International comparison of K-12 STEM teaching practices

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Abstract

Purpose – This study analyzed articles from India, Italy and Singapore regarding how science, technology, engineering and mathematics (STEM) education is conceptualized in the K-12 setting. The research questions that guided our study were as follows: (1) How is K-12 STEM education conceptualized in literature in other countries? (2) Which STEM subject areas are more documented in K-12 STEM literature? (3) How are K-12 STEM teaching practices implemented?

Design/methodology/approach – This study utilized a systematic literature review methodology by (1) creating search terms based on the research questions, (2) choosing databases in which to conduct the search, (3) conducting the search and gathering articles and (4) selecting articles based on inclusion criteria. We chose search terms according to three domains relevant to our study as follows: countries of interest, content of interest and teaching practices. Articles researched were (1) an empirical journal article or literature review; (2) primarily focused on the concept of K-12 STEM teaching practices in one of the countries of interest and (3) written in English.

Findings – Findings from the study revealed few articles addressed a conceptualization of STEM; however, the majority of articles agreed upon the importance of STEM teaching methods in the K-12 classroom setting. Science was documented as the top documented area in K-12 STEM literature for India and Italy, whereas technology and mathematics were the top documented areas in Singapore. Comparing K-12 STEM teaching practices, Italy and Singapore were found to focus more on student-centered STEM teaching practices whereas schools in India mostly utilized student-centered teaching approaches.

Research limitations/implications – The parameters of the systematic literature review, such as key terms used in the search and limited scope of countries investigated, were identified as limitations of the study. By expanding search parameters to include other countries or search terms, STEM education can be viewed on a more global scale.

Practical implications – This study will improve the global perspective of STEM education practices.

Originality/value – This study is unique in that it compared the conceptualization and K-12 STEM teaching practices implemented in India, Italy and Singapore.

Keywords STEM education teaching practices, K-12 STEM education, Science, Technology, Engineering, Mathematics

Paper type Research paper

Introduction

Over the last two decades, scholars have increasingly noted the importance of STEM (science, technology, engineering, mathematics) education in school classrooms (e.g. Thomas and Watters, 2015). With the technological boom and increasing threats to the global environment, it is crucial to provide students with learning opportunities that help them

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thrive in a changing society. Worldwide, nations are responding to pressure to generate globally competitive students. Countries such as Singapore have implemented technology and engineering initiatives such as robotics as early as early childhood stages (Sullivan and Bers, 2018). In the hopes of creating globally aware citizens, fragmented and varied definitions of STEM create barriers to international understanding and collaborative efforts. Though scholars mostly acknowledge the importance of STEM education, there is little consensus regarding how STEM education is conceptualized and implemented in school classrooms. For instance, Carmichael's (2017) study investigated how policy models in all 50 states in the United States defined STEM education. Carmichael (2017) observed the following STEM definitions: (1) disciplinary STEM (10%), which is content specific, (2) integrated STEM (42%), which integrated more than one discipline area, (3) a combination of disciplinary and integrated STEM (30%) and (d) no definition of STEM education (18%). To advance research and practice, the field needs to operationalize STEM education and clearly define the goals of STEM practices.

In this study, we aim to advance research by providing a synthesis of STEM education literature in India, Italy and Singapore. This study is unique in that it compares the conceptualization and K-12 STEM teaching practices implemented in India, Italy and Singapore. This research stands to bolster global K-12 STEM research. Our purpose in choosing these particular three countries is twofold. First, pragmatically, as scholars from the United States, we wish to learn how other countries conceptualize and implement STEM education so as to inform our own research and practice. Second, the three chosen countries prioritize STEM education (e.g. Filippi and Agarwal, 2017; Sullivan and Bers, 2018; Thomas and Watters, 2015), and they represent a diverse range of geographic regions. The research questions guiding our study are as follows: (1) How is K-12 STEM education conceptualized in literature in other countries? (2) Which STEM subject areas are more documented in K-12 STEM literature? and (3) How are K-12 STEM teaching practices implemented?

Literature review

Science, mathematics, engineering and technology (SMET) was introduced in 1993 by the United States' National Science Foundation (NSF) to improve American education (Sharma and Yarlagadda, 2018). In 2001, the NSF director, Judith Ramaley, rearranged the letters to STEM for aesthetic purposes but also to demonstrate an interdisciplinary emphasis. She explained the new letter order implies science and mathematics provide a meaningful connection of support to engineering and technology (Sharma and Yarlagadda, 2018). The acronym STEM was originally used in a political context to call attention to the demands of the future workforce in science, technology, engineering and mathematics-related professions (De Vries, 2018). De Vries (2018) posits:

> At that time [prior to 2019] STEM meant a set of independent disciplines, each of which was abbreviated by one character. Later, educators saw this as a challenge to seek ways of developing integrated STEM education, in which elements from the four individual disciplines could be used in combination (p. 22).

Though international scholars agree on the importance of STEM education (Sokolowska *et al.*, 2014; Sullivan and Bers, 2018), there is currently little consensus regarding how STEM practices should be incorporated in curriculum. Several international organizations recommend teaching and learning practices in each of the content domains (science, technology, engineering and mathematics), but current recommendations fail to consider STEM as an integrated concept. For instance, the International Society for Technology in Education (ISTE) provides international recommendations for technology-related education, while the International Technology and Engineering Educators Association (ITEEA) recommends teaching and learning practices for technology and engineering. These international organizations do important work in creating global content standards, but organizations currently do not treat STEM as an interdisciplinary concept as was envisioned by the early pioneers of STEM education. Furthermore, international organizations often adhere to western philosophies of education, bringing into question whether such organizations represent a global perspective.

With little consensus regarding STEM education from an international perspective, it is vital to compare how countries from a variety of geographic regions conceptualize and implement STEM education. STEM education implementation has changed over the course of several decades. Singapore, for example, originally focused on early childhood education in numeracy and natural sciences but progressed into an emphasis on technology and engineering (Sullivan and Bers, 2018). Italy also highlighted technology stating, "An information society in the foreseeable future will require both specialists [science and mathematics] in narrow fields, as well as educated and informed citizens" (Sokolowska *et al.*, 2014, p. 41). Australia agreed in a technologically advancing global society, believing education is the "driving tool for economic well-being, which directly impacts the economic growth of nations" (Sharma and Yarlagadda, 2018, p. 2000). Comparative studies might provide scholars and practitioners with opportunities to envision a set of international STEM standards similar to those constructed in content-specific domains. It is within this landscape that we analyze the different teaching and learning practices of three countries from different geographic regions so as to create a better understanding of STEM from a global perspective.

Methodology

We utilized a systematic review methodology (Cooper, 2017) to search for and analyze articles relevant to the research questions. A systematic review methodology consists of four parts as follows: (1) creating search terms based on the research questions, (2) choosing databases in which to conduct the search, (3) conducting the search and gathering articles and (4) selecting articles based on inclusion criteria. We chose search terms according to three domains relevant

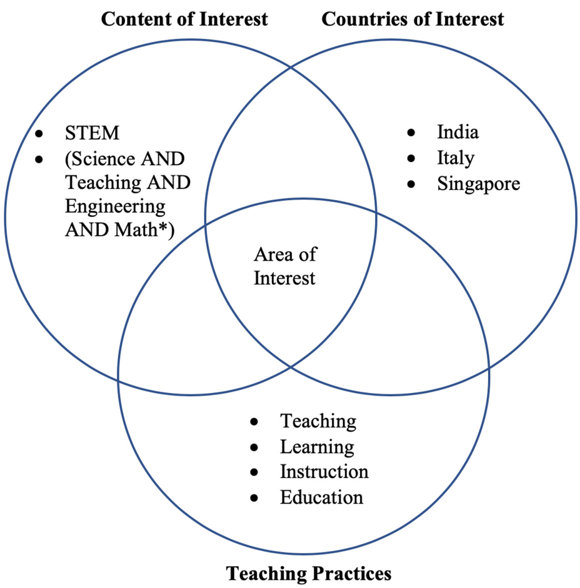

Figure 1.
Search terms

to our study: countries of interest, content of interest and teaching practices. The specific search terms utilized within each domain are presented in Figure 1. After consulting with an education research librarian, we ran a search in September 2019 utilizing the following databases: Eric EBSCOHost, PsycInfo and Education Full Text (H.W. Wilson). The search included each country of interest (e.g. India AND [STEM OR (Science AND Technology AND Engineering AND Math*)] AND (teaching OR learning OR instruction OR education) limiting for peer-reviewed articles written after the year 2000. We chose to limit our search to articles written after 2000 to ensure the literature was relatively recent and still relevant to today's classrooms. The search yielded 96 articles for India, 123 for Italy and 52 for Singapore.

We next transferred all articles included in the search to RefWorks to gather pertinent information such as the title and abstract. From Refworks, the articles were transferred to an Excel spreadsheet for screening purposes. We utilized the following criteria to screen articles for inclusion: The study was (1) an empirical journal article or literature review; (2) primarily focused on the concept of K-12 STEM teaching practices in one of the countries of interest and (3) written in English. We took the remaining articles through three phases of screening. First, we screened the title of each article according to inclusion criteria, eliminating 191 articles. Subsequently, we conducted an abstract screen which eliminated an additional 45 articles. Finally, we scanned the full text of each article, eliminating an additional 7 articles. The screening process left a total of 28 articles for analysis. (6 – India, 5 – Italy, 17 –Singapore). All included articles are designated by an asterisk in the references. A PRISMA diagram (Moher *et al.*, 2009) of our search and screening process is shown in Figure 2.

Following the screening process, we read each of the 28 included articles and coded them according to a literature review matrix based on the research questions. The matrix and an exemplification from the data are included in Table 1. The articles within each country were compared against each other (Glaser and Strauss, 1967) to develop themes relevant to each research question. The following findings section includes a subcategory for each country of interest, and each subcategory is organized to answer the three research questions.

Findings

India

How is K-12 STEM education conceptualized in literature in India?. An analysis of the articles revealed STEM education is mostly conceptualized as a fragmented concept, accounting for sub-domains (e.g. science and technology) but failing to treat the concept as an integration of the four content domains together. Only one study (Sharma and Yarlagadda, 2018) provided an operational definition of STEM education, and most other studies alluded to the importance of STEM education without first foregrounding their conceptualization. Sharma and Yarlagadda (2018) stated, "STEM integrates all four discrete disciplines to develop the skills required to design processes through creativity, development of technologies, and discovery of need-based practical solutions" (p. 2000). In contrast to this definition, most other studies revealed conceptualizations of STEM as an integration between two specific domains. For instance, Filippi and Agarwal (2017) studied the roadblocks to incorporating an enquiry STEM-based project in India, Italy and Canada. Though they referred to the enquiry project as a STEM-based project throughout the analysis, the project was only discussed as a technological support for learning science. Therefore, STEM was treated as a fragmented concept, comprising two parts of the acronym and leaving out other components.

While only one article explicitly defined STEM education, all articles acknowledged the importance of STEM-related competencies for economic growth and solving global problems. For instance, Thomas and Watters (2015) asserted, "STEM education is an essential element of the global response to climate change or any of the other technological issues facing contemporary society" (p. 2). With scholars agreeing on the importance of STEM education in

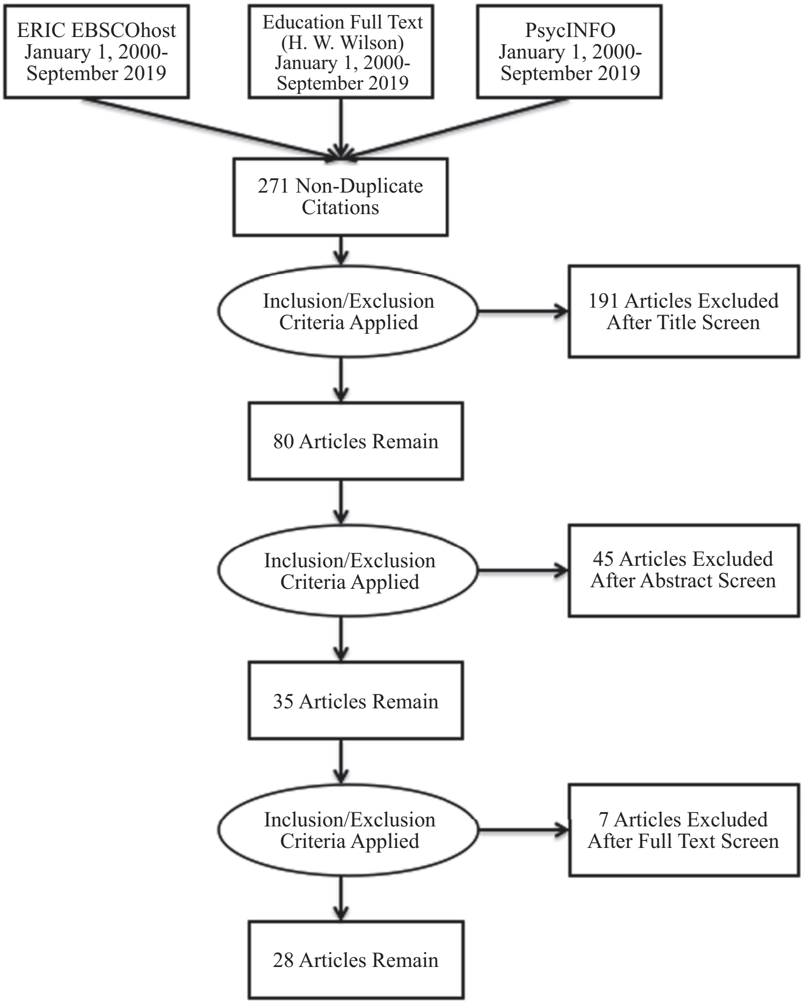

Figure 2.
PRISMA diagram

India, it is imperative that they operationally conceptualize the concept in their work to increase conceptual coherence toward advancing theory.

Which subject areas are more documented in K-12 STEM literature in India?. Science was the most popular content domain in literature, with all six of the articles (100%) analyzing science in some capacity. Technology was also prominently represented (83%), with engineering (67%) and mathematics (50%) being less prevalent in the literature. Even in articles that discussed the importance of mathematics and engineering in STEM education, science and technology overshadowed mathematics and engineering in the empirical analyses. This further supports the finding that STEM education is treated as a fragmented concept in India.

How are K-12 STEM teaching practices implemented in India?. The articles suggested K-12 schools in India mostly utilize traditional teacher-centered approaches, focusing on procedures and drill practice (Filippi and Agarwal, 2017; Sharma and Yarlagadda, 2018; Thomas and Watters, 2015). Scholars noted these pedagogical conceptions, along with other

Citation	Country of study	How is STEM education conceptualized?	How are STEM teaching practices implemented?	Which of domains of STEM were considered in the analysis? (Science, technology, engineering or mathematics)
Filippi and Agarwal (2017), Teachers from instructors to designers of enquiry-based science, technology, engineering and mathematics education: how effective enquiry-based science education implementation can result in innovative teachers and students. Science education international, 28(4), 258	India	Inquiry-based science education to encourage students to be interested in STEM fields. The author calls this the Ark of Inquiry project which originated in Europe	Teachers noted a struggle with the use of technology in their classrooms. Many of them did not have the skills or knowledge to navigate the enquiry-based teaching approach. Also, there was a barrier in relation to students' access to technology. Teachers' understanding of the technology was also a major hurdle. The author notes major challenges specific to countries such as India in low usage of computers, traditionally-oriented teachers, lack of resources, different cultures and languages, sustainability and community creating. In India, most schools do not have access to computers. Traditional teaching approaches prevail in India causing teachers to be hesitant to use new approaches. The culture of education is based on rote learning causing enquiry-based models to be difficult to prevail. Language is also a major hurdle when using online-based resources as they would need to be translated in several different languages	Science, Technology, Engineering, and Mathematics

Table 1.
Literature review matrix

factors such as lack of resources and quality teachers as major barriers to effective STEM teaching practices (Filippi and Agarwal, 2017; Sharma and Yarlagadda, 2018). For instance, Filippi and Agarwal (2017) noted STEM teaching practices are difficult to incorporate in India because many schools lack technological resources such as computers, and teachers are often unequipped to utilize technological resources even if the schools have them. Sharma and Yarlagadda (2018) further suggested there is a shortage of qualified teachers in STEM fields in India. Other problematic concerns of STEM teaching practices in India include gendered assumptions about who is capable of learning STEM concepts. For instance, Cheruvalath (2018) asserted females are often believed to be less competent in subjects such as science and mathematics. This suggests ideals of fairness and equity currently influence STEM teaching practices in India.

Two articles explained specific STEM teaching approaches (Gupta and Fisher, 2012; Kumar and Sharma, 2017).The study of Gupta and Fisher (2012) validated an instrument for measuring technology-rich learning environments. They found technology-supported classrooms positively influence student attitudes and efficacy toward science. Gupta and Fisher conceptualized technology-rich classrooms as those which contained graphics, video, sound and animations to support learning. The authors focused on how technology engaged students rather than how it can be used to support conceptual understanding. Kumar and Sharma (2017) discussed the benefits of utilizing cloud computing software for doing virtual labs in chemistry or biology. These virtual experiments allow students to engage in dissections and other lab-related activities at a lower cost than acquiring the tools required for physical labs.

Together, the articles revealed there are many barriers to effective STEM teaching practices in India. Some of these barriers are physical (e.g. lack of resources), while others are psychological/social (e.g. gendered STEM beliefs). To support STEM education, stakeholders might seek to address these barriers by advocating for the importance of STEM-related competencies and maintaining equitable beliefs about teaching and learning.

Italy

How is K-12 STEM education conceptualized in literature in Italy?. As with India, article analysis divulged STEM education is not conceptualized by all of the same four sub-domains (e.g. science, technology, engineering and mathematics) in Italy. Instead, the literature described or defined STEM using three of the four sub-domains – mathematics, science and technology (MST) (Sokolowska *et al.*, 2014). No studies provided an operational definition of STEM education, but most alluded to one or more components of STEM individually without first frontloading their conceptualization. Filippi and Agarwal (2017) argued that STEM classes, which focus on enquiry-based learning are more engaging and encourage students to become more fascinated with STEM fields but provide no definition of what constitutes as STEM classes.

While no article provided an operational definition of STEM education, four of the articles acknowledged the decline in interest in STEM-related fields and discussed female gender bias in STEM-related fields. Filippi and Agarwal (2017) stated "girls can be blocked from learning and participating in STEM classrooms due to stereotypes about their abilities based on gender" (p. 260). Moè (2016) justified the underrepresentation of women in STEM careers could be explained by their low mental rotation ability. Failure to conceptualize and provide an operational definition of STEM education in Italy has inhibited the advancement of research theory and contributed to the decline in interest.

Which subject areas are more documented in K-12 STEM literature in Italy?. Science was the most prominent domain discussed in the literature with all five articles (100%) featuring science in some way. Four of the articles (80%) discussed technology as a component of STEM, and one article (20%) discussed mathematics as a component of STEM. Lacking in the literature was the discussion of engineering as a domain of STEM. There was no mention (0%) of engineering or engineering practices in articles from Italy. In articles that discussed both science and technology as components of STEM, technology was mostly overshadowed by science. This reinforces the finding that STEM education is treated as a splintered concept in Italy.

How are K-12 STEM teaching practices implemented in Italy?. The articles suggested that K-12 schools in Italy focus on enquiry-based or active learning approaches to teaching STEM. Cinganotto *et al.* (2016) highlighted that through the use of active technology learning approaches to teaching, students improved their learning experience and outcomes, were more engaged and took more responsibility over their learning. Filippi and Agarwal (2017) highlighted the need to promote STEM education and pointed out that enquiry-based science education (IBSE) classes are "engaging and encourage students to become more fascinated with STEM fields" (p. 258).

Sokolowska *et al.* (2014) explored Italy's MST curricula that are applied as three distinct aspects of the curriculum – intended, implemented and attained. This implies learning that occurs for students following STEM teaching practices is not necessarily what was planned for or attempted but what students were motivated to learn. Silm, Tiitsaar *et al.* (2017) viewed IBSE as a solution to address the issue of students' low motivation for learning STEM subjects. In an effort to motivate learners, Chiarello and Castellano (2016) chose a few basic scientific concepts and designed board games around them. After having students engage in playing the games, Chiarello and Castellano (2016) reported growth in both interest and comprehension of scientific concepts. As a second phase of the study, students utilized IBSE through which to investigate complex science concepts and create their own board games.

The literature highlighted a variety of approaches to teaching STEM education in Italy. The literature also implied student motivation for learning STEM content as a barrier. To support STEM education, stakeholders must continue to utilize a variety of instructional methods and maintain equitable teaching practices.

Singapore

How is K-12 STEM education conceptualized in literature in Singapore?. Singapore's articles revealed the presence of STEM schools and curriculum in Singapore. However, as was the case with India and Italy, Singapore's literature did not possess a uniform operational definition of the term STEM. Due to this lack of unified definition and clarification of STEM, Singapore scholars interpreted STEM applications in a variety of ways. For example, STEM was purported to be in use via the implementation of formative assessments that move more toward the integration of ICT in Tay *et al.* (2017a, b, c) study. More than one study treated play as a form of STEM activity. The study of Sullivan and Bers (2018) utilized the Playmaker Programme, which addressed their defined need of implementing technology and engineering at a young age, and Teo *et al.'s* (2017) study emphasized purposeful play. Some articles did not define STEM at all; however, they still implemented teaching practices clearly within the boundaries of STEM such as the implementation of information and communication technologies (ICT) within the mathematics classroom (Tay *et al.*, 2015, 2017a, b, c; Kiru, 2018), hands-on real world science based experiences (Tan *et al.*, 2017; Wang *et al.*, 2019) and reflective science journaling (Towndrow *et al.*, 2008) in the science classroom. Overall, education was viewed as a necessary component for economic growth and student advancement in the classroom and global economy (Tan and Leong, 2014;Tan *et al.*, 2017).

Which subject areas are more documented in K-12 STEM literature in Singapore?. Technology and mathematics were each the most mentioned STEM content area in Singapore with 13 (76%) articles, especially with an emphasis on computers and one-to-one student to device method of instruction. Kiru's (2018) study utilized a sample size of 6,570 mathematics teachers from Australia, Finland, Latvia, Mexico, Portugal, Romania, Singapore and Spain to determine the amount of ICT used within the mathematics curriculum. Based on the analytic sample, Singaporean teachers scored below average in ICT usage in the mathematics curriculum, with Portugal showing the highest ICT usage. The author also observed in general that mathematics teachers' self-efficacy and professional development were strong predictors in the amount of ICT usage implemented in the curriculum. Similar to the study based on India and Italy by Filippi and Agarwal's 2017, Tay *et al.*'s (2017a, b, c) Singapore-based study also emphasized the need for ICT in the K-12 STEM teaching setting.

Another example of technology use tied into reasoning skills was identified in Ayieko *et al.'s* (2017) study. This study reviewed data from a representative sample of 4th and 8th grade teachers and students in Chinese Taipei, Finland and Singapore. Data were analyzed from the 2011 Trends in International Mathematics and Science Study (TIMSS) database regarding computer usage at home and in the classroom. Findings of this study showed, "the frequency of students' computer use at designated places, and their teachers' use of computers in instructional activities in mathematics predict students' mathematics reasoning" (Ayieko *et al.*, 2017, p. 83). Interestingly, a positive link between student computer usage and reasoning skills were identified in Finland, with the opposite result in Singapore. Finland reported student use of computer technology for higher-order thinking skills, such as data analysis or processing; whereas Singapore produced lower reasoning skills scores when using computer technology to analyze data. Ayieko *et al.* (2017) contended this difference in data may be due to the way teachers and students use computer technology on a regular basis, such as teaching with computer technology to assist students understand mathematical concepts versus gaming, social media, etc.

Science was also a leading STEM area represented in the literature from 11 sources (65%); however, engineering's 3 (18%) references were much less prevalent in the literature compared with science, technology and mathematics. A shared emphasis on mathematics and technology education was noted, for example, Koh (2019) stated "well-synthesized considerations of technology, pedagogy and content is recognized as necessary for mathematical reforms" (p. 1196). A possible explanation as to the low representation of engineering in literature may be due to the lack of a definitive identification of the parameters of engineering. For example, although Sullivan and Bers (2018) stated "Singapore has been working to update their early childhood curricula in order to keep up with this international trend and address the growing need for engineering programs in early childhood school" (p. 326), they go onto define engineering programs as new technologies where students are the creators of their digital experience. This definition of engineering implies that technology and engineering are one in the same topic area, which leads to confusion and difficulty in relating research and curriculum.

How are K-12 STEM teaching practices implemented in Singapore?. K-12 STEM teaching practices were implemented in diverse ways in Singapore. For example, Ayieko *et al.*'s (2017) study defined STEM teaching practices as "the transition of use of technology from basic usage, such as computers, smart boards, smart pens, and calculators, to more interactive usage of technology" (p. 67). Ayieko *et al.* (2017) further described a positive relationship between computers as a basis for mathematics instruction, which they defined as good for students' mathematics reasoning. Model-eliciting activities (MEA), KIBO robotics curriculum (Sullivan and Bers, 2018), hands-on real-world experiences (Tan *et al.*, 2017), reflective science journals (Towndrow *et al.*, 2008), ICT (Tay *et al.*, 2015, 2017a, b, c; Kiru, 2018) and mathematics modeling (Eric *et al.*, 2016) are all examples of how STEM teaching practices are implemented in Singapore. Using 21st century skills such as analysis and argumentation were also discussed in Singapore's delineation of K-12 STEM teaching practices (Leong *et al.*, 2013). Tan and Leong (2014) defined teaching practices as methods that help students become "future looking leaders through innovative technology and applied learning" (pp. 11–12). Tan and Leong (2014) also described a scientifically literate citizen as someone with good literacy skills, sound decision-making skills, good knowledge of how the world works and good physical and mental strength. However, Harris and de Bruin (2018) found that "Teachers in Singapore asserted that curricular, cultural and testing constraints (including international moderation processes) were identified as policies that impacted on the development and support of creative practices and environments" (p. 167).

Several studies also recognized the importance of the crossover of STEM fields for deeper STEM understandings. For instance, although Looi and Lim (2009) focused on the implementation of AlgeBAR software (technology) to assist students with solving algebraic word problems, they also recognized the importance of technology being used as a pedagogical bridge between mathematics models to deeper student understanding of algebraic methods. Leong *et al.* (2013) also recognized that although their study centered around a lesson study team tasked with analyzing mathematical problem-solving skills and attitudes possessed by lower secondary normal academic students in Singapore, the implementation of a practical worksheet was needed to assist students with reflection upon their thinking processes. Leong *et al.* (2013) defined the "practical" portion of the worksheet as the scientific basis needed in the study to bridge the gap between mathematics and science understandings.

Discussion

This systematic literature review resulted in 28 articles for final examination (see Table 2). Despite the methodical nature of the search and limits, all articles did not address or demonstrate a unifying use of the term STEM. Discrepancies were also found when studying articles within the same country, such as some articles in Singapore discussed ICT, but not all. MST was also a common theme identified in Italy's K-12 STEM education literature, but not all articles discussed ICT. While the terminology between ICT and MST did not mirror the use of STEM, the intent, meaning and implementation of the curricula and programs addressed are the same broad field of study and research.

Overarching trends and patterns were identified when comparing an overview of study results (Table 3). The first research question investigated how STEM education was conceptualized in the K-12 classroom setting. Based on findings from this study, the majority of articles did not delineate how they defined the term STEM. Of the few articles that addressed a conceptualization of STEM, a unifying definition was not established. Although a common definition was not accepted or discussed by all research studies examined in this analysis, the majority of articles agreed upon the importance of STEM education and believed in the necessity of the implementation of STEM teaching methods in the K-12 classroom setting.

The second research question addressed which STEM areas were most documented in K-12 STEM literature. Interestingly, science was documented in 100% of the articles researched for India and Italy; however, technology and mathematics were the top documented STEM areas for Singapore. The emphasis on technology and mathematics and in the Singaporean education system may have influenced the amount of literature focused on these areas of study. Also interesting to note, technology was ranked in the top two most documented STEM areas of K-12 STEM literature for all three countries. Elevating one

Table 2. Breakdown of STEM representation in articles

Country	Total # of articles	Science	Technology	Engineering	Mathematics
India	6	6	5	4	3
Italy	5	5	4	0	1
Singapore	17	11	13	3	13

Country of interest	RQ 1: How is K-12 STEM education conceptualized in literature in other countries?	RQ 2: Which STEM subject areas are more documented in K-12 STEM literature?	RQ 3: How are K-12 STEM teaching practices implemented?
India	(1) STEM education is mostly conceptualized as a fragmented concept, limited to science and technology (2) Only one article explicitly defined STEM education; all articles acknowledged the importance of STEM-related competencies	(1) Science was the most popular content domain in the literature, with all six of the articles (100%) analyzing science in some capacity Science: 100% Technology: 83% Engineering: 67% Math: 50%	(1) Schools in India mostly utilize traditional teacher-centered approaches, focusing on procedures and drill practice (2) STEM teaching practices are difficult to incorporate in India because many schools lack training and technological resources such as computers
Italy	(1) Defined STEM using three of the four sub-domains – mathematics, science and technology (MST) (2) No studies provided an operational definition of STEM education	(1) Science was the most prominent domain discussed in the literature with all five articles (100%) Science: 100% Technology: 80% Math: 20% Engineering: 0%	(1) Focus on enquiry-based or active learning approaches (2) Student motivation for learning STEM content implied as a barrier
Singapore	(1) Formative assessments that move more toward the integration of ICT (2) Use of play • Playmaker Programme (Sullivan and Bers, 2018) • Purposeful play (3) No studies provided an operational definition of STEM education, but STEM teaching practices were still observed • Information and communication technologies (ICTs) • Hands-on real-world experiences Reflective journaling	(1) Technology and mathematics were the most mentioned STEM content areas in Singapore with 13 (76%) articles (2) Emphasis on computers and one-to-one student to device method of instruction Technology: 76% Math: 76% Science: 65% Engineering: 18%	(1) STEM schools are present in Singapore (2) STEM education focuses on student-centered instruction (3) Use of computers, robotics, hands-on real-world experiences, model eliciting activities, ICT etc.

Table 3.
Overview of results

dimension of STEM, such as technology, may be a response to equalize the efforts of education to generate well-rounded and prepared students. This finding revealed the importance India, Italy and Singapore placed on technology in their societies. Toward the bottom of the ranking scale, engineering was documented the least in K-12 STEM literature in Italy (0%) and Singapore (18%). The lack of mention of engineering or engineering practices in these two countries, especially Italy, reinforced the finding that STEM education is treated as a splintered concept in the education system.

The third research question addressed how K-12 STEM teaching practices were implemented in India, Italy and Singapore. While Italy and Singapore focused on enquiry-based student-centered STEM teaching practices, schools in India mostly utilized student-centered teaching approaches highlighting procedures and drill practice. This difference in teaching methods in India is thought to exist due to lack of technological resources such as computers and training to implement them into the curriculum. Although India's, Italy's and Singapore's conceptualization of STEM education, emphasis on STEM areas and implementation of STEM teaching practices differed, they all acknowledged the importance of addressing STEM education in the shaping of globally aware citizens.

Sokolowska *et al.* (2014) stated, "An information society in the foreseeable future will require both specialists in narrow fields, as well as educated and informed citizens" (p. 41). Filippi and Agarwal (2017) echoed this sentiment by describing innovation in STEM fields as, "imperative to the innovation potential of the world as society begins to face complex problems. These problems include the impacts of climate change, food insecurity, and explosive population growth" (p. 258). Lim (2008) also contended STEM is an integral part of global citizenship, "Regardless of our location, we face a common destiny (at least in the mid-term or long term); where the unfolding of an event in one part of the world affects lives in other parts. In such a new world order, education for global citizenship is essential in preparing our children and young people to be agents of change rather than just passive observers of world events; and at the same time, to live together in an increasingly diverse and complex society and to reflect on and interpret fast-changing information" (pp. 1073–1074). Further calls for investigating STEM (and STEAM) initiatives in education as a means to impact education were articulated by Harris and de Bruin (2018)," demonstrating secondary education teacher practices configured toward multidisciplinary practices also compels the need for further enquiry into the ways STEM and/or STEAM education initiatives based on collaboration, dialogue, environment can effectively impart knowledge and skills with critical and creativity education at its core" (p. 170).

Conclusion

Based on the systematic literature review of the international comparison of K-12 STEM teaching practices in India, Italy and Singapore, a homogeneous international set of comprehensive STEM standards did not exist. The current international state of STEM is difficult to discuss due to the lack of uniform definition, implementation and standards. When discussing the progression of research in STEM education, it is important to define the limitations of the current study and delineate recommendations for future studies. Limitations of this study were identified within the parameters of the systematic literature review. The systematic literature review was also not completely comprehensive as the search parameters were restricted to K-12 STEM classrooms within the three countries of interest, empirical journal articles or literature reviews and articles written in English. Further research is warranted beyond the three countries investigated in this study. For example, a systematic literature review of STEM education in other countries or the extension of search terms may provide deeper understanding of the global state of STEM education. By expanding search parameters to include terms such as MST and ICT and including more geographic regions, the field may move closer toward constructing international standards which treat STEM as an interdisciplinary concept.

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