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Board 168A: Initial Development of a Pre-college Engineering Framework: An Analysis of the Engineering Accreditation Board in Southeast Asia

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Abstract

Pre-college engineering education has been spotlighted to lay the foundation for a new generation with more robust science, technology, engineering, and mathematics (STEM)-related abilities. While much research has been established in the Western side of the world, pre-college engineering education development in Southeast Asia (SEA) countries still needs to be examined. This study is interested in how SEA countries cope with the new emphasis on engineering education. Notably, we are interested in examining the new developments and takeaways in SEA. As the regional education hub, Singapore has ventured into emerging STEM-related industries and education fields. Despite having a world-class education system and a high reputation for its competitiveness and innovativeness, a quality pre-college engineering education framework still needs to be improved. This study aims to reconstruct and define what constitutes a quality K-12 engineering education for regional SEA countries. The framework developed in this study results from research using Singapore as a case study to re-evaluate engineering education strategies and STEM education initiatives. Currently, the only framework that includes engineering fundamentals is the accreditation issued by the Institute of Engineers, the Engineering Accreditation Board (EAB) in Singapore. The EAB documents focus mainly on higher education engineering degree programs. However, a structure is needed to articulate the core ideas in engineering appropriate for pre-college engineering education. Thus, established on extensive literature review and past empirical work, this study aims to identify critical indicators in engineering education at the K-12 level. Re-evaluating the definition of the critical indicators also enables the study to outline criteria for pre-college engineering education. Therefore, in line with this proposal, our research questions are (1) what are the key indicators for quality and comprehensive engineering education at the K-12 level in Singapore? (2) How does the proposed framework play a role in facilitating engineering teaching at the K-12 level? And (3) what other implications does the improved engineering teaching have on other subjects or disciplines? Ultimately, crafting a new framework with the close collaboration of experts in the fields enables educators to gain valuable insights into implementing engineering education at a highly contextualized level.

Introduction

Pre-college engineering education has been spotlighted to lay the foundation for a new generation with more vital STEM-related abilities. Various associations, for instance, the pre-college engineering education (PCEE) division at ASEE, have supported such initiation across the globe to bring high urgency to re-evaluate and integrate pre-college engineering education. The ripples of the initiative have greatly influenced Western countries and their national documents to highlight the importance of STEM (science, technology, engineering, and mathematics) disciplines at the K-12 level. Engineering was seen as a perfect integrator of knowledge and a powerful tool for problem-solving and critical thinking learning. It is believed that through ingraining engineering thinking in pre-college education, educators will groom a new generation of innovators with high qualities in STEM. As pre-college engineering development prospects in the Western world, turning the microscope to the other side is essential and timely. As the regional education hub, Singapore has ventured into emerging STEM-related industries and education fields. Despite having a world-class education system and a high reputation for its competitiveness and innovativeness, a quality pre-college engineering education framework still needs to be improved.

While there are efforts related to engineering education in the SEA region from kindergarten to higher education (e.g., Shamita et al., 2022; Yeter et al., 2022; Yeter et al., 2023; Xiang et al., 2023), this study mainly aims to reconstruct and define what constitutes a quality K-12 engineering education for regional SEA countries. The framework developed in this study results from research using Singapore as a case study to re-evaluate engineering education strategies and STEM education initiatives. Established on extensive literature review and past empirical work, this study aims to identify critical indicators in engineering education at the K-12 level. Re-evaluating the definition of the critical indicators also enables the study to outline criteria for pre-college engineering education.

Why is the Framework Needed in Singapore?

Singapore's education policy has always been in sync with the nation's economic agenda (Sidhu et al., 2010). For instance, upon independence, English was institutionalized as the nation's official language to demonstrate its pro-western identity and strengthen relations with geopolitical power (Teo, 2019). Similarly, technical education was enhanced to strengthen Singapore's restructured economy's industrial labor force in the 1960s (Teo, 2019). As a small nation with limited land and no natural resources, it invests heavily in its human resources. Education in Singapore has always been allocated the second highest budget and is regarded as a "technology of hope" in Singapore (Teo, 2019). Against a global environment where STEM employment will dominate the future, there is an increasing urge to develop STEM skills in response to future employment demands. According to Singapore's Prime Minister Lee Hsien Long's speech, developing STEM skills is essential to Singapore's economic prosperity. (Lee, 2015). Although Singapore does not have a STEM curriculum framework, MOE (Ministry of Education) Singapore has enriched current STEM initiatives by establishing several initiatives.

Firstly, STEM-focused schools. National University of Singapore (NUS) High School of Mathematics and Science offers advanced mathematics and science curriculums to motivated and academically capable students (Teo, 2019). In 2010, the second STEM-focused school, the School of Science and Technology (SST), was established, offering a four-year GCE O-level (The Singapore-Cambridge General Certificate of Education Ordinary Level) examination program. In addition to these STEM-focused schools, elite schools such as Hwa Chong Institution and Raffles Institution also offer specialized STEM-related programs (Teo, 2019).

Secondly, MOE started Applied Learning Programmes (ALP) in 2013 to encourage students in primary (Grades 1-6) and secondary schools (Grades 7-10) to engage in realistic and practical learning experiences (Teo, 2019). ALP curriculum can be designed by onboarded schools in collaboration with STEM-related industries and partners. Due to the program's overwhelming popularity, the former Minister of Education (Schools), Mr. Ng Chee Meng, announced in Parliament that ALP would be available in all primary schools by 2023 (Teo, 2019). However, it is essential to note that the ALP lessons' curriculum is non-examinable. The current non-examinable ALP curriculums offer a crucial entry point for developing an engineering education framework in Singapore which will be discussed later in the paper.

Thirdly, STEM Inc., an entity under the Science Centre Singapore, supports schools implementing STEM-related curriculums. Similarly, the Multi-centric Education Research and Industry STEM Centre at the National Institute of Education (meriSTEM@NIE Centre) also played a vital role in leading and facilitating STEM education development in Singapore. Lastly are the ground-up efforts such as STEM co-curricular activities, competitions, research projects, and industrial visits. The current initiatives have demonstrated a relatively surface level of STEM and engineering integration. Many potentials can be seen, and gaps in the system await educators to address and further refine.

Potentials and Challenges in the System

In 2019, Singapore students in Primary 4 and Secondary 2 (Grade 4 and Grade 8) in Singapore continued to excel in Mathematics and Science in the international TIMSS assessment. While the vital mastery of scientific literacy is commendable, little is known about engineering or STEM education for both primary and secondary schools in Singapore. Furthermore, despite the growing demand for skills needed for future jobs in engineering, there was no specific mention of engineering skills in the MOE Science Syllabus for both Primary and Lower Secondary levels. As for Upper Secondary, the syllabus promotes interest in Engineering but does not include it as a skill in Computing or Electronics. STEM-related disciplines, however, are available at the Institutes of Higher Learning (IHLs), such as universities, polytechnics, and the Institutes for Technical Education (ITE).

The current STEM development in Singapore displays a few potential challenges. Firstly, only a selected group of students can access a quality STEM curriculum, not engineering education. Secondly, freedom is given to schools to craft their programs. By doing so, schools could have different standards and curriculum focus. Moving forth with no framework to evaluate the respective efforts will lead to the uneven quality of STEM education. Thirdly, there are great similarities between the agendas of the ALP program and the overarching goals of engineering education in its application of knowledge and engineering mindsets. However, ALP lessons being non-examinable poses an essential question on the program's quality. The lack of systematic development opportunities and standardized curriculum resources heightens further challenges in STEM education, especially engineering. It is pertinent to ensure that students' first ten years of education include elements of STEM education. To strengthen and uplift the population with better fundamentals and harvest engineering thinking at a young age, a framework is needed to guide the subsequent reforms and initiatives in the education scene.

EAB Presence and Framework

Currently, the only framework that includes engineering fundamentals is the accreditation issued by the Institute of Engineers, Singapore. The document focuses mainly on engineering degree programs to ensure that graduates possess a solid knowledge of the discipline and develop a level of professional competence suitable for fulfilling engineering assignments globally and meeting the profession's local needs (Institution of Engineers Singapore, Engineering Accreditation

Board, 2020:4) (Refer to Table 1). However, a structure needs to articulate the core ideas in engineering appropriate for primary and secondary education.

Table 1: EAB Curriculum and Teaching-Learning Processes (p 17)

No.	Knowledge Profile
Week 1	A systematic, theory-based understanding of the natural sciences applicable to the discipline
Week 2	Conceptually-based mathematics, numerical analysis, statistics, and formal aspects of computer and information science to support analysis and modeling applicable to the discipline.
Week 3	A systematic, theory-based formulation of engineering fundamentals required in the engineering discipline
Week 4	Engineering specialist knowledge provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline.
Week 5	The knowledge that supports engineering design in a practice area
Week 6	Knowledge of engineering practice (technology) in the practice areas in the engineering discipline
Week 7	Comprehension of the role of engineering in society and identified issues in engineering practice in the discipline: ethics and the professional responsibility of an engineer to public safety; the impacts of engineering activity: economic, social, cultural, environmental, and sustainability
Week 8	Engagement with selected knowledge in the research literature of the discipline

Current Engineering Education-Related Studies in Singapore

To date, there are efforts to explore the different influences, levels of awareness, and learning standards relevant to engineering education in Singapore. In research investigating the funds of knowledge for first-generation and continuing-generation engineering undergraduates in Singapore, Venkatesh et al. (2022) argued that funds of knowledge, including experiences in a home or community setting, affect the transfer of engineering knowledge and experiences, which could significantly influence engineering education for students with different background. Furthermore, research examining K-12 Singaporean parents' engineering awareness using the knowledge, attitude, and behavior (KAB) model revealed that Singapore parents have a low level of engineering knowledge and little awareness of engineering in the primary and secondary school curriculums of their children (Zulkifli et al., 2022). Moreover, Zulkifli et al. (2022) also revealed that Singapore parents are generally optimistic about engineering in Singapore. However, despite the positive attitude, the study has indicated a low level of support by the parents in engineering due to the lack of programs, related entertainment, and lifestyle media content on mainstream media platforms (Zulkifli et al., 2022). While the existing studies (e.g., Venkatesh et al., 2022; Zulkifli et al., 2022) investigated factors influencing students' interest, knowledge, and experiences in learning to engineer, Yeter et al. (2022) explored the Singaporean pre-college secondary physics standards and indicated that the engineering indices varied by physics subject and grade. The above research has demonstrated the overall trends and potential surrounding engineering education in Singapore. Developing a framework for Singapore will offer opportunities to extend these current studies into a complete picture. Furthermore, these studies also provide valuable insights to strengthen the framework's multicultural aspects and potential indicators.

Research Questions

As such, this study shares the current research that still needs to be completed in the SEA region's pre-college engineering field. The overarching research question is as follows,

1. What are the key indicators for quality and comprehensive engineering education at the K-12 level in Singapore?
2. How does the proposed framework play a role in facilitating engineering teaching at the K-12 level?
3. What other implications does the improved engineering teaching have on other subjects or disciplines?

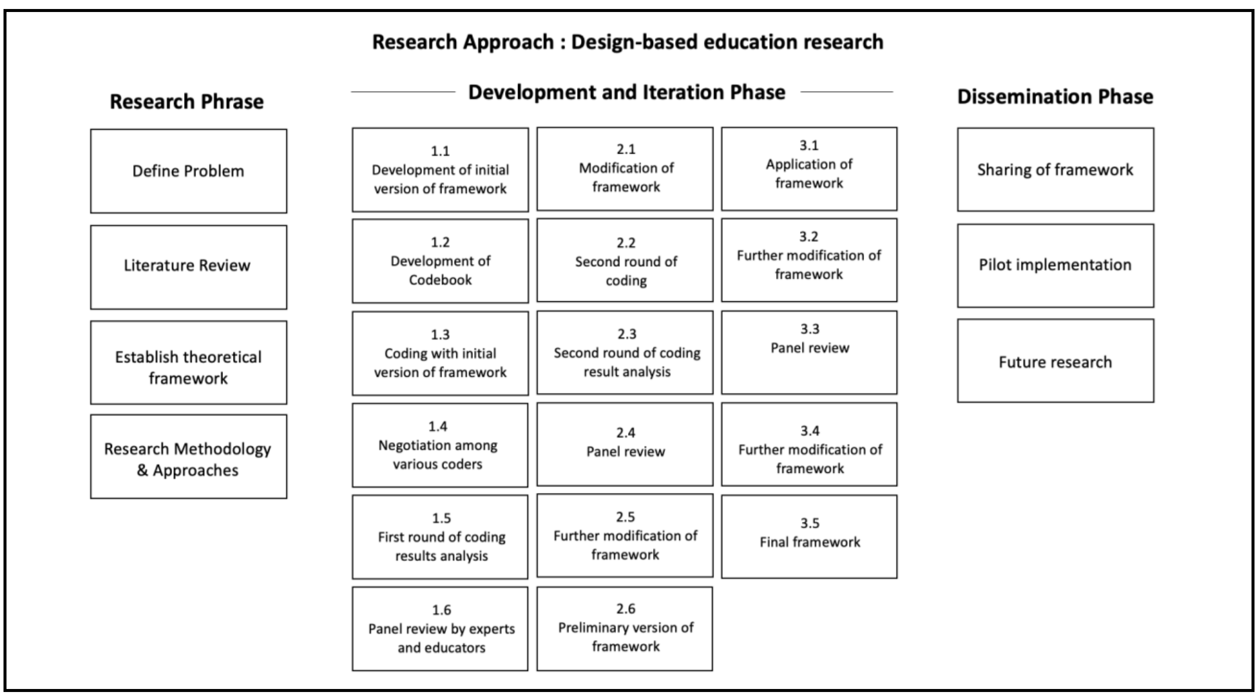
Theoretical Framework

Current educational research, including existing pre-college engineering education research, tends to focus on methodology. More emphasis was given to establishing the research with a conceptual framework. Conceptual frameworks are interconnected sets of ideas (theories) about the functions or relationships among various phenomena (Svinicki, 2010). The framework provides a foundation for understanding interconnections across events, ideas, observations, and experiences. This study must highlight the theoretical framework in play as it rationalizes and supports each logic and action made in this research. Studies have argued that a theoretical framework is essential for informing the study's logic (Svinicki, 2010; Crepon, 2014). This study follows a modified version of Piaget's functioning framework. Based on Piaget's theory of cognitive development, four major stages correspond to an aging childhood period. Stage sequences are universal across cultures and follow the same order. With this concept in mind, the research must consider the different stages of cognitive development as pre-college students interact with engineering education. Ideally, the framework should be able to capture the different stages of the learning phase and holistically define what a quality pre-college engineering education should consist of.

Research Approach

A design-based research approach was employed to design the framework. Design-based research focuses on generating innovative solutions through inquiry and reasoning (Gómez Puente et al., 2013). It is commonly used in educational research. It is beneficial for improving methods in engineering education research. The design-based approach enables engineering research to systematically explore and examine the instructions, developments, and functions of engineering education. Crepon (2014) also argued that design-based research could produce context-sensitive instructional design methods when dealing with a purposeful and relatively small sample. Rouvrais et al. (2018) employed design-based research to study links between organizations' judgment, decision-making skills, and reliability to understand how engineering education and training environments can be crafted to suit the market's needs better. Recent STEM-based engineering design studies (e.g., Xiang, Yang, & Yeter, 2023) have indicated that the engineering design process positively affects students' outcomes. Further studies confirmed that a STEM-based and parent-involved engineering design curriculum for early childhood education uses a design-based research approach (Ata-Aktürk & Demircan, 2020). The iterative cycles in this design-based research proved that using continuously evolving, multiple-layer, and cyclical research processes for engineering education research is beneficial and essential considering the innovative and adaptive nature of engineering. Hence, iterative revision cycles were planned to develop a framework encompassing the essential elements of quality engineering education. The study begins by outlining the final framework and then describes its development from a modified ABET Criterion 3: Student Outcomes. Each time, multiple researchers coded academic standards from multiple states (e.g., MOE's latest physics syllabus), then compared and discussed the results. A detailed coding protocol was developed for each round iteration to facilitate content analysis and maximize the review process's validity and reliability. As part of the design research cycle, the framework was also evaluated by peers and experts at different times.

Figure 1. Research approach and development of the framework



Development of the Framework

A team of professors of engineering education and graduate researchers from communication, education, and engineering developed this framework. Figure 1 shows the structure of the development of the framework. Before the development of the framework, the study had compared and mapped ABET Criterion 3: Student Outcomes and EAB Criterion 2: Student Learning (p 15-16) Objectives to illustrate and visualize potential differences (Refer to Table 2). Overall, the ABET criterion emphasized abilities and competencies in general. For instance, the abilities to design, apply and communicate. While for the EAB criterion, there were greater specifications in the context of the ability. For example, designing solutions appropriately considering public health and safety, cultural, societal, and environmental considerations.

Table 2: ABET Criterion 3: Student Outcomes and EAB Criterion 2: Student Learning (p 15-16) Objectives

No.	**ABET**	**EAB**
1.	An ability to apply knowledge of mathematics, science, and engineering	*Engineering knowledge:* Apply the knowledge of mathematics, natural science, engineering fundamentals, and an engineering specialization as specified in Week 1 to Week 4 (refer to Table 1 for Week 1 to Week 8) respectively, to the solution of complex engineering problems.
2.	An ability to design and conduct experiments and to analyze and interpret data	*Investigation:* Conduct investigations of complex problems using research-based knowledge (Week 8) and research methods, including design of experiments, analysis, and interpretation of data, and synthesis of the information to provide valid conclusions.
3.	An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	*Design/development of Solutions:* Design solutions for complex engineering problems and design systems, components or processes that meet the specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations. (Week 5)
4.	An ability to function on multidisciplinary teams	*Individual and Team Work:* Function effectively as an individual and as a member or leader in diverse teams and multidisciplinary settings. *Project Management and Finance:* Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these to one's work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
5.	An ability to identify, formulate, and solve engineering problems	*Problem Analysis:* Identity, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of

No.	ABET	EAB
		mathematics, natural sciences, and engineering sciences. (Week 1 to Week 4)
6.	Understanding professional and ethical responsibility	*Ethics:* Apply ethical principles and commit to the engineering practice's professional ethics, responsibilities, and norms. (Week 7)
7.	An ability to communicate effectively	*Communication:* Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
8.	The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	*The engineer and Society:* Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to the professional engineering practice. *Environment and Sustainability:* Understand the impact of professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development. (Week 3)
9.	A recognition of the need for, and an ability to engage in life-long learning	*Life-long Learning:* Recognise the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.
10.	A knowledge of contemporary issues	*The engineer and Society:* Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to the professional engineering practice. Knowledge of contemporary issues is also required throughout most designing, applying, and problem-solving learning outcomes to assess the issue and form relevant problem statements. Note: Overlaps and is included in other learning outcomes.
11.	An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	*Modern Tool Usage:* Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling to complex engineering problems, with an understanding of the limitations. (Week 6)

The initial version of the framework was then used to analyze the current national syllabus (e.g., 2023 MOE Physic Primary School (Grade 1 - 6 Syllabus). A codebook was developed to ensure validity and consistency among the different coders. The initial analysis is to determine whether the syllabus contains engineering and the relevant indicators. A score was generated for each indicator to measure the presence of each indicator. The study results were recorded in a spreadsheet and compared by the researchers. The final codes were recorded after disagreements were resolved during discussions. Coding and comparing the results revealed areas where the current framework needed further modification to be appropriate for pre-college applications. The next iteration was then adjusted accordingly.

In the following stage of iteration, a panelist consisting of education and engineering experts, reviewers, educators, specialists, and engineers will be involved in a panel discussion and review of the framework. According to the feedback from the session, the team will further integrate the valuation of the indicators and the framework.

Discussion

Infusing appropriate engineering practices in the school setting is vital to enhance teachers' teaching confidence (Hammack & Yeter, 2022; Yeter, 2021) and improve students' STEM interests (e.g., Burley et al., 2016; Yeter et al., 2016). The study has concluded several differences in comparing ABET- and EAB-driven frameworks. Firstly, in establishing the conceptual foundation, past studies in the field used ABET as a foundation for developing the proposed framework and critical indicators. However, besides ABET, this study has considered EAB objectives and accreditation criteria in developing the indicators and generalizable framework for the context of SEA.

Secondly, as for research context, generalizability, and implications, past studies facilitated curriculum development within K-12 curricula, both in terms of developing units of instruction and defining scope and sequence. This current study measures the quality of engineering education for SEA and finds a solution to how it can achieve a more sophisticated K-12 engineering education in Singapore. Developing a Singapore framework could have a significant impact on the regional countries as well as Asia's education system. A Singapore Framework will give regional studies a better benchmark than the former Western or European style. Asia countries could cross reference and adapt the work to suit their education system. Singapore will continue to be a leading education hub not only by forming a new framework but also because the design-based research process will value-add to existing studies and literature. Furthermore, the study also envisions that there will be differences within the key indicators in its terminology and specification. This is mainly due to the different cultural contexts and educational agendas in the different regions.

Implications, Conclusion, and Recommendations

This study outlined the development of Singapore's quality pre-college engineering education framework, providing a research-based explanation for its purpose, necessity, content, and work mode. The framework was started to fill the need for more definition of quality K-12 engineering education in Singapore. Most importantly, the framework aims to guide the future development of curricula, syllabi, and policies about pre-college STEM integration. To improve STEM education at a pre-college level worldwide, there is a need for continued research in the different regions where different cultures and education methodology exists.

The final framework could be used as an evaluation and facilitation tool for the future development and integration of pre-college engineering education in Singapore and SEA. It will benefit the future curriculum development in areas such as formulation of teaching instruction, module objectives, and sequencing the order and emphasis of topics and materials. Teachers could also use the framework to guide their teaching and benchmark and update their materials as the version of the framework updates. Nonetheless, this is a work-in-progress study where many questions have yet to be answered. Most of the remaining questions will be answered during the operational phase of the research. The framework offers critical indicators for an extensive and quality understanding of pre-college engineering education. The key indicators in this research set the stage for future studies in the region to take place and deepen its understanding of engineering education.

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