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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).

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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

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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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References

Crippen, K. J., Archambault, L. M., & Kern, C. L. (2013). The nature of laboratory learning experiences in secondary science online. *Research in Science Education*, *43*(3), 1029–1050. https://doi.org/10.1007/s11165-012-9301-6

Handbook. (n.d.). Retrieved September 26, 2021, from https://handbook.monash.edu/2021/units/ECE4809

Hasan, N., & Bao, Y. (2020). Impact of “e-Learning crack-up” perception on psychological distress among college students during COVID-19 pandemic: A mediating role of “fear of academic year loss.” *Children and Youth Services Review*, *118*, 105355. https://doi.org/10.1016/j.childyouth.2020.105355

Larsen, K. F., Hossain, N. A., Saad, H. S., Amin, A., & Bae, H. (2018, March 25). *Optimizing the curriculum in an engineering statistics course with realistic problems to enhance learning*. 2018 ASEE Zone IV Conference. https://peer.asee.org/optimizing-the-curriculum-in-an-engineering-statistics-course-with-realistic-problems-to-enhance-learning

Mackh, B. M. (2018a). *Higher education by design: Best practices for curricular planning and instruction*. Routledge.

Mackh, B. M. (2018b). *Higher education by design: Best practices for curricular planning and instruction*. Routledge.

Mativo, J., Sochacka, N., Youngblood, K., Brouillard, D., & Walther, J. (2017). Developing real-life problem-based learning (Pbl) activities through partnership with industry. *2017 ASEE Annual Conference & Exposition Proceedings*, 28148. https://doi.org/10.18260/1-2--28148

Metcalfe, J. (2017a). Learning from Errors. *Annual Review of Psychology*, *68*, 465–489. https://doi.org/10.1146/annurev-psych-010416-044022

https://doi.org/10.52202/066488-0003

Metcalfe, J. (2017b). Learning from Errors. *Annual Review of Psychology*, *68*, 465–489. https://doi.org/10.1146/annurev-psych-010416-044022

Salmon, G., Nie, M., & Edirisingha, P. (2010). Developing a five-stage model of learning in *Second Life*. *Educational Research*, *52*(2), 169–182. https://doi.org/10.1080/00131881.2010.482744

Smyser, B. M. (2021, July 26). *Work in progress: Combining at-home and on-campus students in a measurements and analysis lab course*. 2021 ASEE Virtual Annual Conference Content Access. https://peer.asee.org/work-in-progress-combining-at-home-and-on-campus-students-in-a-measurements-and-analysis-lab-course

Taher, M., & Khan, A. (2015). Effectiveness of simulation versus hands-on labs: A case study for teaching an electronics course. *2015 ASEE Annual Conference and Exposition Proceedings*, 26.582.1-26.582.21. https://doi.org/10.18260/p.23920

Talley, K. (2012). Hands-on project-based learning on a shoestring budget: You don’t have to buy a robotics kit. *2012 ASEE Annual Conference & Exposition Proceedings*, 25.687.1-25.687.15. https://doi.org/10.18260/1-2--21444

Truong, P., Stein, N., & Nguyen, T. (2021, July 26). *Project in a box: Self-contained instructional hands-on kits for electrical engineering outreach*. 2021 ASEE Virtual Annual Conference Content Access. https://peer.asee.org/project-in-a-box-self-contained-instructional-hands-on-kits-for-electrical-engineering-outreach

Zimmerman, T. D. (2012). Exploring learner to content interaction as a success factor in online courses. *The International Review of Research in Open and Distributed Learning*, *13*(4), 152. https://doi.org/10.19173/irrodl.v13i4.1302

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