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ARTICLE

Analysis of Engineering Elements of K-12 Science Standards in Seven Countries Engaged in STEM Education Reform

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Abstract

The purpose of this study was to analyze the K-12 science standards of seven countries that have improved their engineering practices noticeably by integrating engineering and its elements into their science documents, namely, Australia, England, Estonia, Hong Kong, South Africa, Turkey, and the United States. For this purpose, K-12 science standard documents were examined vis-à-vis their inclusion and distribution of engineering and its elements across grade bands. Standards were analyzed through content analysis by employing the Framework for Quality K-12 Engineering Education. The results showed that the United States and to some extent Turkish standard documents had placed a particular emphasis on engineering. The number of standards relating to engineering is the highest in the United States and the lowest in Estonia. These standards across grade bands were distributed evenly in the documents of England and the United States. Science standard documents in early grades included few such standards. In light of the results, we discussed the extent and comprehensiveness of engineering integrated into the K-12 science standard documents and provided implications for integrating engineering elements into science standard documents.

1 Introduction

With the release of the Next Generation Science Standards (NGSS Lead States, 2013), the integration of Science, Technology, Engineering, and Mathematics (STEM) in K-12 science education was highlighted. In the recent reform, "the endorsement for increasing the visibility and understanding of engineering" (Moore et al., 2015, p. 296) was emphasized by citing different arguments (e.g., maintaining the pace of global competitiveness of the United States [U.S.] with the development of new technologies, training talented STEM workforce, and slow growth in enrolment rate of engineering programs) (Pleasants & Olson, 2019; Roehrig et al., 2012; Yoder, 2016). In addition to those, to meet the critical needs of the twenty-first century (e.g., entrepreneurship and teamwork) and the multidisciplinary nature of daily-life problems, the integrated STEM education with an emphasis

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on engineering and design process has received considerable attention worldwide with an expectation that this could tackle aforementioned issues (Australia Office of the Chief Scientist, 2014; European Commission, 2015; Koehler et al., 2016).

Before moving any further, it is crucial to define engineering. It has several definitions in the field with varying emphasis (e.g., engineering as a field, as a process, or as an approach) (Antink-Meyer & Brown, 2019). For instance, Burghardt and Hacker (2004) define it as “a process for creating the human-made world, the artifacts and processes that never existed before” (p. 2). In this study, we have adopted Moore, Tank, and English’s definition (2018) that defines engineering as “a multifaceted field that draws not only from related disciplinary domains such as mathematics and science, but also from disciplines that serve to make engineering solutions more practical or desirable such as economics, social studies, and the arts” (p. 9). In the light of above definition, engineering can be defined as a profession that focuses on solving problems and discovering tools, systems, and/or processes that can make people’s life better and easier by using the knowledge of science, mathematics, and other fields (NAE, 2008).

Although engineering has been seen as a key factor in maintaining the pace of global competitiveness of the countries, training talented STEM workforce, and modern civilization, there is a lack of acknowledgement of this fact among learners and teachers. K-12 students have naïve views about engineering and the limited knowledge of working of engineers (Chou & Chen, 2017; Karatas et al., 2011). Furthermore, in the STEM disciplines, engineering is the very discipline where teachers experienced more difficulties in its integration (Shernoff et al., 2017). Given the limited understanding of engineering and its integration into science and/or mathematics, Bagiati and Evangelou (2018) highlighted the necessity of two steps: the development of an age-appropriate curriculum and the training of teachers. As curriculum documents are important sources for teachers’ training (Desimone, 2009), we argue that development of age-appropriate curriculum has the potential to inform teacher training. In other words, curriculum development is the first step in the integrated STEM reform movement. However, the way integration can be introduced is an important point that has been discussed.

In the engineering education literature, scholars have suggested different ways of integration of engineering into the K-12 education system. First, engineering has to be made more visible by integrating its standards into science standard documents, which is coined as a *complementary approach*. This approach makes it possible for more students to learn about engineering without taking specific engineering courses (e.g., Australian Curriculum, Assessment and Reporting Authority [ACARA, 2016a]; NGSS Lead States, 2013). Another approach is to prepare separate engineering standard documents for different grade bands. There is still a debate going on among the scholars of the engineering field about the integration of engineering in K-12 education (Carr et al., 2012; Moore et al., 2015). The National Research Council (NRC) states that although preparing a standalone standard for engineering is theoretically possible, practically, it is not a viable and promising approach since schools and teachers have very limited knowledge of engineering and the existing overloaded curricula (NRC, 2010). Therefore, the “complementary approach” has been adopted (Brown et al., 2012; NRC, 2010). Recently, the STEM reform in the U.S. put emphasis on integrating engineering and design problems into existing science, mathematics, and technology courses (Johnston et al., 2019), which is also adopted by other countries (Moore et al., 2015).

Summing up, the integration of STEM disciplines has been a recent international attempt (Moore et al., 2015) to train citizens who are capable of solving the problems, making informed decisions, and coping with the challenges of this century (NGSS, 2013). To achieve the goals listed, engineering is viewed as a facilitator (i.e., due to the use of scientific and mathematical knowledge to solve engineering problems and develop technologies)

(Moore et al., 2014). Research revealed that integrating engineering in science and mathematics classes improves the learners' conceptual understanding of science and mathematics due to its potential to provide a context of the real world (Aydin-Gunbatar et al., 2018; Mathis et al., 2018). Likewise, Johnston et al. (2019) and Pleasants et al. (2019) argued that engineering integration is important not only for engineering education but also for science education because the integration into science classes offers students the opportunity to see the real use of scientific knowledge. With this in mind, if integration of engineering is beneficial for science learning, then the integration into the science standard documents, which directs teachers' planning and instruction, should be done properly and comprehensively. To investigate how and to what extent that integration has been done, some important questions should be asked. For instance, to what extent engineering and its elements (e.g., ethics and engineering thinking) were covered in the science documents? To what extent the engineering elements are integrated into different grade levels? (e.g., when elementary, middle, and high school documents are compared?) Is the integration explicit or implicit in the documents? and how are the different countries' integration of engineering into science documents similar or different from each other? (i.e., regarding comprehensiveness of the integration). The answers of these questions would inform science education about the current situation of engineering integration. In the light of results presented, necessary changes that should be made would provide implications for policy makers, curriculum developers, researchers, and science teachers for better engineering integration into science teaching. Although previous research has revealed important findings about the integration of engineering into K-12 into the U.S. national and state documents (e.g., Carr et al., 2012; Moore et al., 2015), the situation in other countries' science standards is an unexplored area. From Moore et al.' s (2015) perspective, "it will be important to continue to develop the research base on what engineering looks like in K-12 settings, particularly when integrated into science classrooms" (p. 315). This study seeks to answer the following questions:

1) To what extent is engineering presented in the K-12 science standard documents of Australia, England, Estonia, Hong Kong, South Africa, Turkey, and the U.S.?

   a) What is the frequency of engineering emphasis through the documents?
   b) What is the frequency of engineering elements stated in the Framework for a Quality K-12 Engineering Education (QEE) and how these elements are distributed across the grade bands?

2) What is the comprehensiveness of engineering presented in the K-12 science standard documents of Australia, England, Estonia, Hong Kong, South Africa, Turkey, and the U.S. regarding

   a) explicit engineering emphasis?
   b) the incorporating elements of engineering determined by the framework of QEE across grade bands?

Although the details of the framework would be presented in the Methodology part, to help the reader understand what we mean by extent and comprehensiveness, it is necessary to define it shortly. In the framework, the essential elements of engineering education (e.g., engineering thinking, ethics, and teamwork) were identified by Moore et al. (2014, 2015). In this current study, the extent of engineering was determined by evaluating the frequency of engineering elements within a standard document and the distribution of the engineering elements across the grade bands. To be considered as comprehensive, engineering standard documents should meet four requirements set by Moore et al. (2015) (e.g., explicit integration of engineering, including some element in all grade bands more than once, and including some of the elements in at least two grade bands more than once).

2 Literature Review

2.1 Engineering and Engineering Design Processes

Engineering has played an important role in creating a modern civilization. Although it has contributed greatly to the culture throughout history, its birth as an academic discipline is stated as the Renaissance (NRC, 2009). Engineers are professionals who solve the problems of people to make their lives better and easier and design products, systems, and processes by using scientific and mathematical knowledge (NAE, 2008; NRC, 2009). That production occurs through a non-linear engineering design process which can be defined as "a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints" (Dym et al., 2005, p. 104). Engineering design process also requires engineers to make informed decisions based on the scientific and mathematical knowledge and the other key factors as mentioned in the definition (e.g., users' needs) (Wendell et al., 2017) and to think creatively for solving the problems faced by people (NAE, 2008), which are important elements that learners need to learn about the engineering and design process through K-12 education (Dym et al., 2005, Moore et al., 2014; NAE, 2008).

Despite the contributions of engineering to society, the typical citizen does not have a solid understanding of engineering (Kruse et al., 2017; NAE, 2008). Therefore, in order to attain to the goals of the integrated STEM education reform (e.g., to meet the critical needs of the twenty-first century) that highlighted the integration of engineering into other disciplines, it is necessary to focus on engineering in precollege education (NAE, 2008; Timms et al., 2018). When STEM disciplines are examined, it is found that students take courses in different fields of science, mathematics, and technology through 12-year compulsory education. However, they generally do not take engineering courses (Antink-Meyer & Brown, 2019). Parallel to the NRC's (2010) preference for "complementary approach" (i.e., integrating engineering elements into the STEM disciplines' documents rather than standalone standards), it is necessary to focus urgently on engineering integration into science and the other STEM disciplines' standard documents. The necessity is also related to NGSS's suggestion that is an implementation of integrated STEM approach by "raising engineering design to the same level as scientific inquiry in science classroom instruction at all levels, and by emphasizing the core ideas of engineering design" (NGSS, 2013, p. 1). Given the requirement of engineering integration into the standard documents, how the integration was done, and to what extent the elements of engineering were integrated are the points that the research should pay attention to (Moore et al., 2015).

2.2 Why Engineering Should be Included: Research Results for Benefits of Engineering

Previous studies have revealed the benefits of integrating engineering with design challenges into the lessons of science and mathematics with different learning outcomes. For instance, it improves the learners' conceptual understanding of science and mathematics due to its potential to provide a context of the real world (Aydin-Gunbatar et al., 2018; Mathis et al., 2018). In a quantitative mixed method design, Aydin-Gunbatar et al. (2018) reported that pre-service teachers' knowledge of science content significantly increased through an integrated STEM course in the pre- and post-test settings ($z = 2527$, $p < 0.005$, $r = 0.629$). The analysis of reflection papers revealed that engineering design activities that required participants to conduct research for a solid solution led the participants to review the science concepts and to think critically on the ideas for design thinking. Another argument that supports the integration of engineering into the education system is that it helps learners develop twenty-first century skills. In order to solve engineering problems, learners work collaboratively, share ideas, design a process or product by using scientific or mathematical knowledge, and market their product via posters and/or through other means of advertisement (Aydin-Gunbatar et al., 2020). Furthermore, integration of engineering into K-12 education increases their interest in STEM jobs and careers (Moore et al., 2015). In a quasi-experimental design study, Colston et al. (2017) highlighted that introducing engineering and engineers to fifth-grade students enhanced their understanding engineers (i.e., with the help of engineer-visit and engineer-video instructional formats) and changed their attitudes about engineering profession. Pre- and post-test comparisons showed the usefulness of engineering videos for learners to gain interest in engineering jobs. Additionally, Cantrell et al. (2006) revealed that integrating engineering into middle school science had a potential to reduce the science achievement gap concerning gender differences, low socioeconomic status of students, and students with learning disabilities. Cantrell et al. (2006) argued that the results showed the lack of engagement of low income students with materials and tools and "[s]uch engagement may have provided a rich learning experience that resulted in their increased ability to design and build an object and verbalize their conceptual understanding better than they could otherwise do on a pencil/paper test" (p. 307). Given the advantages of integrating engineering and engineering design process into other courses, "it is not surprising that learning through engineering design contexts serves as a popular instructional model used in science, mathematics, and technology education to meet many aspects of the standards" (Brophy et al., 2008, p. 371).

To conclude, the literature has reported that integrating engineering and its elements into science classrooms is beneficial for conceptual science learning, development of twenty-first century skills (e.g., collaboration) (Aydin-Gunbatar et al., 2020), decreasing the science achievement gap (i.e., among girls and boys) (Cantrell et al., 2006), and increasing learners' interest in the engineering profession (Moore et al., 2015). The list of the benefits of engineering integration has provided valuable support for the necessity of the engineering integration into science standard documents and classrooms.

2.3 A Framework Problem: The Requirements to Identify Core Engineering Concepts, Elements, and Skills

After the introduction of the integrated STEM approach especially with the release of NGSS (2013), many countries (e.g., Australia, Ireland, Taiwan, and Turkey) have integrated engineering into K-12 science standard documents (Morgan & Kirby, 2016). The success of the recent reforms depends on the determination of a roadmap for this integration (NRC, 2010) as it also plays an important role to inform documents, materials, and instruction for engineering education (Johnston et al., 2019). Therefore, the first step in this reform movement is to identify the core engineering concepts, ideas, and skills included in the standards (Brophy et al., 2008; NRC, 2010). With regard to that call, Moore et al. (2014, 2015) attempted to suggest a framework for key engineering elements (i.e., "indicator" is used by Moore et al., 2015; therefore, this term will be used through the study) that should be a part of K-12 engineering education within the U.S. context. In order to develop this framework, Moore et al. (2015) stated that they had followed a research-design paradigm through which they reviewed related literature and carried out content analysis of the standard documents (e.g., NRC, 2009) and took experts' opinions to determine the elements of K-12 engineering education. Through this way, Moore et al. (2014, 2015) proposed a framework that compiled twelve indicators for developing the students' understanding of engineering through K-12 education. The indicators and their descriptions provided by the Framework for Quality K-12 Engineering Education (QEE) are presented in Table 1.

Regarding the order of the indicators, it should be noted that the list starts with the ones that are highly specific to engineering (e.g., indicators related to the work of engineers). Through the end, the indicators (e.g., teamwork and communication) are also shared by other disciplines (e.g., science). Among the twelve indicators, Moore et al. (2015) identified complete POD, SEM, EThink, CEE, and ETool as central to engineering. The reason behind it was that they included unique to engineers' practices (e.g., design process). Finally, ISI, Ethics, Teamwork, and Comm-Engr were categorized under professional skills used by engineers (Table 1). This categorization of indicators (i.e., central indicators, etc.) was used to determine the comprehensiveness of documents by Moore et al. (2015), which is mentioned in the methodology section.

In this study, the Framework for QEE was employed as a theoretical as well as analytical framework due to its success in defining clear-cut ideas, concepts, process, and skills about engineering. Owing to this *reference tool* (Moore et al., 2014, p. 4), we analyzed the inclusion of engineering indicators in K-12 science standard documents of different countries that brought about integrated STEM education reforms. In other studies, for instance, Carr et al. (2012) analyzed the documents regarding "Big Idea Words: Word Count of 80 Most Used Engineering-Related Words Found in Standards" (p. 554), which is not as strong to be used as a framework for the analysis. Therefore, the key indicators of the framework and their definitions provided by Moore et al. (2014, 2015) were used in this study without any changes.

Table 1 Framework for the QEE (Moore et al., 2014, 2015)

Key indicators	Descriptions
Complete process of design (POD)	Design processes are the main focus of engineering practice. Solving engineering problems including stages as planning, testing, evaluating the solution, and revising the design to improve the current design
Problem and background (POD-PB)	The starting point of the engineering design process is the identification or formulation of an engineering problem. When students come across a problem, they should make research, gain fundamental background knowledge about the problem, and come up with engineering solutions to solve the problem
Plan and implement (POD-PI)	At this phase, students improve a plan to make a design solution. This phase including discussion, emerging variety of solutions, and assessing the constraints of competing solutions
Test and evaluate (POD-TI)	At this stage, students generate testable hypotheses or questions, conduct experiments to collect data, and test and evaluate the prototype or model. Due to the iterative nature of the engineering design process, the data gathered from the experiments should be used to make redesign and revisions to improve the design
Apply science, engineering, mathematics knowledge (SEM)	Engineering practice is a harmony of the application of science, mathematics, and engineering knowledge. Students should have a chance to utilize the appropriate science or mathematics knowledge to solve engineering problems
Engineering thinking (EThink)	Engineering leads learners to be independent, insightful, and metacognitive thinkers who could be able to search for knowledge when coming across a problem and improve new knowledge on their own. Also, this process empowered learners to learn from failure and seek out a better solution for a problem. Students also learn to handle uncertainty, risk, safety factors, and product reliability. Besides, systems thinking, creativity, optimism, perseverance, and innovation are additional ways of engineer thinking
Conceptions of engineers and engineering (CEE)	Students participate in the engineering design process, but at the same time, they gain awareness regarding what an engineer does and the discipline of engineering. This includes the nature of engineering such as ideas/conceptions of engineering, how their work is shaped through the needs of a client, considering the constraints while making a design, and keep in mind that no design is perfect. Moreover, students should have an opinion about different types of engineering disciplines and engineering as a profession

Table 1 (continued)

Key indicators	Descriptions
Engineering tools, techniques, and processes (ETool)	Students need to be aware of the variety of techniques, skills, processes, and tools and be proficient in using them. Techniques refer to a step by step task (e.g., DNA isolation). Skills can be explained as performing a task as creating flow charts. Tools are utilized to make the work easier. Processes are defined as a series of actions or steps taken to achieve a particular end
Issues, solutions, and impacts (ISI)	To solve daily-life problems, students need to be able to understand the impact of their solutions in a global, economic, environmental, and societal context. Also, students should learn current events and contemporary issues both locally and globally such as urban/rural shift, transportation, and water supply issues
Ethics (Ethics)	Ethical situations taking place in the engineering practice should be included in K-12 engineering education. Engineers should take into consideration the potential effects of the products on individual or public health. Also, governmental regulations and professional standards should be considered to address the issues, and engineers should be aware of these standards
Teamwork (Team)	During K-12 engineering education, it is essential to improve students' ability to become contributor team members. Gaining this ability may lead students to improve teamwork skills (e.g., interpersonal skills and listening skills), being effective in collaborative groups and activities, and work together to reach a common goal or project
Communication related to engineering (Comm-Engr)	Communication is a kind of ability to get information effectively and share understandings with others in an engineering context. Engineers utilize technical writing to explicate the design and process they carry out in their work. Engineers use a variety of ways to represent information such as verbal communication, symbolic representation, and pictorial representation. For instance, a report may include both written language and drawings, plans, and schematics

2.4 Research on Standard Document Analysis Regarding Engineering and Integrated STEM

In the literature, there has been some research focusing on how engineering, educational values, and nature of STEM disciplines (e.g., nature of engineering) were integrated into the documents. For instance, Carr et al. (2012) analyzed engineering standards in fifty U.S. states' science, technology, and mathematics documents. It revealed that 41 states included engineering indicators. Among them, only five included weak emphasis on engineering and technology design, which means that they only mentioned engineering and technology design components in the standards. Thirty-six of them had included strong emphasis on engineering, which means they included engineering content explicitly in the standards or presented engineering in the context of technology design. In terms of the distribution of engineering elements across grade bands, 22 states' documents had these elements at K-5, whereas 30 documents had these elements at middle school level and 39 documents had engineering at high school level. For all grades up to K-12, 21 state documents included engineering.

In another curriculum analysis study, Moore et al. (2015) compared and contrasted only the NGSS document and state science standard documents released before the NGSS regarding engineering indicators. Results showed that before NGSS, only 14 state standard documents out of 50 included engineering indicators. Twelve states mentioned engineering explicitly in their documents. Moreover, there was an uneven distribution of engineering across the grade bands. In middle and high school standards, engineering was emphasized more than the early grade bands (i.e., K-2 and 3–5). The results also revealed that only very limited features of engineering (e.g., teamwork, applying science, engineering, and mathematical knowledge) were included, which resulted in lacking the comprehensiveness of documents. Concerning the distribution of engineering-related standards across grade bands, findings showed that though a larger number of engineering elements were emphasized in the 6–8 (28%) and 9–12 (34.9%) grade bands, all grade levels included some engineering elements. In the NGSS, 49 performance expectations were coded as engineering related, and engineering elements were evenly distributed among grade bands. The NGSS was found to be almost comprehensible in terms of engineering elements due to the lack of engineering thinking (i.e., EThink) indicator in grade band 3–5.

Unlike the previous studies above, Hoeg and Bencze (2017) examined the NGSS with regard to the educational values embedded in the standard documents through a discourse and content analysis. Performance, accessibility, innovation, and creativity were the themes used in the associated analysis. The results revealed that almost 60% of the NGSS performance expectations were highly performative, which means they were highly structured and teachers were not allowed to interpret or change the expectations. Regarding accessibility, more than half of the performance expectations were coded as non-participatory. Innovation and creativity were included 26 and 43 times, respectively, in the NGSS documents. Very limited performance expectations (i.e., 6%) "describe potentially participatory practices, in which students and teachers are able to make decisions about what innovative practices could satisfy an expected performance, allowing the creation of new ways to demonstrate learning" (p. 290).

In a recent study, Park et al. (2020) focused on the nature of STEM disciplines in the standard documents of the U.S., Korea, and Taiwan. Park et al. (2020) argued that although scholars have conducted many studies on the nature of science in science curriculum documents, understanding of other STEM disciplines represented in the science curriculum documents did not take much attention. They used the family resemblance approach (FRA) as the framework to examine the nature of STEM disciplines presented in science standard documents with regard to the disciplinary aims, values, and practices. Results showed how science documents of the three countries that covered the nature of the STEM disciplines are varied. Science documents analyzed included the indicators of science alone and elements common to both science and engineering. Elements related to mathematics were the ones least frequently mentioned in the documents. NGSS (2013) provided far richer information than the science documents of Korea and Taiwan concerning the three aspects (e.g., disciplinary aims and values and practices) examined in the study in terms of nature of the STEM disciplines.

To conclude, in the past, some studies focused on how engineering elements were covered in the U.S. states' science documents before and after the release of NGSS (e.g., Moore et al., 2015), mathematics and technology documents (e.g., Carr et al., 2012), as well as others analyzing the NGSS regarding other variables such as educational values (e.g., Hoeg & Bencze, 2017), and how the nature of STEM disciplines was emphasized in different countries' science documents (e.g., Park et al., 2020).

2.5 Significance and Contribution of the Study

Standard documents and the standards themselves are important to all the stakeholders in education for the description of what learners are supposed to achieve when they complete a grade level (Moore et al., 2015; NRC, 2010). As Brophy et al. (2008) stated "[w]hat gets taught in P-12 classrooms is often a function of what gets emphasized in national and state content standards" (p. 370). Furthermore, Desimone (2009) stated that "even curriculum materials are themselves a potential source of professional development when they are designed to be "educative" (p. 182). Given the lack of framework for engineering elements and teachers' limited knowledge of the field, the documents are highly important to the success of the integrated STEM education movement. Therefore, it is crucial to ask "Do the standards generate enough interest in engineering?" and "Do the standards provide adequate preparation for engineering?" (Fadali & Robinson, 2000, p. 1).

Although there has been some research on integration of engineering into standard documents (e.g., Carr et al., 2012; Moore et al., 2015), those studies shed light on the situation in the context of the U.S. Yet, the question of how different countries have integrated engineering into their science documents has no answer. Additionally, Park et al. (2020) focused on how the U.S., Korean, and Taiwan's science documents integrated nature of STEM disciplines; however, they used the FRA framework and focused on the nature of engineering (i.e., Park et al., 2020 used nature as "a set of family resemblance" to state important aspects of a discipline [p. 903]) and other disciplines. In other words, the study of Park et al. (2020) was different from the current study in terms of aim, the framework used, and the countries whose documents were analyzed. Moreover, Park et al. (2020) focused on the nature of engineering, whereas this study focused on engineering and its elements in the science documents, which is another difference among the studies. Moore et al. (2015) mentioned that the difference in the nature of engineering and its design is equivalent to the difference in the nature of science and scientific inquiry. Hence, the lack of international comparison on how and to what extent engineering was presented in the K-12 science standard documents of different countries (i.e., the ones that integrated engineering into the science standard documents) has motivated the current study. Our aim was to identify which engineering elements have been integrated into their science standards by using the framework for QEE proposed by Moore et al. (2014, 2015). Although the framework for QEE was developed with a U.S. lens and countries having different contexts, the key indicators of engineering presented in the framework for QEE depended on Criterion 3 of ABET (2020) which were "used to accredit U.S. and international post-secondary education programs in applied sciences, engineering, and technology and describe the desired characteristics of students who have completed accredited undergraduate engineering programs" (Moore et al., 2014, p. 6), and they were compatible with the international criteria of engineering (Moore et al., 2014). Therefore, the results of the current study would present valuable information about different nations that focus on engineering and its aspects in science standard documents with a knowledge of their different aspects.

3 Methodology

This study is qualitative in nature and aims to provide a prime view of how engineering was integrated into science documents of different countries that have different historical context, socioeconomic status, and standardization (Patton, 2002). Additionally, these countries have the engineering components (e.g., engineering thinking, teamwork, and ethics) in their K-12 science documents. For that purpose, we used content analysis which "is a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" (Krippendorff, 2004, p. 18).

3.1 Selection of the Countries

The standard documents of the countries that have made integrated STEM reform would be part of this comparative study. However, due to limited time and resources, we could not reach and analyze the documents of all those countries. The selection of the documents had two steps. First, the countries, which made integrated STEM education reform in their K-12 education system and incorporated engineering indicators into their documents, were identified (i.e., about 10–12 countries) through a superficial analysis of the documents by using *STEM education*, *engineering integration*, and *design* keywords. The first step included determining purposefully the countries that have information-rich cases about the phenomena we focused on (Patton, 2002). However, it should be noted that we did not collect all documents of the countries that had reflected the integrated STEM movement and integration of engineering. In the second step, standard documents of seven countries were chosen based on (a) attainability of the documents on the web, (b) having English versions of the documents (e.g., excluded South Korean documents due to lack of English version), and (c) that could be downloaded for free (e.g., excluded Finnish documents due to the amount of the money asked for each grade bands for each document). Due to their feasibility for the researchers, we focused on the documents of Australia, England, Estonia, Hong Kong, South Africa, Turkey, and the U.S. for this study. It could be claimed that by covering those seven different countries, we had a depth and breadth of countries (i.e., culturally or socioeconomically, etc.). Therefore, the second part of the selection was convenient. However, those seven countries are good for providing an international perspective beyond national contexts. Our aim was neither to generalize our findings to other countries' documents nor to draw conclusions about the strongest one. Rather, we aimed to provide a first view of how engineering was integrated into science documents in different countries that have different historical context, socioeconomic status, and standardization. In the Appendix section, summaries of the unique characteristics of the science standards and documents of different countries have been provided.

3.2 Data Sources

Once the countries were identified, first, we read previous research (e.g., Guo et al., 2016; la Velle & Erduran, 2007) and documents published (e.g., Education Council, 2015) to get a deeper understanding of those countries' education systems and the structure of their science documents. It was important to be knowledgeable about the education systems and school science curricula of these different countries to understand and standardize the differences among them. Second, the English version of the science standard documents of all grade levels, which were the data sources of the current study, was obtained directly from official websites of each country. Colleagues from the selected countries confirmed that the documents researchers had downloaded were the updated/current ones.

3.3 Data Coding and Content Analysis

The researchers carried out content analysis of seven countries' science standard documents for K-12 regarding the extent and the comprehensiveness of the documents through line-by-line analysis. The analysis of the documents had multiple steps (Fig. 1).

Regarding the first research question focusing on the extent to which engineering elements are represented in the documents, we focused on to calculate (i) the frequency of engineering emphasis throughout the documents and (ii) the frequency of engineering elements stated in the Framework for QEE, and how these elements have been distributed across the grade bands. In order to achieve these goals, we first identified standards that have engineering emphasis (Fig. 1, phase 2). Due to the fact that the NGSS marked engineering-related standards with an asterisk, we did not need to identify them. Before we started to determine the engineering-related standards of other countries, we focused on the standards given in NGSS, which helped us gain a basic familiarity with engineering standards in the compilation step. After the NGSS, we worked together to identify the

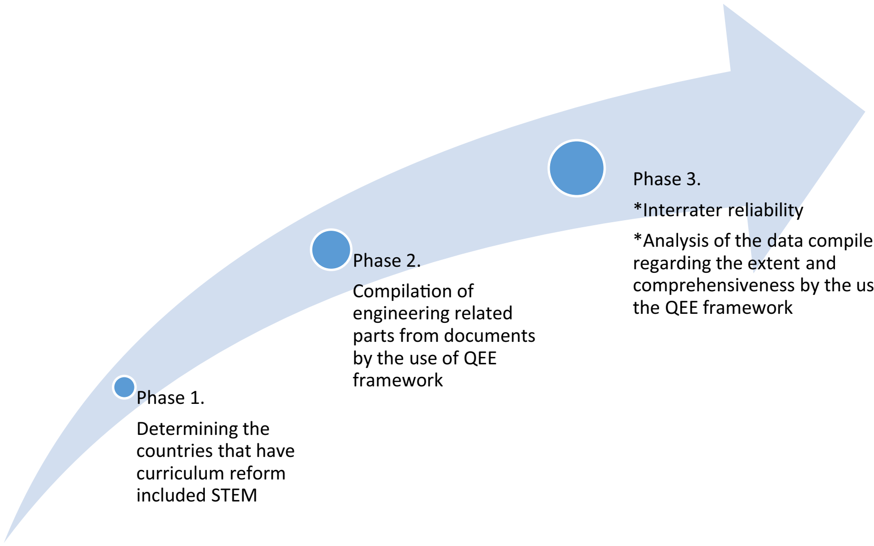

Fig. 1 Summary of the data compilation and analyses

engineering elements in the documents of other countries that did not specify engineering-related standards. In this step, we used open coding through which "events/actions/interactions are compared with each other for similarities and differences. They are also given conceptual labels. In this way, conceptually similar events/actions/interactions are grouped together to form categories and subcategories" (Corbin & Strauss, 1990, p. 12). To be more specific, in this process, if the standard included traces of any one of the key indicators given by the Framework for QEE (see Table 1), it was included in the database for further discussion. The researchers independently determined the standards that would be coded in the later steps. Then, they came together and compared and contrasted their decisions about including or excluding standards. That procedure was repeated for each standard document. When the authors faced a disagreement, the description of the engineering elements and examples provided by Moore et al. (2014, 2015) were used to dissolve the problem. The final version of the database was formed through agreement among the authors.

Regarding the first research question, different from Moore et al. (2014, 2015), we faced a situation. Standard documents of different countries included engineering not only in science standards but also in some other parts of the documents (e.g., introduction of the curriculum, assessment guidelines, and suggested teaching and learning activities). To handle that difference, we decided to analyze not only science standards of the documents but also those other parts incorporating engineering elements, which were especially useful for understanding the way of integration of the countries preferring implicit approach. For more clarity, a standard or suggested activity or context example should be included in the engineering design process in which learners participate (e.g., MS-PS1-6. "Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes" from NGSS, 2013, p. 56), or they should include parts that contribute to their understanding of engineering (e.g., "Developing new household electrical devices, improving the efficiency of existing devices and ensuring consistency of electrical standards require international cooperation between scientists, engineers and manufacturers" from ACARA, 2016b, p. 159).

After the compilation of engineering-related standards and the other parts from the countries' science documents (Fig. 1, phase 2), we coded the standards in the light of the QEE and calculated the frequency of engineering-related standards and the parts across countries (Fig. 1, phase 3). That coding also lets us analyze distribution of key indicators across grade bands in each country.

At this stage, before we started to code the countries' standards, we coded the NGSS standards independently by using the Framework for QEE, to ensure consistency in the coding. Each researcher independently coded the standards of the NGSS by using key indicators of Framework for QEE (see Table 1). Then, researchers came together and compared and contrasted the coding generated independently. When a conflict was observed, we discussed and solved it in the light of details (e.g., description of the engineering indicators and example standards presented by Moore et al., 2014; 2015) provided in the analytical framework. This standardization of coders' understanding of the key indicators took three meetings (i.e., each meeting focused on one of the countries' Data Coding) for each of which inter-rater reliability values were calculated by using the formula of "Number of agreements"/(Total number of agreements + disagreements) × 100″ suggested by Miles and Huberman (1994). The reliability coefficients were 0.79, 0.87, and 0.96, higher of which calculated for the

Table 2 Framework for a Quality K-12 Engineering Education with examples

Key indicators		Examples from different countries
Complete process of design (POD)		• Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. (U.S., Grades 9–12)
Sub-indicators of POD	POD-PB	• Make design for isolation of living spaces in order to supply energy saving. (Turkey, Grades 9–12) • Pupils might work scientifically by exploring falling paper cones or cupcake cases and designing and making a variety of parachutes and carrying out fair tests to determine which designs are the most effective. (England, Grades 3–5)
	POD-PI	• Design and make a water-saving device to be fixed on water tap for daily use. (Hong Kong, Grades 6–8) • Investigating requirements and the design of systems for collecting and recycling household waste. (Australia, Grades 6–8)
	POD-TE	• Researching, designing, making, and evaluating a musical instrument (such as a guitar, shaker, drum, and blowing instrument such as pan pipes, whistles, and flutes) that uses movement energy to make sounds. (South Africa, Grades 3–5) • Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment. (U.S., Grades 6–8)
SEM		• Investigating how a range of people, such as clothing designers, builders, or engineers use science to select appropriate materials for their work. (Australia, Grades 3–5) • Produce solutions to the real-life problems related to lifting force by using the lifting force and/or the Bernoulli Principle. (Turkey, Grades 9–12)
EThink		• Using criteria to assess a constructed object and then stating or carrying out ways to refine that object. (South Africa, Grades 3–5) • Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. (U.S., Grades 6–8)
CEE		• Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. (U.S., Grades 9–12)
ETool		• Understand how knowledge of chemical systems is used to design synthesis processes, and how data from analytical techniques provides information about chemical structure. (Australia, Grades 9–12) • Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity. (U.S., Grades 9–12)
ISI		• Students should be taught about life cycle assessment and recycling to assess environmental impacts associated with all the stages of a product's life. (England, Grades 9–12) • Make justified decisions about dilemmas concerning gene technology and show a responsible attitude toward the risks accompanying the use of gene technology. (Estonia, Grades 9–12)

Table 2 (continued)

Key indicators	Examples from different countries
Ethics	• Explain the possibilities of using gene technology in medicine and the ethical and moral problems associated with it. (Estonia, Grades 9–12)
Team	• Recognizing that the study of the universe and the exploration of space involve teams of specialists from the different branches of science, engineering, and technology (Australia, Grades 9–12) • To work individually or collaboratively with peers to identify problems and design feasible solutions. (Hong Kong, Grade 2)
Comm-Engr	• Develop a project to take precautions against global warming. Students are encouraged to introduce their projects with posters, brochures or PowerPoint presentations. (Turkey, Grades 9–12) • Designing, making, and evaluating a rocket model using a balloon and release the inflated balloon and measure how far it travels along the fishing line. Draw bar graphs and evaluate different balloon rockets. (South Africa, Grades 3–5)

last meeting. According to Miles and Huberman (1994), reliability among the coders should be 0.80 or above.

After reaching consensus, each researcher coded the rest of the three countries' data compiled earlier. In Table 2, examples of assigning the key indicators to science standards in different countries were provided. In the analysis, the unit of the analysis was phrases such as "PS2-4. Define a simple design problem that can be solved by applying scientific ideas about magnets" (NGSS, 2013). The analysis carried out in this study was "*deductive analysis* where the data are analyzed according to an existing framework" (Patton, 2002, p. 452).

In the second research question, we focused on the comprehensiveness of the documents analyzed regarding engineering emphasis and indicators. To attain that goal, we used the criteria set by Moore et al. (2015), which were to be considered as comprehensive, and engineering standard documents should meet four requirements:

The standard documents should.

a) emphasize engineering explicitly,
b) include POD, SEM, and EThink in all grade bands more than once,
c) include CEE and ETool in at least two grade bands more than once,
d) include ISI, Ethics, and Comm-Engr in at least one grade band more than once.

Regarding the first criterion, we aimed to determine how engineering was incorporated into the documents in different countries. As suggested by Moore et al. (2015), explicit, implicit, or none categories were used. They were considered to explicitly include engineering if they used terms such as "engineering," "design," or "technological design." If the standard did not include these terms but still provided clear indications related to engineering, they were categorized as having an emphasis of implicit engineering. If standard documents did not emphasize engineering, they were categorized as "none."

Regarding the other criterion for comprehensiveness, as the readers would remember, Moore et al. (2015) provided the list of twelve engineering indicators and presented them in an order (see the framework section and Table 1). Moreover, Moore et al. (2015) stated that, in the light of the NRC (2009), complete POD, SEM, and EThink are central indicators of engineering because they are unique practices of engineers. Likewise, CEE and ETool were categorized as key indicators of engineering professions. Finally, they categorized ISI, Ethics, Teamwork, and Comm-Engr under professional skills used by engineers. Hence, those four criteria were set for comprehensiveness analysis. In the current study, we used them in answering the second research question.

4 Results

4.1 Research Question 1: The Extent of Engineering Presented in the Documents

The extent of engineering presented in the science standard documents is revealed in two subheadings. First, the total number of engineering emphasis in the standard documents of seven countries was presented to give an overall idea for the research question. Second, the frequency of key indicators and their distribution across grade bands for seven countries was provided.

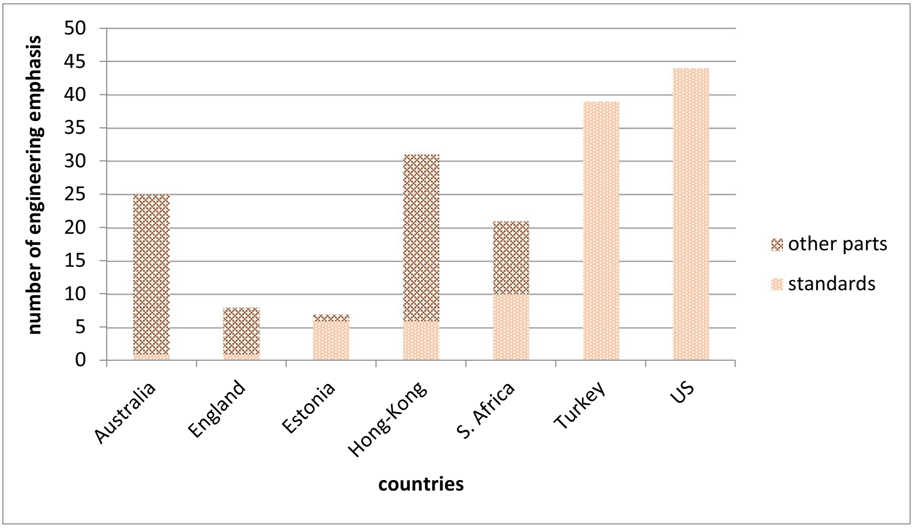

Fig. 2 Number of engineering emphasis (both in standards and other parts) in the documents of seven countries in K-12 science

4.2 Number of Engineering Emphasis in the Documents

As it is apparent from the Data Coding part that emphasis on engineering in the science standard documents was detected not only in standards but also in other parts of the documents (e.g., introduction of the curriculum and assessment guidelines), that were not observed in previous studies the analysis of engineering indicators in the documents (e.g., Carr et al., 2012; Moore et al., 2015). Therefore, to understand the results provided in this study, the details about the frequency of engineering emphasis on science standards and the other parts of the documents given below are necessary (Fig. 2).

The results presented in Fig. 2 will be examined in the following part.

4.2.1 Standards Including Engineering Emphasis

The range of the number of engineering-related standards is very large as it was provided in Fig. 2. Among the countries, the U.S. with NGSS had the greatest number of engineering-related standards with 44 standards. Australian and English documents had only one engineering-related standard.

4.2.2 The Details of Other Parts Including Engineering Emphasis in the Standard Documents

Analysis has revealed that there were some patterns of emphasizing engineering aspects through the standard documents. First, Turkish and the U.S. standard documents were similar and included elements of engineering only in the standard parts (e.g., MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystem services)

(NGSS, 2013, p. 32). Estonian way of document organization was also very much similar to those of Turkey and the U.S. Six engineering-related standards were detected, whereas only in one part of the documents engineering indicators were emphasized in the science documents of Estonia.

Second, Australia, England, and Hong Kong showed a resembling tendency, where documents had more engineering emphasis in other parts than those of standards. For instance, Australian documents provided good examples of what engineers did and how they solved everyday problems in "examples in context" and "unit description" parts. The only standard that directly addressed engineering in Australian documents was "to understand how knowledge of chemical systems is used to design synthesis processes, and how data from analytical techniques provides information about chemical structure" (ACARA, 2016b, p. 77). Similarly, English documents also suggested engineering-related activities and some useful ideas for teachers to implement in the classroom in "notes and guidance (non-statutory)" and "key ideas" sections of the documents. For instance, the document suggested an activity: "Pupils might work scientifically by: systematically identifying the effect of changing one component at a time in a circuit; designing and making a set of traffic lights, a burglar alarm or some other useful circuit" (Department for Education, DfE, 2013a, p. 34).

Unlike other countries, standard documents of South Africa had almost equal number of engineering-related standards (e.g., in Strong Frame Structures topic, the standard states: "learner should be (i) exploring ways to join struts to make a strong structure (joining struts into triangular and square shapes), (ii) designing, making and evaluating a strong structure using tubular struts, such as a model of a tower, bridge, pylon, chair" (Republic of South Africa Department of Basic Education, DBE, 2011a, p. 22) and statements in different parts of the documents (e.g., Major Process and Design Skills parts).

To sum up, engineering emphasis was made in different parts of the documents in different countries that is a new finding of the analysis made in this study. In addition to the standards, as revealed in Moore et al. (2015), documents' guidance, introduction, and unit description parts also incorporated engineering and its indicators. In addition to integrating engineering either in standards or other parts, documents of South Africa almost equally distributed indicators in both parts.

4.3 Distribution of Engineering Elements Determined by the Framework for QEE across Grade Bands

In order to gain a deeper understanding of the emphasis on engineering indicators of the Framework for QEE in K-12 science documents, we classified engineering emphasis (i.e., both in standards and other parts) across grade bands. In this way, we aimed to provide details of how engineering emphasis was distributed among the grade bands through K-12 in addition to providing frequency of the emphasis in the documents, which were the focus of the first research question. In the following section of the results, science standards including engineering indicators were presented with regard to the key indicators presented in the framework for QEE across grade bands. Starting from the K-2 level, all grade bands were examined in terms of distribution of key indicators for each country (i.e., "POD" refers to the complete POD, including three the sub-components POD-PB, POD-PI, and POD-TE).

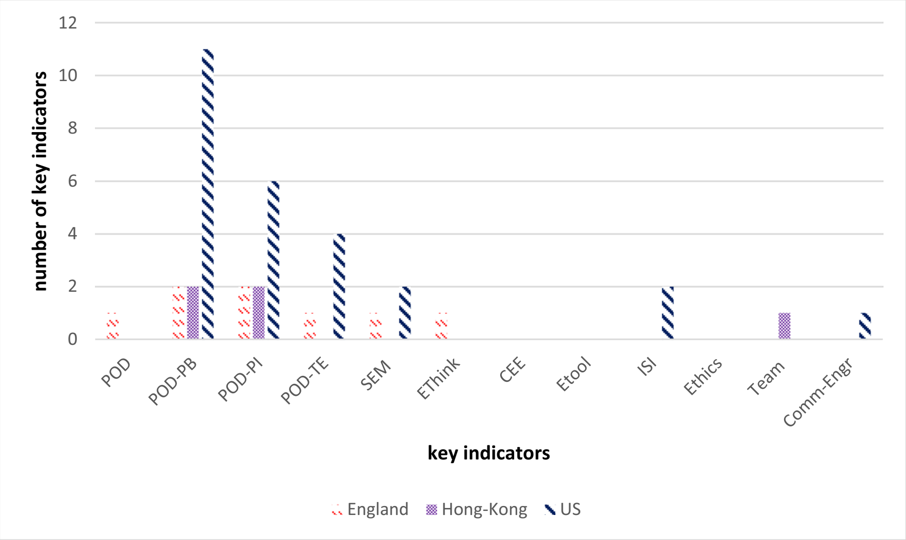

Fig. 3 Distribution of key indicators at K-2 level in seven countries' documents

4.3.1 K-2 Level

Australia, Estonia, South Africa, and Turkey did not offer any course in science at K-2 level. Therefore, Fig. 3 includes only England, Hong Kong, and the U.S.

At K-2 level, none of the countries included CEE, ETool, and Ethics elements in their documents. Hong Kong emphasized POD-PB, POD-PI, and Teamwork. In addition to that,

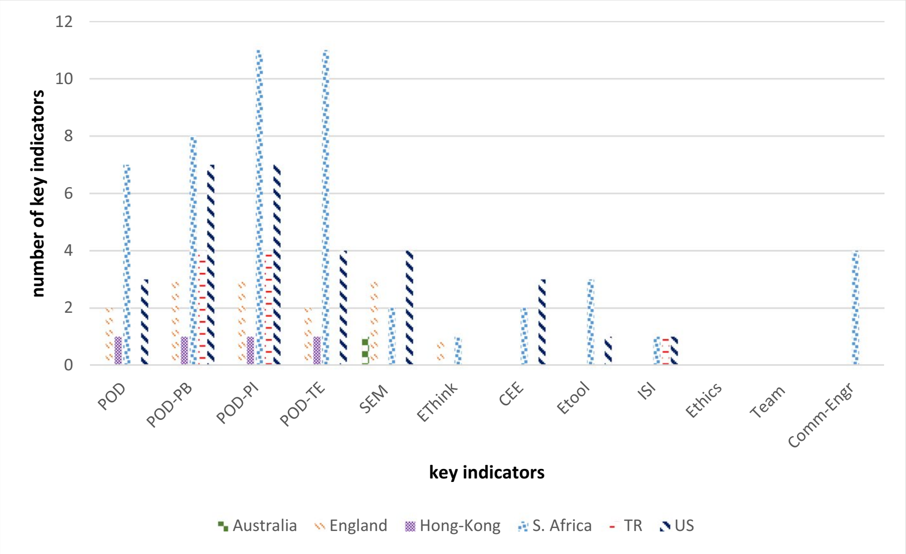

Fig. 4 Distribution of key indicators at 3–5 grade band in seven countries' documents

England and the U.S. also emphasized other key indicators in the K-2 engineering-related standards of science. For instance, K-ESS3-3 standard in the NGSS stated "Communicate solutions that will reduce the impact of humans on the land, water, air, and/or other living things in the local environment," which emphasized both on ISI and Comm-Engr aspects. At this grade band, it can be stated that the standard documents generally addressed different aspects of the engineering design process (e.g., "Problem and Background" and "Plan and Implement") and introduced it to small children. The lack of ethics and other aspects may be explained due to their abstract nature, which may not be suitable to be emphasized at K-2 level.

4.3.2 Grade 3–5 Level

Details about the key elements of the framework in the grade 3–5 band for the countries are presented in Fig. 4.

In the grade 3–5 band, Estonia did not have any engineering-related standards or any emphasis throughout the document. The number of engineering-related standards vary widely from country to country. When compared to the K-2 level, there seems to be a wider distribution of engineering indicators and higher numbers of engineering-related standards than those in the K-2 level. South Africa had a greater number of key indicators and their distribution than any other countries. Moreover, the Comm-Engr indicator was emphasized in a remarkable number of standards in South African documents at this grade band. The U.S. followed South Africa in terms of the number of engineering-related standards and key indicators emphasized in this grade band. Although CEE and ETool were not mentioned in the K-2 level, they were integrated into South African and the U.S.'s documents. For instance, in the South African document, learners are supposed to learn "[t]he creation of structures, systems and processes to meet peoples' needs and improving the quality of life" (DBE, 2011a, p. 9). Regarding ETool aspect, 4-PS4-3 standard from NGSS can be given as an example:

> Generate and compare multiple solutions that use patterns to transfer information. [Clarification Statement: Examples of solutions could include drums sending coded

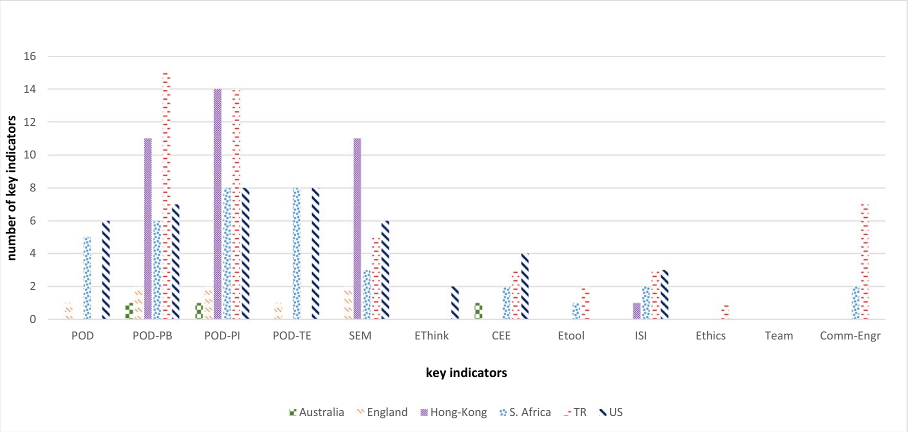

Fig. 5 Distribution of key indicators in the 6–8 grade band in seven countries' documents

information through sound waves, using a grid of 1’s and 0’s representing black and white to send information about a picture, and using Morse code to send text] (p. 37).

In the standard, learners are supposed to realize that engineers use different tools (e.g., codes) to solve the problems focused and to provide the solutions. Contrary to CEE and ETool integration, Ethics and Teamwork indicators were still missing in the documents at this grade band.

4.3.3 Grade 6–8 Level

Estonia did not have any engineering emphasis at the 6–8 grade band. The details for this band are summarized in Fig. 5.

In contrast to other grade bands, Hong Kong and Turkey’s documents stood out as including the greatest number of emphasis in the 6–8 grade band. However, documents of Hong Kong contained POD-PB, POD-PI, SEM, and ISI indicators. In addition to these, Turkey also included CEE, ETool, Ethics, and Comm-Engr indicators, which were addressed rarely in the documents of other countries. The only indicator that was not emphasized by any country at this grade band was Teamwork. Finally, there was only one country emphasizing EThink (i.e., the U.S.) and Ethics (i.e., Turkey) in their science documents in the 6–8 grade band. For EThink, in the NGSS, “MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved” (p. 153). In the standard, it was aimed to address that engineering problems necessitate an iterative process through which engineers learn and try to find a better solution through their knowledge. In the Turkish standard document, standard: F.8.2.5.2 stated: “Learners are supposed; to discuss the dilemmas created within the scope of biotechnological applications, and the beneficial and harmful aspects of those applications” (National Ministry of Education, NME, 2018, p. 48).

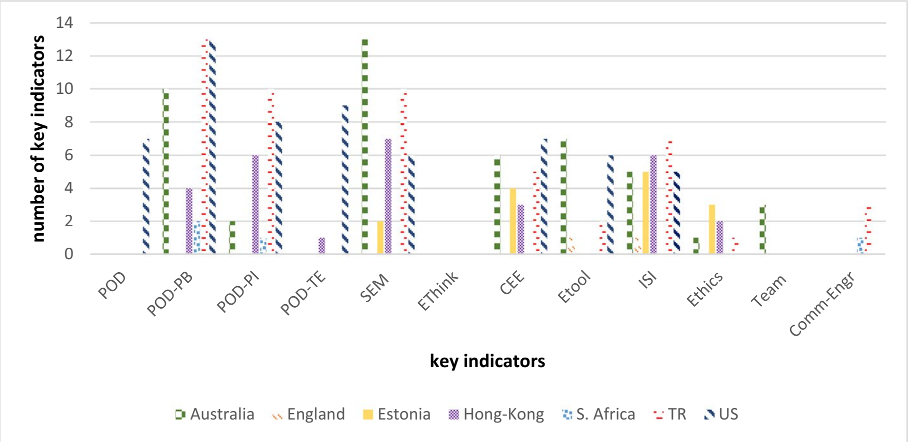

Fig. 6 Distribution of key indicators in the 9–12 grade band in seven countries’ documents

4.3.4 Grade 9–12 Level

The results are summarized in Fig. 6 for this band.

In this band, the number of the standards and the presence of key indicators were each greater than that found in other grade bands. SEM, CEE, ISI, Ethics, and Comm-Engr indicators were the ones integrated intensively. In the previous grade bands, those aspects were not mentioned frequently. In Estonian document, ethical issues were addressed as following standard: "students are expected to have the capacity to: solve dilemmas about genetic engineering applications considering their scientific, economic and ethical aspects as well as legislation" (Estonian Ministry of Education and Research, MER, 2014b, p. 13–14).

SEM aspect was mentioned in Australian document as: "Further work on collision theory enabled a quantitative approach to be taken which allowed for the prediction and control of chemical reaction rates; These understandings are now used by chemical engineers to design efficient, safe and economically viable industrial processes" (ACARA, 2016a, p. 70). ISI was addressed in Hong Kong documents as: learners are supposed to "be aware of the potential impact of biotechnology on society" (Curriculum Development Council, CDC, 2015, p. 70).

The Ethics and ISI aspects of engineering were addressed by focusing on ethical issues of biotechnological applications of genetic engineering and their effects on society. Different ethical issues (e.g., the honest use of the project budget or building earthquake-resistant structures, etc.) for different engineering types (e.g., civil engineering) were not mentioned in the documents. Contrary to frequent emphasis on those indicators, there was an engineering indicator that was missing in the standards at this grade, which was EThink. Moreover, POD-PE was included only in Hong Kong, and Teamwork was emphasized only in Australian documents.

Before focusing on the second research question, it would be useful to see the overall distribution of the engineering indicators (i.e., without focusing on each indicator of the QEE) across grade bands for each country (Fig. 7).

To conclude, although Fig. 7 does not provide the details for each of the engineering indicators of the QEE framework, it presents the big picture regarding how those

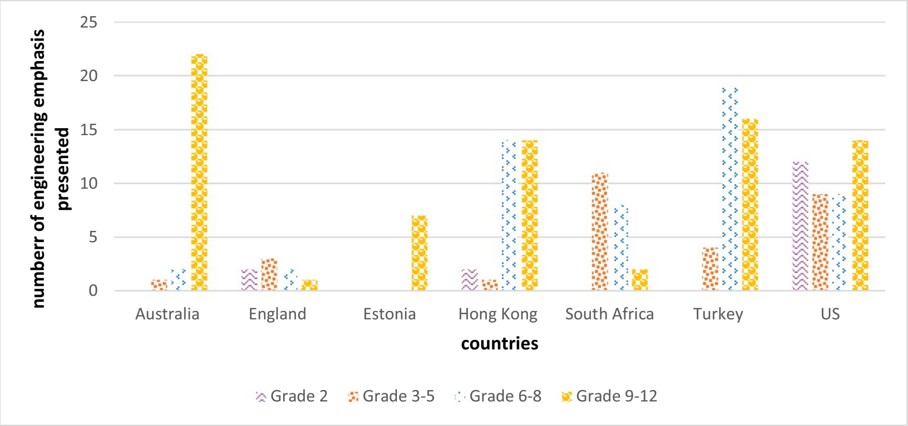

Fig. 7 Number of engineering emphasis (both in standards and other parts) for seven countries across grade bands

Table 3 Inclusion of engineering in the K-12 science standard documents of the seven countries

Countries	Grade levels			
	K-2	3–5	6–8	9–12
Australia	Implicit	Implicit	Implicit	Implicit
England	Implicit	Implicit	Implicit	Implicit
Estonia	None	None	None	Implicit
Hong Kong	Implicit	Implicit	Implicit	Implicit
South Africa	No science education for this band	Implicit	Implicit	None
Turkey	No science education for this band	Explicit	Explicit	Implicit (Biology, Physics) None (Chemistry)
U.S	Explicit	Explicit	Explicit	Explicit

engineering indicators in total were emphasized across K-12 grade bands. The documents of the U.S. (i.e., with more emphasis) and England documents (i.e., with less emphasis on the indicators) showed an even distribution of engineering emphasis through grades. In the NGSS, the number of engineering-related standards across grade bands was almost evenly distributed. Contrary to the U.S. and England, documents showed an uneven distribution (i.e., Turkey, Hong Kong, and Australian documents) and put more emphasis on engineering aspects at higher grades than they did at lower grades. Contrary to this tendency, South African documents mentioned engineering aspects more in lower grades than in higher ones. Finally, documents of Estonia had seven standards only at 9–12 grade band.

4.4 Research Question 2: Comprehensiveness of Engineering within the Standard Documents across Seven Countries

The comprehensiveness of engineering presented in the standard documents was determined by applying four criteria set by Moore et al. (2015) (see the Data Coding and Content Analysis part for the criteria to be considered as comprehensive). The first criterion for being comprehensive was the requirement to include an explicit engineering emphasis. The standards in the K-12 science standard documents of seven countries were classified as being explicit, implicit, or none, considering their inclusion of engineering (Table 3) (i.e., see the Data Coding part for the definition of being explicit vs. implicit).

It is obvious that there are different types of inclusion of engineering into the documents (Table 3). For instance, the U.S. is the only one integrating engineering into documents explicitly through K-12. However, science standard documents in Australia, Hong Kong, and England had implicit inclusion of engineering across all grades. Contrary to those countries which consistently include engineering either explicitly or implicitly, the documents of Estonia, South Africa, and Turkey showed an inconsistent way of incorporation through the grade bands. Consequently, there are also differences in ways countries included engineering indicators into science documents. Nations have their own way of integration of engineering, interpretation of what the integrated STEM approach brings to their education system, and how those changes should be addressed. Furthermore, some countries showed inconsistent ways to include engineering aspects regarding grade bands, which may also be related to the disconnection or miscommunication among the communities for curriculum development of different grade bands. To sum up, only the U.S. documents and to some extent Turkey's documents (i.e., except the documents for 9–12 grade band) placed explicit emphasis on engineering.

Although Turkey's documents did not meet the first criterion (i.e., implicit engineering emphasis in the documents for 9–12 grade band), we continued with Turkey's documents due to the fact that the explicit emphasis could be achieved easily by mentioning engineering in the modified documents in future. Another reason to include Turkey's documents was to provide more data for the analysis of comprehensiveness. However, any other researcher might exclude Turkey's documents for further analysis. The second criterion was including complete POD, SEM, and EThink, which are basic engineering indicators according to Moore et al. (2015) in all grade bands. Australia, England, Estonia, Hong Kong, and South Africa's standard documents did not meet the second criterion. When we considered the U.S. and Turkey (i.e., to some extent explicit), which had explicit engineering emphasis in the documents, we encountered that science standards of Turkey did not meet this criterion either. Although science standards included a sufficient number of POD-PB and POD-PI, they did not include POD-TE. Therefore, complete POD was not found in many occasions across all grades in the Turkish standard documents. Considering the second criterion, NGSS did not include EThink in any of the grades in different occasions. Therefore, the NGSS was not comprehensive either.

So far, it is clear that none of the documents was comprehensive according to the criteria set by Moore et al. (2015). However, in order to provide details for the third and the fourth criteria to inform the policy makers, curriculum developers and researchers continued to carry out analysis about what is missing in the documents concerning the integration of engineering. Third criterion stated inclusion of CEE and ETool in at least two grade bands more than once. Regarding this, the U.S., South Africa, and Turkey had CEE and ETool indicators in at least two grade bands more than once. Finally, none of the countries fulfills the necessary conditions for the last criterion (i.e., including ISI, Ethics, and Comm-Engr in at least one grade band more than once). Although South African and Turkish documents integrated ISI and Comm-Engr indicators in at least one grade band more than once but did not include Ethics indicator not even once in the grade band.

5 Discussion and Implications

In this study, science standard documents of seven countries that have improved their engineering practices noticeably by integrating engineering and its elements into their science documents were analyzed by employing the Framework for QEE proposed by Moore et al. (2014, 2015). The results showed that the numbers of engineering-related science standards had a considerable variation for both country and grade bands. Moreover, the place where the engineering indicators incorporated is also another point that needs attention. The results revealed that the integration of engineering into the documents was also different regarding the place of incorporation of engineering indicators (e.g., standards, introduction of the curriculum, assessment guidelines, and suggested teaching and learning activities). This point has not been focused on by previous studies that explored engineering indicators in the standard documents (e.g., Carr et al., 2012; Moore et al., 2014, 2015). Yet another difference was also revealed for levels of the inclusion of engineering (e.g., explicit, implicit, or none) into the science documents. To conclude, each country has its own unique engineering integration, which may be related to countries' and committees' differences in interpretation of integrated STEM education and how to incorporate engineering into science documents. Regarding the second research question, none of the science standard documents analyzed was comprehensive enough as per the list of criteria Moore et al. (2015). The results related to the current situation of the engineering elements in science standard documents may be related to one of the limitations of the study. In this study, we could analyze only seven countries' K-12 science standard documents. Analysis of standard documents of different countries that have integrated engineering into the documents would provide a better understanding of the situation.

Regarding the first part of the first research question, although there is no rule of a thumb for the number of the standards with engineering emphasis through the documents, we focused on the relative number and the place of the engineering emphasis made by different countries' science standard documents. The high number of the engineering-related standards could be interpreted as a strong indicator of how much importance is attached to teaching different aspects of engineering through K-12 (Glancy et al., 2014). Results showed that the U.S., Turkey, and Hong Kong had more engineering emphasis in their documents than other countries focused on. However, the place where the engineering emphasis was made into the documents was different. The U.S. and Turkey integrated engineering into the standards, whereas Hong Kong mostly integrated engineering in other parts of the documents (i.e., in the suggested learning and teaching activities part). The possible reason behind this result may be the differences in the curriculum developers' views about how much and where the engineering emphasis should be made in the documents. Given the fact that standards are directing what gets taught in classrooms (Brophy et al., 2008; Olson, 2018) and what gets written in the textbooks (Summers et al., 2019), for the success of the integrated STEM reform highlighting the integration of engineering, the engineering emphasis should be made more in the standard part. Likewise, McComas and Nouri (2016) revealed that most of the teachers pay more attention to the standards than they do on appendices or guideline sections in lesson planning. Hence, as an implication for curriculum developers of Australia, England, Hong Kong, and South Africa, future modifications made on the documents should focus on integrating engineering into standard parts of the K-12 science standard documents.

The second part of the first research question focused on the frequency and distribution of engineering indicators stated in the Framework for QEE across the grade bands. Concerning complete POD, results showed that it was presented in the standards of lower grades to some extent. However, it was missing at the higher grades in the standards of all the countries. About the sub-indicators of complete POD, the documents mostly included POD-PB and POD-PI, whereas POD-TE (i.e., related to testing and evaluating students' designs) was rarely incorporated. Regarding the current situation, we argue that the possible reason behind it can be the differences in the views of the communities responsible for curriculum development of different grade bands and lack of a framework describing which indicators of engineering should be integrated into the documents. As an implication, the communities should communicate to provide better integration of engineering into the standard documents. Moreover, the complete process of engineering design should be included in K-12 standards. Curriculum developers should pay attention to the missing aspects of the engineering design process (e.g., testing and evaluating learners' designs) in the modifications of the documents. By this way, learners would have the opportunity to learn from failure and develop problem solving skills in early ages as a result of the iterative nature of the design (Moore et al., 2018).

Regarding the SEM indicator, in most countries, it was included in the higher grades more than in the lower grades. Koehler et al. (2015) argued that the focus in lower grades was more on mathematics and language arts, which may explain the low frequency of the SEM indicator that highlights the use of scientific knowledge in engineering practices. The SEM indicator is important both for engineering and science education, as integrating engineering into science classes offers students the opportunity to see the real application of scientific knowledge (Johnston et al., 2019; Pleasants et al., 2019). The inadequate emphasis on SEM aspect may be an explanation of why learners' in elementary and middle schools drew engineers as if they were workers working with hands (Capobianco et al., 2011; Chou & Chen, 2017). Moreover, the learners' drawings and interviews did not include any use of scientific knowledge, higher-order actions, or thinking processes of engineers. Therefore, more emphasis on how engineers use scientific knowledge while solving engineering problems should be integrated in lower grades' standards of South Africa, Australia, Turkey, and Hong Kong.

The results of this study revealed that, similar to SEM indicators, EThink was not included in all grades throughout standard documents. What is more, EThink is one of the least emphasized indicators among the documents of the seven countries. EThink is one of the fundamental indicators of engineering that is essential for teaching learners how an engineer thinks (i.e., reflective, metacognitive, and independent) when they need to solve a problem, troubleshoot, and manage risks, etc. The current limited integration of EThink may be related to the fact that promoting engineering thinking is a complex process. It is not easy to incorporate it in the curriculum in isolation (Lippard et al., 2018). It often goes along with the engineering design process as a unique indicator to the engineering profession and it "underlines design processes and includes systems thinking, innovative problem finding and solving, visualizing, and collaborating and communicating" (English, 2018, p. 274). Therefore, when the standard did not have a heavy emphasis on the engineering design process (i.e., POD-TE was rarely included as mentioned above), they came short on the attention on EThink as well. Given the learners' and teachers' limited knowledge of what engineers do and how they do it (Chou & Chen, 2017), more emphasis on EThink would be a solution for narrowing the knowledge gap. Hence, in the future modifications, Ethink should be more integrated into all countries' science documents.

Regarding the CEE indicator, none of the documents mentioned CEE at K-2 level. In 3–5 grade band, only in the U.S. and South African documents integrated SEM. A possible reason for the limited integration of CEE into the lower grade bands (e.g., K-2 and 3–5 grade bands) may be related to a belief that engineering and some of its concepts (e.g., the nature of problem solving in the engineering profession and how the clients' desires and other design limitations shape engineers' work) should be taught in higher grades (King & English, 2016) Therefore, for a complete and accurate description of engineering and the work of engineers, CEE emphasis should be realized especially in lower grades' standards in future modifications made in Australian, English, Turkish, and Hong Kong's science standard documents.

Ethics indicator was also one of the least mentioned by all the documents. As Antink-Meyer and Brown (2019) stated "the importance of ethics is thus alluded to in the standards, but never elaborated on" (p. 549). Similar situations were also revealed for other indicators as well (e.g., Teamwork and Comm-Engr) in our study. The limited emphasis on ethics and other indicators may stem from a lack of a framework determining and describing the essential aspects of engineering that should be integrated into the standards (Johnston et al., 2019; Moore et al., 2015). In light of the results, the modifications regarding the engineering indicators integration into the science standard documents are necessary to provide a complete and clear understanding of engineering (Moore et al., 2014). As an implication, in the future modifications in the science standard documents, the indicators emphasized rarely (e.g., Ethink, SEM, and Ethics) should be incorporated frequently by curriculum developers. Moreover, the emphasis on those indicators should be done consistently through K-12.

Regarding the second research question (i.e., focuses on the comprehensiveness of the documents), as stated earlier, none of the seven countries' documents that were comprehensive according to the detailed comprehensiveness list formed by Moore et al. (2015) was used. As the frequency and distribution of the key indicators across grade bands were discussed in the aforementioned paragraphs, only the results about the first criteria (e.g., explicit emphasis of engineering in the standard documents) were discussed to avoid redundancy. The first criterion for comprehensiveness was the explicit emphasis of engineering. Among the countries focused on, only the U.S. put explicit emphasis on engineering through K-12 documents. A possible reason for this mismatch (i.e., the recent call for explicit emphasis for engineering integration but the implicit and limited integration observed in the science documents), may be due to the existing differences in the views of the curriculum developers related to integration of STEM disciplines. For instance, Timms et al. (2018) argued that "[t]he Australian Curriculum is not based on a modern conceptualization of STEM. It is structured around discrete learning areas and does not integrate explicit STEM learning progressions across the school years" (p. 19). More or less, other countries may have similar problems, which may result in less explicit integration of engineering and its indicators in science standard documents. Given the teachers' limited knowledge about engineering and difficulties in integrating engineering into science teaching (Bagiati & Evangelou, 2018; Shernoff et al., 2017), science standard documents — which play a north star role for teachers for engineering integration — should provide explicit emphasis on engineering indicators to make teachers alert to the integration.

All the problems related to the explicitness, evenness, and comprehensiveness of the engineering standards presented in the results of this study could be also explained with the lack of a solid framework that enlightens which indicators of engineering should be integrated, how they should be integrated, and where they should be integrated. As NRC (2009) stated,

> [t]he absence of standards or an agreed upon framework for organizing and sequencing the essential knowledge and skills to be developed through engineering education at the elementary and secondary school levels limits our ability to develop a comprehensive definition of K-12 engineering education (p. 151).

The QEE framework used in this study could provide solutions to lack of framework problem. With the development of different frameworks and/or the use of the QEE framework in different analysis, necessary modifications made would enrich the science standard documents. By this way, learners would have a chance to have a better learning of engineering profession and the work of engineers and its impact upon lives. With this in mind, in order not to fall into the situation reported in the NOS literature (i.e., little changes in the integration of NOS aspects into science standard documents over the 30 years as revealed by Summers et al., 2019), which indicates "a gap between advances in research on NOS and incorporation of research in curriculum policy" (Park et al., 2020, p. 900), the research and curriculum development should feed each other in engineering education. Therefore, curriculum developers should take this and other similar studies' results into account in the modification process.

One of the important points regarding the results and conclusions of this study is that they were received by the use of the QEE framework. Hence, the conclusions drawn for the documents concerning the integration of engineering indicators may be different from other studies that would use different criteria and the frameworks for the analysis. Likewise, the results and conclusions made in this study may be diverse from the studies that would analyze other disciplines' standard document (e.g., mathematics). As stated, one of the limitations of this study was its focus only on science standard documents of selected countries. In the future studies as Carr et al. (2012) did, other STEM discipline documents (e.g., mathematics and technology) should be analyzed in order to obtain a broad picture of how and to what extent engineering was integrated into the documents of all STEM disciplines for the K-12 grades.

To conclude, integrating engineering and its indicators into science standard documents has an important role in introducing what engineering is and what engineers do to precollege students. Johnston et al. (2019) showed that teachers tend to focus on engineering indicators that are highly stressed in the standard documents. In that study, the teacher could not integrate Ethics and ISI aspects sufficiently, which was explained by the lack of emphasis on those aspects in the standard documents. In the light of findings of our study and the Johnston et al. (2019), it is reasonable to conclude that teachers in those seven countries would pay less or no attention to ignored aspects of engineering. Given the importance of standard documents as a potential source of professional development for teachers (Desimone, 2009), activities focusing on less emphasized indicators and short examples of engineering pedagogies (e.g., engineering talk and reverse engineering) should be provided in appendix or guidance parts of the documents to support teachers who face difficulties in integrating engineering into science courses. With regard to engineering integration, explicit emphasis on engineering indicators in standards as cognitive outcomes is different from mentioning engineering in the supplementary part of the materials of science documents. Most of the teachers do not pay attention to appendices or guideline sections in lesson planning. However, the most important part for them is the standards (McComas & Nouri, 2016), which provides yet the final implication of the results, namely standards should include explicit engineering indicators as learning outcomes through K-12.

Appendix. Details about the education systems and science standard documents of different countries

Australia

In the Foundation-Year 10 (F-10) document, it was stated that "Science has three interrelated strands: science understanding, science as a human endeavor and science inquiry skills" which provides "understanding, knowledge and skills through which they can develop a scientific view of the world" (ACARA, 2016a, p. 7). The document states that "the order and detail in which the content descriptions are organized into teaching and learning programs are decisions to be made by the teacher." (ACARA, 2016a, p. 11). For each grade level (i.e., in the document "year" is used to represent grade level), content description is provided for three strands of science. Additionally, each strand is elaborated further for the guidance of teachers.

The Australian senior secondary science standard document (ACARA, 2016b) starts with an overview of the document. In the *How the Subject Works* part, for each science field (e.g., Biology and Earth Sciences), the aim/rationale and the structure of the discipline is specified. After learning objectives, a content description of the core science content that is supposed to be focused upon in class is provided.

In the documents, teamwork, issues, solutions, and impacts on society (e.g., sustainable transportation), plan and evaluate design, application of scientific knowledge in engineering, ethical considerations, contemporary problems, and solutions to them have been explicitly mentioned (ACARA, 2016a).

England

Science standard documents of England include chemistry, biology, and physics subject disciplines for key stages 1 and 2 and key stages 3 and 4 (DfE, 2013a, 2013b, 2014). For each key stage level, at the beginning of the documents, “Working scientifically” was described separately in order to clarify how scientific ideas should be developed. Then, the statutory requirements and notes and guidance (non-statutory) have been provided in each unit. Documents do not explicitly mention engineering concepts through standards. On the other hand, there is an emphasis on STEM in the notes and guidance section.

In the documents, engineering was not explicitly mentioned; however, activities related to the engineering design process were suggested to teachers. In those non-statutory parts of the documents, daily-life problems, engineering way of thinking (i.e., troubleshooting), designing, constraints in design process, and the use of scientific knowledge in design process are the aspects of engineering that have implicitly been mentioned (DfE, 2013a).

Estonia

The Estonian MER released national science standard documents for basic and general upper secondary schools (Estonian MER, 2014a, b). These two documents include general information and appendices. In the general information section, these documents provide information about the core values, learning and educational objectives of the basic/general upper secondary school education, the concept of learning and the learning environment, organization of studies, school curriculum, and assessment of students’ knowledge and skills. An appendix is provided for each subject field and for cross-curricular topics. The Natural Sciences appendix is one that provides syllabuses for each science course.

The Natural Sciences curriculum at basic education level includes science (i.e., forming the basis for natural science subjects), biology, physics, geography, and chemistry courses. At the upper secondary level, the Natural Sciences curriculum is composed of compulsory (e.g. Biology and Physics) and optional (e.g. Applied Biology, and Principals of Chemical Processes) courses. Also, six interdisciplinary optional courses are offered in the curriculum; however, they were not included in this study. The Estonian documents are implicit regarding engineering aspects. However, the document highlighted problems related to engineering, science and engineering relation, ethical aspects of genetic issues, and their impact on the society (Estonian MER, 2014c).

Hong Kong

The education system of Hong Kong includes four stages: early childhood education, primary, lower secondary, and senior secondary school. In primary school, science is covered in General Studies documents (CDC, 2017) under the name of Science and Technology in Everyday Life. At the lower secondary level, science is covered in the strands Life and Living, The Material World, Energy and Change, and The Earth and Beyond. At senior secondary level, there are three science courses: physics, chemistry, and biology. Science documents have three main parts: students should learn, students should be able to, and suggested teaching and learning activities.

The Hong Kong documents implicitly mentioned the engineering and design process. The emphasis was put on the parts relating to "Science, Technology, Society and Environment (STSE)." The engineering aspects mentioned were problems and solutions to them by using scientific principles, constraints in design, impact of design solutions on environment, and ethical issues in genetics and its applications (CDC, 2015).

South Africa

In South Africa, the National Curriculum Statement is published under the name of Curriculum and Assessment Policy Statement (CAPS) for every grade and for every subject as a single document to improve consistent implementation. Science courses are mentioned with different names among the grades: Natural Science and Technology at the Intermediate Phase Natural Sciences at the Senior Phase and Life Sciences and Physical Sciences at the FET (Further Education and Training) Phase.

In the CAPS documents (e.g., CAPS for Grades 4–6 and Grades 7–9), general aims are stated to "identify and solve problems and make decisions using critical and creative thinking" and "use science and technology effectively and critically showing responsibility toward the environment and the health of others" (Republic of South Africa DBE, 2011b, p. 5). The engineering aspects mentioned "identifying a need, planning and designing, making (constructing), evaluating and improving products, communicating" and ethical issues (Republic of South Africa DBE, 2011a, p. 9).

Turkey

In Turkey, for all courses and for all grade levels, a national curriculum is prepared by the National Ministry of Education. Teachers all around the country have to use the curriculum as released. The standard documents basically have two main parts, namely, the introduction part and standards part. In the former part, the goals of the Turkish Education system, the assessment and evaluation system to be implemented, the skills to be developed, and the structure of the curriculum are provided. In the later part, standards are provided for grade levels each of which has five to seven units. In 2018, engineering aspects were integrated into middle school science standard documents (NME, 2018). It was stated that one of the main purposes of science education was to train learners who had fundamental knowledge about science and engineering. Moreover, in addition to science skills, the document highlighted the development of "Engineering and design Skills." Finally, the document mentions aspects of engineering (e.g., daily-life problems and solution to them, design process, constraints, the relation between science and engineering, engineering solutions, and their impact on society.)

The U.S.

The NGSS was released in 2013 based on the Framework for K-12 Science Education (NRC, 2012) "to provide all students an internationally benchmarked science education" (NGSS, 2013, p. xiii). In the document, science standards have been introduced based on the performance, foundation, and coherence. Performance expectations are statements that define what students should know and be able to achieve related to the unit. The foundation section consists of three dimensions, which are science/engineering practice, a core disciplinary idea, and a crosscutting concept that presents the complete picture of what students ought to achieve when combined with each performance expectation. In the final section, performance expectations are connected to other disciplines in a coherent way.

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Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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