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Exploring the Presence of Engineering Indices in the Singaporean High School Physics Standards: A Content Analysis (work-in-progress)

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Abstract

Singapore is one of the leading countries globally in industry indicators, ranking second in the 2018 World Economic Forum's Readiness for the Future of Production Report and first out of 120 nations in the 2017 Danish Institute of Industry Global Industry 4.0 Readiness Index. This reflects Singapore's robust and diversified industrial capacity, as well as its leadership in sectors such as avionics, computing, biological engineering, and microelectronics. Underlying this global competitiveness is the Singaporean education system, which hinges on fostering students' engineering knowledge, skills, and interest. Towards understanding how engineering is supported across levels of education, this work-in-progress examines potential engineering indices embedded in existing science courses (i.e., physics) across high school and identifies entry points for new engineering ideas. A content analysis technique was employed to investigate reform documents from the Ministry of Education (MOE) website using the Framework for Quality K-12 Engineering Education. We iteratively reviewed the magnitude of engineering indices infused in the standards and the ramifications of including aspects of engineering in various scientific domains. Preliminary findings indicate that observed engineering indices fluctuate across both physics subjects and different grade levels. In addition to the extended discussion, this study also provides future directions for potential studies.

Introduction

Academic research suggests integrating engineering ideas in science and mathematics classes. Several scholars suggest that the inclusion of engineering features in STEM classes towards improving students' readiness for the 21st-century world and preparing them for problem-solving and decision-making within a real-world context (Aydin-Gunbatar et al., 2018; Burley et al., 2016; Mathis et al., 2018; Youngblood et al., 2016). Others suggest that the inclusion of engineering in education offers students a perspective on real-life applications of abstract scientific knowledge (Johnston et al., 2019; Pleasants & Olson, 2019). As an integrator of real-life STEM issues, engineering can also improve adolescents' cognitive and problem-solving abilities (Burley et al., 2016; Bryan & Guzey, 2020), foster 21st-century skills (Bybee, 2018), and facilitate positive STEM experiences that support their pursuit of future STEM careers (McDonald, 2016; Yeter et al., 2016). More recent international studies (e.g., Van den Bogaard et al., 2021) suggest that attributes like students' STEM attitudes, interest, and exposure to STEM curriculum prior to entering higher education are important indicators (Savelsbergh et al., 2016). Given the importance of engineering to Singapore's economy, the inclusion of engineering in Singapore's national educational system could foster positive perceptions of engineering and encourage students to consider the pursuit of potential careers in engineering.

Singapore: International Outlook

Engineering plays a significant role in the Singaporean economy. According to a governmental report, as of 2020, manufacturing is the largest industry in Singapore, contributing to 21.5% of Singapore's GDP. In January 2021, the Ministry for Trade and Industry (MTI) announced a 10-year plan to grow Singapore's manufacturing sector by 50%. The majority of the investment aims to be allocated to engineering fields. In 2020 alone, the Economic Development Board (EDB) attracted 13.1 billion SGD of investments into the manufacturing sector, including commitments of 6.5 billion SGD and 4.1 billion SGD towards investments in fixed assets within the engineering clusters, including electronics and chemicals, respectively. Furthermore, the country's commitment to the United Nation (UN)'s 2030 Agenda for Sustainable Development involves, amongst other benchmarks, developing a city in nature, increasing sustainable living, and building a green economy. Solar energy, an expansion of existing rail networks, and the design of low carbon alternatives, green buildings, and sustainable infrastructure are all key growth sectors that Singapore will increasingly attend to in the near future, demonstrating the need for engineering expertise.

Singapore: The Nation's School System and Engineering Education

Contrary to its central role in the economy, Singapore's pre-college education system lacks an emphasis on engineering. From a broader angle, Singapore's education system follows the United Kingdom's education system. For instance, students undergo compulsory education for their first six years in primary school (aged 7-12) before entering secondary school (aged 13-16/17). After that, students may opt for one of many post-secondary educational institutions (PSEIs), which include:

- Junior Colleges, which continue students' academic training through qualifying with the general certificate examination (GCE) "A Levels" or international baccalaureate (IB)
- Polytechnics, which qualifies students with a diploma in important areas within Singapore's industry, provides students with hands-on, practice-based learning experiences
- Institutes of technical education (ITE), which provides technical and vocational education for students

Students' choice of PSEIs is typically governed by their performance in their GCE "O Level" examinations, the equivalent of a national high school examination for most Singaporean students. Several different pathways, such as the integrated program (IP), allow students to be exempted from this national exam. In contrast, other pathways, such as the direct polytechnic admission (DPA), downplay the significance of these examinations in affecting students' choice of PSEIs. However, the GCE "O Level" exams are still used as the primary mode of admitting students into various PSEIs. Given the importance of the GCE "O Level" exams in affecting their future areas of studies and potential careers, schools place significant importance on adequate student preparation. Exams are mostly pen and paper tests. Throughout students' first ten years of formal education within primary and secondary schools, they do not typically encounter engineering features in their educational experience. It is only through PSEIs that students begin to specialize in a field of study related to engineering.

Significance of the Study

While there has been an extensive emphasis on implementing and investigating engineering practices within K-12 STEM education in the Western regions (e.g., Capobianco et al. 2021; Yeter, 2021; Yeter et al., 2019), very few examples being conducted in Asian regions (e.g., Bin Zulkifli et al., 2022). As such, this study explores to what degree engineering indices may be integrated into the Singaporean pre-college education curricula. With a focus on introducing engineering elements into the Singaporean secondary school physics curriculum, we propose this study as significant work to investigate the proliferation of engineering ideas within the existing Singaporean pre-college education system. While there is currently no direct course for integrating engineering within Singaporean pre-college education levels, elements of engineering may be latently embedded within the existing curriculum. In turn, documenting this embeddedness may allow for more direct inclusion of engineering-related ideas, introducing Singaporean students to engineering and related problem-solving skills earlier in their schooling. A deep understanding of the current Singaporean educational landscape is needed to find seamless areas for the integration of engineering. This work aims to provide a thorough analysis of Singapore's existing pre-college education curricula, starting with science subjects from kindergarten to high school. As part of this larger plan, the current study focuses on analyzing secondary physics standards. The following question guided this work: *To what extent is engineering evident in the Singaporean physics curricula for secondary schools?*

Methods

Context of the Study

In the Singaporean curriculum, students in primary school undergo a common standards-based, foundational science curriculum. Students in lower secondary (aged 13-14) also undergo a common science curriculum before choosing to study at least two out of the three main branches of science - physics, chemistry, or biology - at either the "combined" or "pure" level in upper secondary (aged 15-16). These are the subjects that students are graded on in the GCE "O Level" examinations. At the "combined" level, students learn about the domain of science at a lower degree of comprehension and rigor than at the "pure" level. This work in progress focuses on the secondary (high school) science standards for "pure" physics. To answer our research question, we analyzed these standards based on the elements of engineering education indicated in the

Framework for Quality K-12 Engineering Education identified by Moore et al. (2014) which are described in more depth in the data collection and analysis section.

Research Design

This qualitative study uses a case study approach (Yin, 2009) and content analysis (Krippendorf, 2013) to explore the Singaporean pre-college secondary physics standards. All related standard documents were combined and analyzed with a focus on the concepts of engineering content and skills (Patton, 2002). According to Krippendorf (2013), the background of the coders during the data analysis is important for the research findings to ensure replications amongst cases. Preliminary content analysis was completed by two independent researchers in education with expertise in elementary and engineering education and three engineering education scholars with experience in teacher professional development with a concentration in engineering practices.

Data Collection and Analysis

For each standard, specific terminology is used to describe the concepts of which K-12 teachers and students should be aware. It should be noted that the official terminology in the Singaporean pre-college education system for “standard” is operationalized as the “syllabus” or “learning objectives.” However, to streamline this language we used the term “standard” to refer to these “learning objectives” and “syllabi.” The data (e.g., reform documents) are publicly available for retrieval on the Ministry of Education (MOE)’s website (https://www.moe.gov.sg/). Each pre-college grade level was searched through the official MOE website.

The study used the Framework for Quality K-12 Engineering Education (QEE) developed by Moore et al. (2015) and qualitative content analysis (Krippendorff, 2013) to analyze the standards documents. This framework was initially based on ABET criteria and later adjusted to a K-12 environment and includes tenets or *indicators* of: a complete Process of Design (*POD*); the application of Science, Engineering, and Math knowledge (*SEM*); Engineering Thinking (*EThink*); Conceptions of Engineers and Engineering (*CEE*); Engineering Tools and Techniques (*ETools*); Issues, Solutions, and Impacts (*ISI*); Ethics (*Ethics*); Teamwork (*Team*); and Engineering Communication (*Comm Engr*). These indicators guided our content analysis and served as a coding rubric showing engineering content evidence. The standard was coded only when the engineering content was met and if students were doing and involved in the engineering framework. One standard could have multiple key QEE indicators. Each researcher coded the standard separately to reach the consistency of and validate the codes with the QEE framework.

Each standard document included key terms and definitions, for instance, design, solution, investigation, criteria, constraints, materials, test, failure, and model. These key terms and definitions served as guidance for the raters during the coding phase. The standards related to engineering were all combined for the data record. During the coding phase, the researchers rated "0", "1" or "2" for each phrase from standards that contained engineering relevance. Similar coding approaches to the K-12 standards exist in other studies (e.g., Yetter, Livengood, & Smith, 2017). For example, the physics O level, Newtonian mechanics-dynamics, has a standard related to engineering context where the key indicator called "sub-indicator of POD – PI" was rated as "1". As we agreed that the standard met the key indicator requirement. "(d) recall and apply the relationship resultant force = mass × acceleration to new situations or to solve related problems." Another key indicator called "SEM" associated with engineering context in the physics O level, waves-electromagnetic spectrum, was rated as "2" because the standard definition met the key indicator requirement "(c) state examples of the use of the following components of EM [electromagnetic] spectrum," for instance "(vi) X-rays (e.g. radiological and engineering applications)."

Findings

Following content analysis, standards revealed a total of 56 engineering indices within the O-level physics curriculum based on the nine QEE framework indicators. Instances of several engineering indices were exhibited across the standards documents (Table 1) that represented embedded yet discrete entry points into engineering.

Below, we summarize these emergent engineering indices with examples of each one from standards documents (Table 1). The frequencies of each type of indicator are listed along with the percentages of the total number of indicators. This allowed for more specific identification and characterization of indices and revealed where more attention may be provided to expand upon what engineering is embedded.

As shown below, most instances of standards-based language were coded with *SEM, POD, Ethics* and *ETools*. This was perhaps not surprising given that standards are part of a comprehensive and "pure" physics curriculum, but also illustrated the multifaceted approach that Singapore takes to providing learners with ethically bound STEM-related ideas and practices. The above instances, for example, appear to focus on fostering understandings of crosscutting concepts that include pattern recognition and analysis (Duncan & Cavera, 2015) and conceptualize physics as necessary to solving global issues (Bryan & Guzey, 2020). By definition, standards should focus upon and span a variety of important disciplinary ideas, practices, and processes, and this focus was shown in the current study regarding Singaporean secondary physics reform. Related, engineering has its own specialized suite of practices, tools, and norms (Johri & Olds, 2010; Lawson & Dorst, 2013). Instances of *SEM, POD, Ethics,* and

ETools may therefore be areas that can be expanded in order to more explicitly integrate engineering.

Table 1. Example of coded high school physics standards (syllabus 6091)

Code/QEE Indicator	**Example**	**Frequency**	**Percentage**
SEM	Present reasoned explanations for phenomena, patterns, and relationships (Physics, 6091)	14	25.0
POD	Candidates should be able, in words or by using symbolic, graphical, and numerical forms of presentation, to [solve problems] (Physics, 6091)	11	19.6
Ethics	Stimulate interest in and care for the local and global environment (Physics, 6901)	8	14.3
ETools	Candidates should be able to demonstrate knowledge and understanding in relation to [scientific instruments and apparatus, including techniques of operations and aspects of safety] (Physics, 6091)	7	12.5
ISI	Recognise the usefulness and limitations of scientific method and to appreciate its applicability in other disciplines and in everyday life (Physics, 6091)	5	8.9
Team	Study and practice of science are cooperative and cumulative activities and are subject to social, economic, technological, ethical and cultural influences and limitations (Physics, 6091)	4	7.1
Comm Engr	Develop abilities and skills that [Encourage effective communication] (Physics, 6901)	4	7.1
EThink	Use information to identify patterns, report trends and draw inferences (Physics, 6901)	3	5.4
CEE	[None]	0	0

These indices were followed by the lesser representations of *ISI, Team, Comm Engr,* and *Ethink*. While standards definitively conceptualized physics in terms of disciplinary knowledge, less emphasis appeared to be placed on collaboration, contextualization, and communication. However, along with opportunities for decision-making and reflection (Wendell et al., 2017), these are all core components of K-12 engineering design-based tasks or activities (Bryan & Guzey, 2020; Moore et al., 2014) that connect with fostering 21st-century skills needed to succeed in engineering careers (Bybee, 2018). They are also more non-cognitive yet essential elements that are central to design thinking (Coleman et al., 2020) and designerly ways of knowing (Cross, 2012). As such, these indices represented additional areas of expansion into engineering as a highly social and contextualized endeavor (Bucciarelli, 2001).

Aligned with the above-mentioned trends, and despite the importance of engineering within the Singaporean industry, there were no explicit instances of CEE. To clarify, this meant that “engineering” and “engineers” were not mentioned as part of the standards. This suggested more efforts are needed to explicitly discuss engineering as a set of disciplinary knowledge and career paths that center on the collaborative development of design solutions (Vo & Hammack, 2021). As shown in literature, teachers and learners are often not familiar with engineering or engineers (Capobianco et al., 2011; Hsu et al., 2011). Connected with this unfamiliarity, teachers have been found to be challenged with enacting engineering design-based science instruction (Hammack & Ivey, 2017; Radloff et al., 2019). Related, learners cannot be expected to pursue STEM careers they know potentially little about. Within an economy that is reliant upon engineering, earlier engagement with authentic depictions and instances of engineering is necessary, and standards documents are a prime area of articulation.

To summarize, while this study reflects specific and preliminary findings, our ultimate goal is to explore engineering indices across all levels of foundational Singaporean education. In this current work, we aimed to illuminate how content analysis may uncover entry points within reform to systematically integrate engineering. We plan to use these results as a springboard and template for further-curricular exploration.

Implications and Conclusions

Building the capacity to integrate multidisciplinary STEM ideas and processes is crucial to K-12 education and beyond (Aguirre-Muñoz et al., 2021; Bybee, 2018). This reform exposition’s main objective was to identify the key components of engineering present in the Singaporean high school curriculum. Aligned with the Singaporean motive to engage students in STEM fields, this work-in-progress study indicates that engineering indices are present across the pre-college physics curriculum. Furthermore, in the institute of higher learning (e.g., universities), Singaporean students are being educated on engineering and technology design both in formal and informal manners. Thus, the need is apparent to proceed with the integration of engineering into existing STEM standards and/or the creation of a national pre-college engineering curriculum.

Education in engineering at the pre-college level is crucial for the cultivation of widespread STEM literacy and the development of future STEM practitioners (Savelsbergh et al., 2016). The failure to include engineering practices in Singapore’s educational system has impacted Singaporean perceptions of engineering. Many perceive engineering-related jobs to be about performing repetitive tasks in a structured environment, disincentivizing many from considering engineering as a possible career path, in spite of its central role in Singapore’s economy and its highly innovative features. The practice of preparing students for their national examinations also narrows students’ scope of knowledge to content within the current national curricula, which does not directly integrate engineering into students’ primary or secondary school experiences.

As mentioned by Penuel and Fishman (2012), it is pertinent to use the present landscape as a foundation to build upon and to come to an agreement on education in engineering at a K-12 level, so as to not repeat the same mistakes that have been made. This is especially essential in proceeding with meaningfully incorporating engineering into the existing standards of science, class outlines, teaching, and practice (Ekiz-Kiran & Aydin-Gunbatar, 2021). However, the landscape first needs to be mapped, starting with standards.

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