishing in AJEE.

OUTCOMES

Participants will have a better understanding of the scope of AJEE and be better equipped to submit successful manuscripts and revisions for publication.

KEYWORDS

Journals, publishing, writing for publication

PRESENTERS' BACKGROUNDS

This workshop will be facilitated by the Editorial Team of AJEE: Editor-in-Chief, Sally Male, Deputy Editors, Scott Daniel and Kacey Beddoes, and Associate Editors, Ray Eaton, Rosalie Goldsmith, Julia Lamborn, and Sasha Nikolic.

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Research in Engineering Education Symposium &
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WORKSHOP

Simulation across the disciplines – exploring simulation as a learning mode

Dr Elyssebeth Leigh[a], Jan Roche[b]
University of Technology Sydney - FEIT[a], Australian Catholic University[b]
Corresponding Facilitator's Email: elyssebeth.leigh@icloud.com

WORKSHOP MODE

Hybrid mode during Perth business hours

OVERVIEW OF WORKSHOP

This workshop uses simulations to explores aspects of the Engineering Futures 2035 report, specifically: *Will professional engineers be required to work more at .. problem definition in multi-disciplinary teams with more representatives of communities we serve, requiring greater and deeper communication skills?* (Crossthwaite, 2019 p1) including *… enabling skills such as complex problem solving and critical thinking … identified as critical by employers (Ibid p14).*
Simulation and modelling are familiar engineering tools, and this workshop extends that awareness by using simulations designed to aid learning about *complex problem solving* and *environmental awareness.* The workshop demonstrates how familiar basic modelling and simulation principles apply equally to non-technical topics, while exploring additional skills and knowledge which educators need to be proficient with non-technical simulations. It introduces ways in which simulation can be used to achieve learning objectives and assessment tasks across the engineering syllabus.

ACTIVITIES

The workshop employs three different simulations to explore possible futures of engineering education and help participants learn about employing similar activities in their own contexts for teaching about such things as problem finding, complexity, and working in teams.

1. The first simulation introduces problem finding and working with complexity. Debriefing includes discussion of educator skills and knowledge required for using similar activities.
2. The second activity focuses on key points of the Engineering Futures 2035 report to identify implications of the future engineer profile set out in the diagram on P63.
3. The final activity provides participants with means of continuing to develop their capabilities for using simulation for new learning experiences as they prepare the engineers of the future.

TARGET AUDIENCE

No prior knowledge is needed to participate. The workshop will be of value to those looking to extend their capabilities for using interactive approaches to teaching and assessment.

OUTCOMES

Participants will enhance their awareness of simulation as an educational tool, and learn to expand their own capabilities for developing novel techniques for preparing the engineers of the future.

REFERENCES

Crosthwaite, C. (2019). *Engineering Futures 2035*. Retrieved from https://tinyurl.com/tkzvh4kc 3/8/2021

KEYWORDS
Educational simulation; engineers of the future; working with complexity; problem definition

PRESENTERS' BACKGROUNDS

Dr Leigh is a simulation professional with more than 30 years' experience as an academic educator and researcher.

Jan Roche is a doctoral candidate and simulation specialist on the academic staff at Australian Catholic University in Sydney.

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Research in Engineering Education Symposium &
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5 – 8 December, 2021 - Perth, WA

WORKSHOP

Improving Student Practicums

Susan Kreemer Pickford[a], Sally Male[b,c], Sonia Ferns[d], Martina Calais[e], Nazim Khan[c], Majid Rad[f], Douglas Bruce[a], Brian Haggerty[a,c], Lorie Jones[a], Kym Spann[a], Bernadette Foley[a], Jeremy Leggoe[c], David Parlevliet[e], Luke McGuirk[g]

Engineers Australia[a], The University of Melbourne[b], The University of Western Australia[c], Curtin University[d], Murdoch University[e], Edith Cowan University[f], Institute of Public Works Engineering Australasia[g]

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By engaging with practice, engineering students develop capabilities, self-efficacy, motivation, and professional identity, among other outcomes. Many students engage with practice by completing work experience, also known as a practicum. However, availability and quality of practicums vary. Engineers Australia leads a working group of senior engineers, university staff and students to improve the availability and quality of students' engagement with practice. To understand students' recent experiences, especially during the COVID-19 pandemic, we surveyed stakeholders.

WORKSHOP MODE

Hybrid mode during Perth business hours

OVERVIEW OF WORKSHOP

Strengths, weaknesses, opportunities and threats to developing engineering capability through practicums will be explored and addressed. Participants will contribute to research.

ACTIVITIES

Preliminary results of a survey of Australian engineering students and graduates about their practicums will be presented. In facilitated discussions, workshop participants will explore explanations for the survey results, and identify recommendations.

TARGET AUDIENCE

Engineers, university staff, and engineering students from around the globe are welcome.

OUTCOMES

Participants will understand the current experience of practicums for students of Australian universities, and contribute to recommendations to enhance engineering capability development.

KEYWORDS

engineering education, employability, work integrated learning, placements

PRESENTERS' BACKGROUNDS

The facilitators are senior managers of Engineers Australia, senior engineers who are office-bearers of Engineers Australia, engineering academics, and work integrated learning practitioners in universities, including leading researchers in work integrated learning in engineering.

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Research in Engineering Education Symposium &
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WORKSHOP

User Centered Design Thinking to Drive Student Engagement in a Makerspace

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ABSTRACT

Telstra Creator Space is a University makerspace located at the University of Melbourne's innovation precinct, Melbourne Connect. It is accessible to students and staff from the Faculty of Engineering and Information Technology (FEIT) and to Melbourne Connect tenants to; design, fabricate and test their early prototypes.

The University of Melbourne has appointed QinetiQ Australia to manage the operations of Telstra Creator Space and drive engagement with the broader FEIT.

How might we generate engagement with teachers and students to connect them with makerspace capability?

Determining and understanding the needs of various groups has been key to developing a makerspace where users can design and complete their practical projects. A high level of engagement across the groups is required to overcome their respective challenges and maximise the benefits of a makerspace.

This workshop will take a user centred, design thinking approach to the problem of attracting and driving student engagement in a University makerspace. The workshop will guide participants to identify and explore the barriers and hurdles that impact on wider university engagement and limit usage of makerspaces.

The participants will discover, define and explore, then develop and test their solutions. Participants will apply this framework to their makerspace challenge, develop and share their solutions, and receive feedback from the facilitators and the wider group.

WORKSHOP MODE

The workshop will be facilitated in hybrid mode.

OVERVIEW OF WORKSHOP

Applying design thinking methods to attract and engage users (students, academics and others) to a University makerspace.

ACTIVITIES

The workshop will apply the principles of user centred design to understand and define the problem of, and a solution to, attracting and driving student engagement in a University makerspace. In small groups attendees will be guided through the process by the team from the University of Melbourne's Telstra Creator Space.

- Understanding who the users are and where they are coming from, including how to identify all potential users
- Defining the problems the users are encountering prior and during engagement with a makerspace
- Defining a solution or solutions to the issue and the fastest and most meaningful way to validate them
- Understand where the solution fits in the users experience, and how it might be further iterated to improve engagement or better understand the user

Groups will be given the opportunity to share their solutions to the workshop and compare notes.

Non-standard materials will not be required, pens, markers and paper will be provided.

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TARGET AUDIENCE

Academics looking to transition their units to more hands-on teaching, existing makerspace staff looking to generate further student engagement.

OUTCOMES

Attendees will gain first-hand experience with understanding user needs and rapidly validating proposed solutions for driving student engagement in a makerspace. Attendees will use design thinking to generate a minimum viable concept for their particular makerspace problems.

KEYWORDS

Makerspace engagement, User centred design, design thinking.

PRESENTERS' BACKGROUNDS

Matthew McCoy is the Service Lead at the University of Melbourne's Telstra Creator Space, Matthew has overseen the process of service design and engagement, from inception to delivery.

As the Service Designer, Sara has applied design thinking to develop the user experience and engagement at the Telstra Creator Space, working with academics and students to understand, define and develop solutions.

Filip Surla has been supporting the service development in a variety of ancillary roles including training management and student mentoring.

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Research in Engineering Education Symposium &
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WORKSHOP

Reflecting on the COVID induced transition from paper-based to digital assessment

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WORKSHOP MODE

Hybrid mode during Perth business hours

OVERVIEW OF WORKSHOP

Participants will share knowledge and experience related to digital assessments. Best practices and effective strategies to minimise academic misconduct and to design quality digital and online assessment will be explored. Topics include: individualised assessment considerations; do digital questions need to be different from paper questions? strategies to ensure an equitable online assessment experience; promoting academic integrity in an unsupervised exam setting; project-centric assessment - can we get rid of exams altogether?

ACTIVITIES

This workshop will be conducted as a "World Cafe" style discussion by topic. Through open and group discussion, participants will share their own experience while learning from others about this difficult period of transition. This session will provide them with opportunities to reflect on what did and did not work in assessment and enable the development of strategies to take forward into future assessments. Groups and facilitators will share discussion summaries to conclude the session.

TARGET AUDIENCE

Educators, lecturers, and support staff involved in online or hybrid delivery.

OUTCOMES

At the conclusion of this session participants will have: shared views about practices across institutions; discovered new strategies to implement successful digital assessment in their own delivery; highlighted aspects of digital assessment that require further investigation.

REFERENCES (OPTIONAL)

Engineering Educational Design team (2020). *Experiences of Assessment During COVID-19*. Unpublished manuscript. Faculty of Engineering, University of Monash. Retrieved from https://tinyurl.com/7j4u97m2

KEYWORDS

Digital assessment, online assessment, academic integrity, COVID response

PRESENTERS' BACKGROUNDS

Nik, Foez, Michael and Yogita are Educational Designers in the Faculty of Engineering at Monash University and Professor Julia Lamborn is the Faculty's Associate Dean of Education. Together they led many of the transition initiatives to online learning during 2020-21, advising and collaborating with academics on technology and pedagogical solutions.

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WORKSHOP

Teaching the Entrepreneurial Mindset to Engineering Students

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WORKSHOP MODE

Online only

OVERVIEW OF WORKSHOP

Workshop participants will walk away with a "self-contained kit" for integrating the entrepreneurial mindset into K-16 coursework (with particular focus on engineering undergraduate coursework).

ACTIVITIES

Workshop activities include short lectures to showcase theoretical information, active learning to ideate lesson plans, and networking to share best practices.

TARGET AUDIENCE

The target audience is K-16 engineering educators and/or pre-service engineering educators (e.g., students about to enter the academic job market). No prior knowledge is required.

OUTCOMES

This workshop will provide participants with (1) a fool-proof step-by-step process for integrating the entrepreneurial mindset into the classroom, (2) provide an overview of how to convert the entrepreneurially-minded learning intervention into engineering education research for publication and dissemination, and (3) make a case for getting stakeholders (e.g., administration, peer instructional colleagues, students) onboard.

REFERENCES

Bosman, L. & Fernhaber, S. (2021). Teaching the Entrepreneurial Mindset Across the University: An Integrative Approach. Springer-Verlag GmbH

Bosman, L. & Fernhaber, S. (2018). Teaching the Entrepreneurial Mindset to Engineers. Springer-Verlag GmbH

KEYWORDS

Entrepreneurial mindset, experiential learning, instructor resources

PRESENTER'S BACKGROUND

Dr. Lisa B. Bosman, Assistant Professor in the Department of Technology Leadership and Innovation at Purdue University, is an educator, researcher, innovator, and author. Her education research interests include the entrepreneurial mindset, interdisciplinary education, and faculty professional development. Dr. Bosman's desire to increase STEM (science, technology, engineering, mathematics) education accessibility and attainment has resulted in her founding of the Purdue University iAGREE Labs (www.iagree.org). She has authored over 50 publications in international and national journals and conferences. As a principal investigator, Dr. Bosman has obtained over $2M in education research funding from agencies including the National Science Foundation, Environmental Protection Agency, National Aeronautics and Space Administration, and Agency for International Development. Dr. Bosman has been an invited speaker and workshop facilitator for numerous education-related engagements. She currently serves as a division officer for the American Society for Engineering Education and engineering councilor for the Council for Undergraduate Research.

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WORKSHOP

Variation and phenomenography: recognising and understanding qualitatively different experiences of engineering learning

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OVERVIEW OF WORKSHOP

Phenomenography is a research methodology well suited to exploring how engineering students and academics experience engineering education. The significance of phenomenography to engineering education research (EER) and practice lies in its potential to account for differences and changes in meanings individuals hold about concepts and practices in their discipline. By emphasizing variation, this methodology highlights that existing forms of knowledge are not fixed and therefore these are possible to change. The dataset used for hands-on analysis in this workshop has to do with how individuals understand design and knowledge creation, how this varies by professional degree program (architecture vs. civil engineering), and how student conceptualisations change or evolve over time.

Case and Light (2011) identified phenomenography as one of the emerging qualitative methodologies in EER, as it can contribute to broadening the type of research questions and ways of thinking about engineering education. They suggest this methodology is well suited to explore variations in the ways students understand engineering concepts. This can support the design of engineering curricula, pedagogical approaches, and assessment methods.

This session describes using phenomenographic research methodology to identify variation in the ways individuals understand phenomena. The methodology is relevant to studying contexts where learning and teaching occur, including higher education. It seeks to identify ways in which individuals differ, by identifying different conceptions held by individuals within and across a group (Marton & Booth, 1997). The methodology helps researchers identify shared conceptions among group members and describe relationships among the various conceptions held.

ACTIVITIES

In this workshop, participants will be introduced to the historical development of phenomenography and will examine its position within the wider qualitative paradigm. They will discover and practice using this methodology in conducting engineering education research, applying phenomenographic approaches to generating and analysing data. They will work in groups to undertake their own analysis of interview data from a study with engineering students exploring how they conceptualize design creation. Participants are likely to have prior understanding of issues explored in the interview transcripts and will feel motivated to contribute to group work, discussing their research interests with facilitators and other participants. At the end of the hands-on data analysis activity, workshop participants will discuss their approaches to analysing the data and compare their findings. Ultimately, participants will discuss how the results of phenomenographic studies might contribute to more meaningful engagement in engineering education and research.

TARGET AUDIENCE

No prior knowledge is required to participate in the activities.

OUTCOMES

By the end of this workshop, participants should be able to:

- Describe aspects of the theories underpinning the phenomenographic approach to generating and analysing qualitative interview data.

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- Identify implications of variation for teaching and learning in Engineering Education.
- Work effectively and efficiently within the time constraints of the workshop to analyse data and present results of phenomenographic analysis.
- Discuss variation as a tool for enhancing student learning and pedagogical outcomes.

REFERENCES

Case, J. M., & Light, G. (2011). Emerging Research Methodologies in Engineering Education Research. *Journal of Engineering Education*, *100*(1), 186–210.

Marton, F., & Booth, S. (1997). Learning and Awareness. Mahwah, NJ: Lawrence Earlbaum Associates.

KEYWORDS

Methodology, phenomenon, qualitative analysis.

PRESENTERS' BACKGROUNDS

The group has delivered similar workshops for multiple audiences in engineering education and general higher education. The lead presenter is an expert in the subject with multiple publications using the methodology.

AUTHOR INDEX