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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

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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.

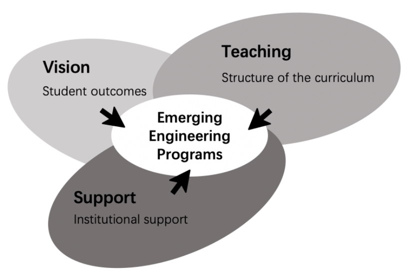

Figure 1. M-VST Framework for Curriculum Design in Emerging Engineering Programs

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, 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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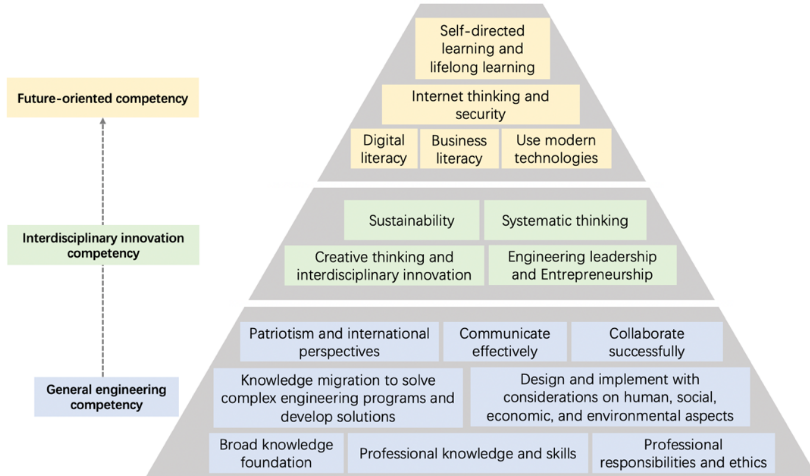

Figure 2. Student Outcomes Identified in Emerging Engineering Programs

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).

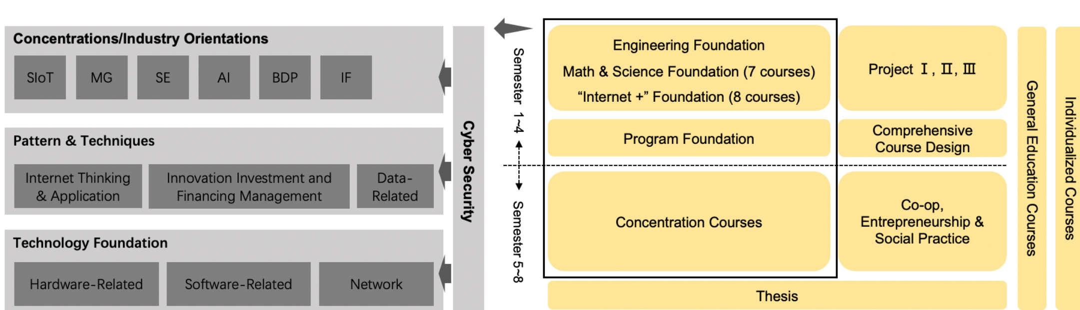

Figure 3. Curricular Structure of the "*Internet* +" program

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.*

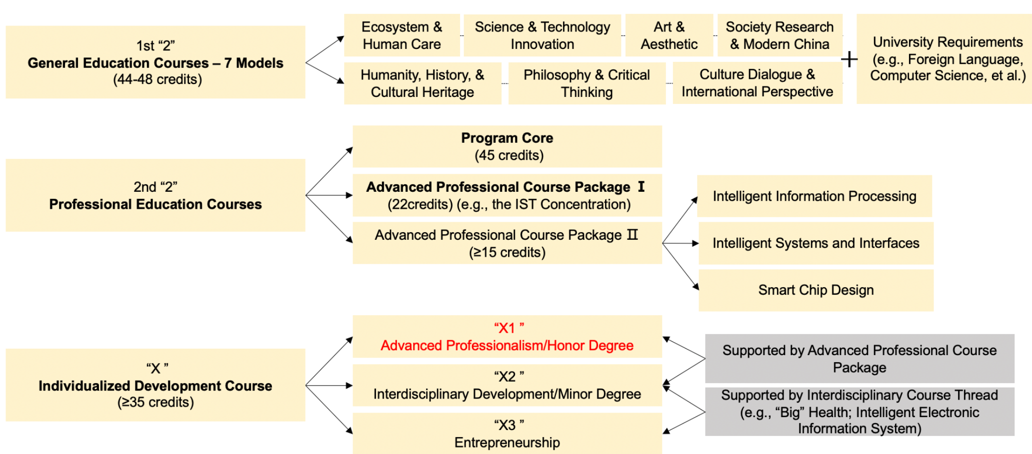

Figure 4. Curricular Structure of the "*New Engineering*" program

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 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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