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Mathematics Teachers' Practices of STEM Education: A Systematic Literature Review

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Abstract: Science, technology, engineering and mathematics (STEM) education is regarded as one of the formulas to embracing many of our imminent challenges. STEM education benefits the learners by encouraging interest in STEM disciplines. This daunting task needs everyone's concerted efforts in creating and innovating mathematics teachers' classroom practices Therefore, a systematic review was conducted to identify best practices for STEM education following the guidelines of the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) by Moher et al. (2015). The reviewed articles were published from 2016 to 2020 and accessed using the Scopus and Web of Science (WoS) databases. Three themes for best practices were identified namely (a) core competencies encompassing 21st-century teaching skills; (b) instructional designs; and (c) requisite STEM execution. Results of PRISMA determined the dominant STEM practices were critical thinking, communication, collaboration, problem-solving, research-based pedagogy, problem-based learning and project-based learning, technological integration, accessibility, professional development and learning support, evidence of effectiveness, access to materials and practitioner support, and scalability. Mathematics teachers should determine the best STEM practices to employ even though there is a lack of studies on integrated STEM domains. When more students are interested in venturing and exploring into the field of STEM, the high demand for STEM related careers could be met by the younger generation.

Keywords: *Instructional approaches, mathematics, STEM education.*

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Introduction

Several international research studies have found that science, technology, engineering and mathematics (STEM) human resources' need is in line with expeditious advances in technology today (Evans et al., 2020; Zaza et al., 2020). Despite the immense need for a STEM workforce, it has been found that students' interest in STEM subjects is declining, and this is demanding attention in most countries across the world (Attard et al., 2020; Tubb et al., 2020; Zaza et al., 2020). STEM subjects are said to be difficult even to tertiary education although it is believed that STEM has had a specific effect on students' objectives learning (Kaleva et al., 2019; Kennedy & Odell, 2014; Pohjolainen, 2018; Siregar et al., 2019). To overcome the decline in student enrollment in the field of STEM teachers need to use their wisdom to furnish themselves with relevant instructional approaches according to the level of student performance (Kelley et al., 2020; Kennedy & Odell, 2014; Siregar et al., 2019).

Teachers' readiness and competencies in delivering STEM subjects through the teaching process play a role to engage students' interest (Maass et al., 2019; Park et al., 2017; Stohlmann et al., 2012; Van Haneghan et al., 2015). The knowledge and skills of teachers mastering the learning and facilitation of the integrated STEM open up space for students to recognize and explore STEM disciplines in schools either formally or informally (Asghar et al., 2012; Attard et al., 2020; Bryan et al., 2015; Park et al., 2016). Teachers' pedagogical skills in producing 21st-century skilled students are a necessity to implement teaching using integrated STEM (Beswick & Fraser, 2019; Nadelson et al., 2012; Nadelson & Seifert, 2013). Mustafa et al. (2016) suggested that more research is needed to identify appropriate strategies to integrate STEM disciplines. Therefore, the purpose of this research is to discover teachers' core competencies support 21st century teaching skills and instructional designs related to mathematics teachers' practices using STEM and

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identify STEM implementation based on a global scale. The following research questions were defined to attain the purpose.

1) What are the core competencies that support 21st century teaching skills among secondary school mathematics teachers?

2) What are the instructional designs involved in using the STEM approach among secondary school mathematics teachers?

3) What is the type of implementation enhancing the outreach activities?

Literature Review

Many initiatives have been offered on enhancing STEM education by increasing students' interest, teachers' skills and abilities, and awareness among students and the public (English, 2016). Teaching styles need to be different because tradition teaching and learning with one-to-one communication are no longer appropriate to prepare the future generations facing the coming global changes (Koehler et al., 2015; Park et al., 2016). Thus, practical, meaningful, and varied teaching strategies can promote high-level thinking and 21st century skills in mathematics teaching and learning (Fitzallen, 2015; Gravemeijer et al., 2017; Grootenboer & Marshman, 2015; Penprase, 2020). Students' engagement with STEM knowledge-based activities connected to real-world problems assisted their learning process (Capraro et al., 2016; Yavuz et al., 2020). However, efforts to implement continuous and high-quality STEM learning are posing significant issues (English, 2016). Accordingly, more structured and comprehensive action is needed to ensure that the level of STEM mastery is enhanced in line with a country's needs in the future (Attard et al., 2020; Bybee, 2010a).

By applying pedagogically integrated STEM, teachers approach students using the concepts and practices of mathematics, science, and engineering in design making and evaluating solutions to problems (Maass et al., 2019). Technology education integrates the doing of mathematics and science into design-based activities (Sanders, 2012). STEM integration, 21st century learning and teaching must go beyond the traditional ways of providing knowledge and memorizing, to one where students take more responsibility for learning and the teacher acts as a facilitator of the activities (Koehler et al., 2015; Penprase, 2020; Sanders, 2012). Factors of the school system, such as size of the class and student attendance are not as important as teachers' effectiveness in influencing student achievement (Allen et al., 2016; Darling-Hammond, 2010; Rivkin et al., 2005). Capable and altruistic teachers are strong personalities to deliver innovative STEM instruction across elementary and secondary education (Al Salami et al., 2017; Beswick & Fraser, 2019; Bowen & Shume, 2020; El Nagdi et al., 2018). They understand the standards for what students should know and be able to do. They know how to cleverly integrate those standards throughout curriculum and instruction (El Nagdi et al., 2018). Teachers drive formal STEM learning by developing and delivering hands-on, project-based instruction (Han et al., 2015, 2016; Morrison et al., 2020; Wells, 2016). Advancing policies that effectively prepare new teachers and sharpen the effectiveness of those already practicing, particularly in the STEM disciplines, will have a positive impact on student performance (Allen et al., 2016; El Nagdi et al., 2018; Wang et al., 2020; Yoder et al., 2015).

As for the higher institution, in preparing the digital, intellectual and STEM-literate workforce, students are required to equip themselves with STEM-related knowledge (Gogia & Pearson, 2018; Hafni et al., 2020; Nouri et al., 2020; Silva et al., 2020). The exploration and implementation of effective strategies in teaching enhance student engagement, standards, and competence not only in STEM fields but also in 21st century skills such as creative problem solving, collaboration, and digital and information literacies (Allen et al., 2016; Fuller & Deshler, 2020; Gogia & Pearson, 2018; Hafni et al., 2020; Nouri et al., 2020; Silva et al., 2020). The notion of 21st century skills has developed out the need to respond to economic and societal problems that are emerging due to the rapid pace of change in the world (Allam, 2020; Bowen & Shume, 2020; Schwab, 2019).

Although the words project-based learning (PRBL) and problem-based learning (PBL) are often used interchangeably, each approaches a situation through a problem scenario but, the result differs (Capraro & Slough, 2009). The PRBL comes out with an innovation or tangible creation of a product whereas PBL results in new knowledge (Archer, 2020; Capraro & Slough, 2009; El Sayary et al., 2015; Han et al., 2015, 2016; Morrison et al., 2020; Wells, 2016). Ideally, the integration of STEM disciplines within PBL allows the learner to holistically approach a real-world problem learning, the content and tools necessary to provide its answer (Capraro & Slough, 2009; El Sayary et al., 2015; Han et al., 2015, 2016; Morrison et al., 2020). Additionally, teachers encourage the utilization of information technology (IT) as presentation tools and user-created content on an individual or group level, exposing students to digital and science computer literacies (Changpetch & Seechaliao, 2020; Nouri et al., 2020; Silva et al., 2020). Indirectly, teachers embolden students to have careers or interests connected to science and technology (Ajmain et al., 2020; Hafni et al., 2020; Yavuz et al., 2020).

STEM implementation based on Sanders (2012) integrated STEM education as best practices were validated by the communities in which they are provided. This process begins with the introduction of new instructional materials and practices, typically through curriculum development, publication of supporting materials, and professional development. The early endorsers within the community begin to utilize the new teaching materials while academics in the community begin to examine their productiveness or effectiveness. Through these processes, each of the STEM education communities such as Science for All Americans (American Association for the Advancement of Science, 1989), Standards for Technological Literacy (STL, ITEA, 2000), The National Academy of Engineering (NAE, 2010), and The National Mathematics Standards (NCTM, 2000) have begun to validate integrated STEM education over the past two decades.

Methodology

The preparation of this systematic review followed the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines by Moher et al. (2015). This section discusses the method used to retrieve articles related to best practices in STEM education among mathematics teachers based on a global perspective. PRISMA method includes resources from (Scopus and Web of Science) used to run the systematic review, eligibility and exclusion criteria, steps of the review process (identification, screening, eligibility), and data abstraction and analysis. According to Higgins et al. (2019), systematic reviews are essential, worthwhile, and inspiring to recognize the upcoming studies' precedence and the extent of human knowledge for an appropriate authoritative decision.

PRISMA

According to Sierra-Correa and Kintz (2015), PRISMA offers three unique advantages which are 1) defining clear research questions that permits a systematic research, 2) it identifies inclusion and exclusion criteria and 3) it attempts to examine large database of scientific literature in a defined time. PRISMA provides a standard peer accepted methodology that uses guideline checklist to contribute the quality assurance of the revision process and to its replicability (Abelha et al., 2020; Moher et al., 2015). Utilizing PRISMA guidelines allowed an accurate search for best practices in STEM education among secondary school mathematics teachers encompassing teaching competencies of 21st century skills, instructional designs and STEM implementation.

Resources

Scopus and Web of Science (WoS) were the leading and primary journal databases to find empirical research. Based on the PRISMA guidelines, this systematic review presents the important phases, including the (a) eligibility and exclusion criteria; (b) the identification review; (c) screening; (d) eligibility; and (e) the data abstraction and analysis (Moher et al., 2015). Clarivate Analytics currently maintains WoS, which is a robust database encompassing 12,000 high impact journals and 160,000 sets of conference proceedings. It supports 256 disciplines in science, social science, arts, and humanities, and cross-disciplinary fields. The selection is based on (a) impact evaluations; (b) availability of open-access journals; and (c) spans multiple academic disciplines. Scopus covers 34,346 journals worldwide from 11,678 publishers. Scopus is known as Elsevier's abstract and citation database of peer-reviewed literature. Science fields of life, social, physical, and health are among the top-level subject fields in Scopus. However, Scopus and WoS complement each other in their journal coverage (Baykoucheva, 2010).

Systematic review process

Identification

The review process was performed in December 2020. The first phase identified keywords used in the search process. Several past research papers were used to determine keywords related to best practices in STEM education among mathematics secondary school teachers. As a result, the terms were used to create three research questions involving core competencies of 21st century teaching skills, instructional designs, and implementation. The search results were discussed with (R.R.) as peer-reviewed studies to avoid bias. Delgado-Rodrígueza and Sillero-Arenas (2018), suggested the use of query strings and article searches performed by two researchers for rigorous result. As confirmation agreed with the chosen keywords, we widened search terms and strategies to identify as many eligible studies as possible. Using Thesaurus electronic dictionary with informatics phrase searching, wild card, truncation, and combined Boolean operators, we modified the search terms together as shown in Table 1 for Scopus. The same search string was pasted into the WoS database using the TS (title search) command.

Table 1. The keywords and strategy to search for information

Database	**Keywords used**
Scopus	TITLE-ABS- KEY (("21st century teaching skill*" OR "instructional design*" OR "instructing act" OR "teaching act" OR "instructing practice*" OR "teaching practice*" OR "teaching and learning implementation*" OR "putting into effect*" OR "fulfillment") AND ("science education" OR "technology education" OR "engineering education" OR "mathematic* education" OR "science and mathematics* education" OR "technology and mathematic* education" OR "engineering and mathematics* education" OR "STEM education") AND ("middle" OR "secondary" OR "high") AND ("school*" OR "education"))

Screening and eligibility

In this process, the reviewers applied a multiple set of eligibility and exclusion criteria. First, the literature type selected were journal articles with empirical data, excluding systematic review articles, book series, books, book chapters, and conference proceedings. Second, focusing on English journal articles helped to overcome the possibility of difficult or uncertain translations. Third, the reviewers considered articles published within the last five years (between 2016 and 2020). The criterion was set because of the current STEM education issues involving a gap in the STEM workforce required to achieve the 4IR (Topcu, 2020). Articles indexed in physical sciences based in material science, chemistry, physics, engineering, computer science, and mathematics were selected, as STEM subjects' teachers play a part in implementing STEM education. No specific countries or territories were excluded. In the final part of the inclusion and exclusion process, the reviewers concentrated on articles dealing with at least the mathematics domain. The final inclusion reviewed the potential full text relevant studies and revised together with fellow researchers (N. A. R, R.R., and A. S. R.). The eligibility process produced full articles, as shown in Figure 1. Eleven journal articles were rejected because they did not fit the requirements as they were not relevant to best practices in integrated STEM education. Journal articles that did not deal with at least mathematics domain were also rejected. The final phase of the review process produced 19 articles (see Figure 1).

Data Abstraction and Analysis

The 19 articles were studied and examined. Themes and sub-themes were appropriately identified by reviewing the article abstracts, followed by reading the full articles (in-depth). Using qualitative content analysis, themes were identified in the 19 articles related to mathematics teachers' best practice in STEM. The authors then organized sub-themes around the main themes established by typology. Reviewers used thematic analysis to identify the findings of previous studies by grouping the finding based on similarities or relevance and categorized them (Adams et al., 2021).

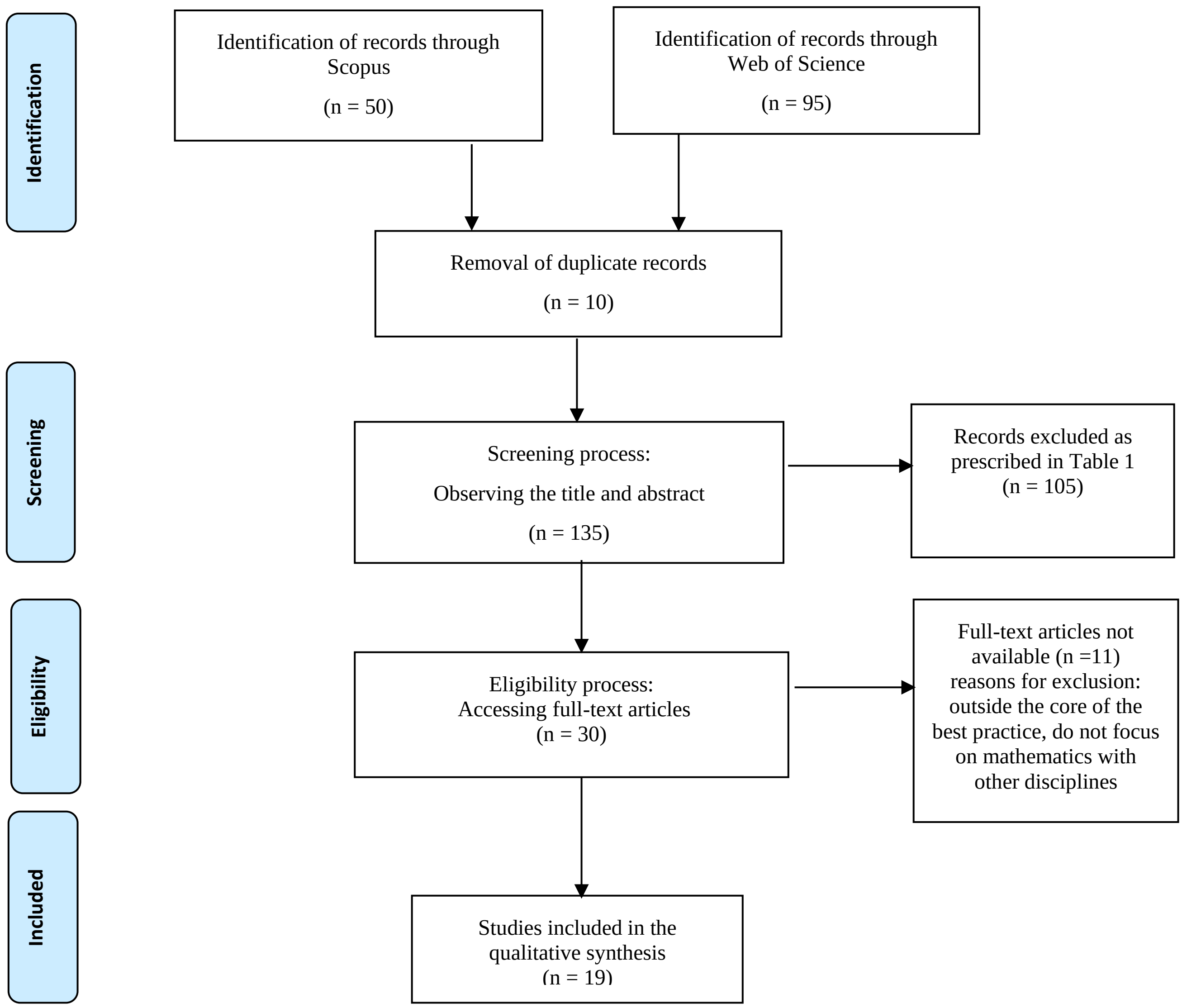

Figure 1. Study flow diagram (Moher et al., 2015).

Quality assessment

As for the quality assessment, the first author (N.A.R.) read and coded all 19 articles with other co-authors (R.R. and A.S.R.). The authors coded randomly selected papers and compared these results to address any inconsistencies in the coding process. When inconsistencies occurred, the authors (N.A.R., R.R., and A.S.R.) discussed and coded 19 selected articles in the set and adjusted accordingly to ensure consistency. A consensus agreement among authors based on the coding process was reached by asking second opinion from (L.H.), an expert in STEM field for quality assessment. An important consideration for this stage is that the criteria be reasonable and defendable (Okoli, 2015). After taking consideration through second opinions and making some improvement, the research group achieved a mutual agreement between authors regarding the themes and sub-themes as shown in Table 2.

Results

The finding of the result in this section through the abovementioned systematic revision process, organized according to quantity of articles by year and method of research, STEM teaching practices based on S-T-E-M, STEM teaching practices based on different countries, and research questions that guided our search and analysis. Out of the 19 research studies, two were published in the year 2020, seven in 2019, three in 2018, five in 2017, and two in 2016. The reviewers discovered that nine studies used a qualitative method, six studies applied quantitative, and the remaining four used mixed methods.

STEM teaching practices based on S-T-E-M

The studies focused on the approach of integrating two, three, or four disciplines in STEM. The reviewers determined that only three studies discussed all four domains of STEM (Bell et al., 2018; Bergsten & Frejd, 2019; Uyangor, 2019). Whereas, only one study mentioned integrating three domains of science, technology, and mathematics (Luneeva & Zakirova, 2017) and fifteen studies concentrated on two domains (Albano & Iacono, 2019; Brown, 2017; Dvoryatkina et al., 2019; Jacobs et al., 2017; Kul, 2018; Mailizar et al., 2020; Nygren et al., 2019; Parker et al., 2017; Polo et al., 2019; Poon & Wong, 2017; Radovic & Passey, 2016; Reinhold et al., 2020; Riordain et al., 2016; Rodriguez et al., 2018; Telegina et al., 2019). The majority of these research works (n=13) discussed the two disciplines of mathematics and technology, while the other two studies addressed integrating mathematics and science.

STEM teaching practices based on different countries

The studies related to best practices in STEM education covered various countries across the world. Albano and Iacono (2019) discussed teaching mathematics effectively using a linguistic digital toolkit (language tiles) to foster Italian students' argumentative competency. Teachers in Italy managed to test students using digital interactive storytelling in mathematics as a competency-based social approach (Polo et al., 2019). An investigation in the USA found that teachers' cultural awareness and dispositions in the mathematics classroom enable the teachers to know and support students' manners (Parker et al., 2017). Learning and teaching geometry (LTG) using video, on the other hand, assisted US mathematics teachers with geometry concepts (Jacobs et al., 2017). In Turkey, Kul (2018) concentrated on professional development, using GeoGebra, mathematics teachers with technical assistance. Uyangor (2019) reported using graph theory among teachers who taught STEM subjects to integrate with other disciplines. Telegina et al. (2019) revealed integrated mathematics and science project-based learning is one of the catalysts among Russian students in mathematics learning. This finding was supported by Luneeva and Zakirova (2017) based on training given to Russian teachers in project-based activities. Riordain et al. (2016) also clarified the effect on Irish students when integrating mathematics and science in the process of teaching and learning (T&L). Research in England and Wales identified STEM teachers' participation in the STEM cohort influenced their classroom teaching practices (Bell et al., 2018). In Spain, the Initial Teacher Education (ITE) 21-week programs using video vignettes, developed pre-service teachers' feedback competency (Muñiz-Rodríguez et al., 2018). Preparation of lesson proposal with 21st century skills train Swedish pre-service teachers to plan innovative STEM activities in classroom (Bergsten & Frejd, 2019). Meanwhile, a comparison study between England and Serbia discovered that technological resources supported mathematics learning across informal, non-formal, and formal learning environments (Radovic & Passey, 2016). Digital technology in teaching practice led to increased Australian students' knowledge (Brown, 2017). For instance, Reinhold et al. (2020), discussed interactive and adaptive material using eBooks and iPads for learning fractions in German. Similarly, in South Africa, the INBECOM model, a combination of the UFraction game and the Activemaths tutoring system proposed by Nygren et al. (2019), enhanced student learning of fractions. The application of dynamic geometry software (DGS) allowed Hong Kong students to explore the concept of triangles (Poon & Wong, 2017). Dvoryatkina et al. (2019) introduced chess game as the key component of creativity in learning mathematics by the Armenian students. Even though facing a barrier from the students' perspective, the Indonesian teachers implemented E-learning in carrying out mathematics T&L during the COVID-19 pandemic (Mailizar et al., 2020). The reviewers also discovered 21 sub-themes within the main themes of the best practices in STEM education, as shown in Table 2. The result of a comprehensive investigation of STEM education's current best practices among secondary school mathematics teachers are based on the research questions of this research as follows:

Table 2. The themes and sub-themes of best practice in STEM education

Authors	21st century teaching skills							Instructional designs								STEM Implementation					
	CT	PS	CR	CM	CL	DL	DC	RP	STEMi	RA	PBL	SF	AS	CS	TI	AC	AL	PL	EE	AP	SC
Albano and Iacono (2019)	✓	✓		✓	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Bell et al. (2018)	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓
Bergsten and Frejd (2019)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓
Brown (2017)	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
Dvoryatkina et al. (2019)	✓	✓	✓	✓	✓			✓			✓		✓		✓	✓	✓	✓	✓	✓	✓
Jacobs et al. (2017)	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
Kul (2018)		✓		✓	✓	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Luneeva and Zakirova (2017)	✓	✓	✓	✓	✓			✓		✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
Mailizar et al. (2020)	✓			✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓
Muñiz-Rodríguez et al. (2018)		✓		✓	✓	✓	✓	✓		✓	✓				✓	✓	✓	✓	✓	✓	✓
Nygren et al. (2019)	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓		✓	✓	✓	✓	✓	✓	✓
Parker et al. (2017)		✓		✓	✓			✓		✓	✓			✓	✓	✓	✓	✓	✓	✓	✓
Polo et al. (2019)	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
Poon and Wong (2017)		✓		✓	✓	✓	✓	✓			✓		✓		✓	✓	✓	✓	✓	✓	✓
Radovic and Passey (2016)	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Reinhold et al. (2020)	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Riordain et al. (2016)	✓	✓	✓	✓	✓			✓		✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
Telegina et al. (2019)	✓	✓	✓	✓	✓			✓		✓	✓				✓	✓	✓	✓	✓	✓	✓
Uyangor (2019)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓

21st century teaching skills
CT = Critical thinking
PS = Problem-solving
CR = Creativity
CM = Communication
CL = Collaboration
DL = Data literacy
DC = Digital literacy & computer science

Instructional designs
RP = Research-based pedagogy
STEMi = STEM content integration
RA = Real-world application
PBL = Project or problem-based learning
SF = Scaffolding
AS = Assessment
CS = Cultural relevance & sensitivity
TI = Technological integration

STEM Implementation
AC = Accessibility
AL = Alignment to local content
PL= Professional development & learning support
EE = Evidence of effectiveness
AP = Access to materials & practitioner support
SC = Scalability

Research Question 1: What are the core competencies that support 21st century teaching skills among secondary school mathematics teachers?

The best practice among secondary mathematics teachers in implementing STEM education focused on core competencies of the 21st century teaching skills resulting in 7 sub-themes. These skills are the competencies that must be established by teachers to nurture students' skills towards 21st century teaching and learning (Beach et al., 2020; Beswick & Fraser, 2019). The reviewers identified eight common 21st century skills that were emphasized in the selected empirical research, for instance a) critical thinking, b) problem-solving, c) creativity, d) communication, e) collaboration, f) data literacy, and g) digital literacy and computer science (GSA-NYAS, 2016). All 19 studies discussed different aspects of these core competencies of 21st century teaching.

Critical thinking

Fifteen studies discussed the importance of critical thinking skills for mathematics teachers when integrating STEM (Albano & Iacono, 2019; Bell et al., 2018; Bergsten & Frejd, 2019; Brown, 2017; Dvoryatkina et al., 2019; Jacobs et al., 2017; Luneeva & Zakirova, 2017; Mailizar et al., 2020; Nygren et al., 2019; Polo et al., 2019; Radovic & Passey, 2016; Reinhold et al., 2020; Riordain et al., 2016; Telegina et al., 2019; Uyangor, 2019). For developing students' critical thinking, teachers need to have the ability to think clearly and rationally, understand and address issues effectively, conceptualize, apply, analyze, and synthesize and evaluate the information generated by communication, reflection, reasoning, observation, and experience as a guide to belief and action (Abdallah, 2020; Hafni et al. 2020; Priatna et al., 2020). When teachers are equipped with these skills, they facilitate discussion and assess the variety of sources and primary materials used to gain relevant information in integrating STEM (Abdallah, 2020; Hafni et al., 2020; Priatna et al., 2020).

Problem-solving

Mathematics teachers should be competent problem solvers by providing guidance and reasoning to various problems and scenarios based on the integration approach. Teaching through problem-solving could be done by defining the problem, ascertaining the cause of the problem, identification, arranging according to priority, selecting alternatives for a solution, making judgments and decisions, and students' implementation (Asghar et al., 2012; El Sayary et al., 2015; English et al., 2017) Sixteen of the studies highlighted the problem-solving aspect of STEM teaching practices in their research involving mathematics teachers (Albano & Iacono, 2019; Bell et al., 2018; Bergsten & Frejd, 2019; Brown, 2017; Dvoryatkina et al., 2019; Jacobs et al., 2017; Kul, 2018; Luneeva & Zakirova, 2017; Muñiz-Rodríguez et al., 2018; Nygren et al., 2019; Parker et al., 2017; Polo et al., 2019; Poon & Wong, 2017; Radovic & Passey, 2016; Reinhold et al., 2020; Riordain et al., 2016; Telegina et al., 2019; Uyangor, 2019).

Creativity

Eleven research articles reported the significance of creativity competence (Bergsten & Frejd, 2019; Brown, 2017; Dvoryatkina et al., 2019; Jacobs et al., 2017; al. (2017), Luneeva & Zakirova, 2017; Nygren et al., 2019; Polo et al., 2019; Radovic & Passey, 2016; Riordain et al., 2016; Telegina et al., 2019; Uyangor, 2019). Instilling creativity in the classroom enables mathematics teachers to encourage students to generate or recognize ideas, alternatives, and possibilities that may help solve problems (Altan & Tan, 2020; Beach et al., 2020; Tubb et al., 2020). Teachers can observe students' communications with others and develop work products by representing and explaining their perspectives or approaches to solutions (Altan & Tan, 2020; Tubb et al., 2020).

Communication

Teaching towards 21st century skills involves communication ability, meaning that mathematics teachers must have the potential to articulate their thoughts effectively using a plethora of communication forms in various contexts (Beswick & Fraser, 2019; Penprase, 2020). Teachers should also listen to students to understand their meaning, attitude, intention, and reasoning. By considering the purpose of communication as part of the integration approach, teachers wisely make assessments of self-communication among students. Teachers use their communication skills for various purposes by using media and technology to communicate with impact (Beswick & Fraser, 2019; Bowen & Shume, 2020; Changpetch & Seechaliao, 2020).

Collaboration

Besides communication, collaboration is also emphasized among the 21st-century teaching skills that involve interaction and a personal lifestyle where students are responsible for their actions. Teachers' collaboration skills allow students to engage in group work and to plan, organize, and conduct activities. Students learn and respect the abilities and contributions of their peers. Teachers play a role in structuring group activities to support joint construction and work products. For example, students are given roles in groups so that each group member can contribute (English & King, 2019; Han, 2016; Wells, 2016; Wang et al., 2020). All the selected studies stated a crucial task for improving mathematics teachers' communication and collaboration skills as a part of the best STEM practices for student learning.

Data literacy

Despite the rapidly progressing worldwide technological climate and easy access to big data, the 21st-century skill of data literacy is needed by teachers to transform information into action in terms of instructional knowledge and practice by gathering, examining, and illustrating different forms of collected data (evaluation, the environment of a school, manner, an informal photograph, longitudinal, continuous experience, etc.) for helping them to identify appropriate steps of instructions (Mandinach & Gummer, 2016). When teachers are competent as data analysts, they could facilitate students in using data analytics in STEM disciplines as mentioned in seven empirical articles (Albano & Iacono, 2019; Bell et al., 2018; Bergsten & Frejd, 2019; Brown, 2017; Jacobs et al., 2017; Kul, 2018; Mailizar et al., 2020; Muñiz-Rodríguez et al., 2018; Nygren et al., 2019; Polo et al., 2019; Poon & Wong, 2017; Radovic & Passey, 2016; Reinhold et al., 2020; Uyangor, 2019). Teachers need to familiarize and understand the combination of data with standards, knowledge of disciplinary and practices, curricular, pedagogical, and how children learn (Mandinach & Gummer, 2016).

Digital literacy and computer science

In relation, digital literacy and computer science capability enable teachers to guide and assist students in using proper technological tools for a given STEM activity (Fuller & Deshler, 2020; GSA-NYAS, 2016; Nouri et al., 2020; Silva et al., 2020). Several studies discussed the way these skills could be developed during STEM learning (Albano & Iacono, 2019; Bell et al., 2018; Bergsten & Frejd, 2019; Brown, 2017; Jacobs et al., 2017; Kul, 2018; Mailizar et al., 2020; Muñiz-Rodríguez et al., 2018; Nygren et al., 2019; Polo et al., 2019; Poon & Wong, 2017; Radovic & Passey, 2016; Reinhold et al., 2020; Uyangor, 2019). These skills lie in the areas of problem-solving, data literacy, critical thinking, and logic-based thinking.

Research question 2: What are the instructional designs involved in using the STEM approach among secondary school mathematics teachers?

Based on the analysis, the reviewers found another significant aspect of the best practice in STEM education, which were the instructional designs or teaching approaches used, resulting in eight sub-themes. The reviewers identified different types of instructional designs that usually applied to the secondary school level such as a) research-based pedagogy, b) STEM content integration, c) real-world applications, d) project-based or problem-based learning, e) scaffolding, f) assessment, g) cultural relevance and sensitivity, and h) technological integration (GSA-NYAS, 2016).

Research-based pedagogy

Research-based pedagogy was the most common STEM instructional design applied (19 articles, see Table 2), in which teachers often informed decisions on student learning. In research-based pedagogy, teachers utilized evidence through observation, tests, peer-assessments, and related learning activities for gauging educational attainment (Beach et al., 2020; Milner-Bolotin, 2018; Peterson & Hipple, 2020). Specifically, the information gained would help teachers improve their instructional practices, identify students' strengths and weaknesses, restructure programs and plans, and communicate student achievement (Beach et al., 2020; Dong et al., 2020; Milner-Bolotin, 2018).

STEM content integration

Among the 19 studies, only three mentioned all four disciplines of STEM integration (Bell et al., 2018; Bergsten & Frejd, 2019; Uyangor, 2019). One article referred to the integration of three of the disciplines (Luneeva & Zakirova, 2017), and the rest referred to only two STEM disciplines. In utilizing the STEM content integration, teachers need capabilities for an integrated and multidisciplinary approach by giving students' space to apply STEM knowledge and skills such as in the context of STEM problem activities or practices like modeling and argumentation (Bryan et al., 2015; El-Deghaidy et al., 2017; English & King, 2019; Kelley & Knowles, 2016; Stohlmann, 2020; Weinhandl et al., 2020).

Real-world application

In relation, using real-world applications is one of the best practices for teaching and learning STEM. Content should contain scenarios related to problems or challenges that students may face outside the school at some point in their lives. Teachers can make explicit connections to students regarding the relationship between the teaching content and real-world applications (Kelley & Knowles, 2016; Kennedy & Odell, 2014; Weinhandl et al., 2020). The reviewers identified thirteen of the studies that discussed real-world applications (Bell et al., 2018; Bergsten & Frejd, 2019; Brown, 2017; Jacobs et al., 2017; Luneeva & Zakirova, 2017; Muñiz-Rodríguez et al., 2018; Parker et al., 2017; Polo et al., 2019; Radovic & Passey, 2016; Reinhold et al., 2020; Riordain et al., 2016; Telegina et al., 2019; Uyangor, 2019).

PBL

Another common teaching approach widely used throughout STEM learning involves project-based learning and/or problem-based learning (PBL). Teachers facilitate students in identifying, organizing, discovering, exploring, and altering the context of problems that affect their school or community (Morrison et al., 2020). Students have the opportunity to work on or solve the problem individually or collaboratively in groups by implementing one or more solutions, and they present their work to their peers (English & King, 2019; Han, 2015, 2016; Wells, 2016). Most of the selected studies, except that of Mailizar et al. (2020), discussed the application of PBL for learning STEM subjects.

Scaffolding

Two studies explaining scaffolding were those by Albano and Iacono (2019) and Reinhold et al. (2020). Scaffolding also significantly allows teachers to support students' movement progressively towards having a deeper understanding and becoming more independent in the learning process of STEM subjects. Teachers' proficiency in evaluating the influence of scaffolding through one-to-one, peer, or computer-based scaffolding affects whether it can be implemented (Belland, 2017; Sanders, 2012).

Assessment

An undeniable aspect of mathematics teachers' STEM best practice is classroom assessment. The instructional design for evaluating competence requires teachers to prepare material for formative and summative evaluation of the classroom's hands-on instruction (Beach et al., 2020; Brahier, 2020; Peterson & Hipple, 2020). Assessment must align with the learning objectives and use a variety of formats including scoring forms, guidance on using results to form data-based decisions, and pedagogical strategies to address the conceptual challenges identified through assessment (Mandinach & Gummer, 2016; Peterson & Hipple, 2020). Fourteen of 19 selected studies focused on assessment.

Cultural relevance and sensitivity

Six articles focused on the practice of cultural relevance and sensitivity as an important part of the instructional design in STEM education (Bell et al., 2018; Bergsten & Frejd, 2019; Kul, 2018; Mailizar et al., 2020; Parker et al., 2017; Radovic & Passey, 2016). It leads teachers to use the students' culture to empower them and help them achieve success in school or education. It also refers to various historical, cultural, and political contexts that include appropriate social studies standards. This standard acts as a framework for teachers, schools, districts, states, and other nations as a tool for curriculum alignment and development. Teachers can provide proper guidance to lead student discussions and activities that recognize and appreciate others' backgrounds, cultures, and experiences, especially in the current field of STEM employment (Tunks et al., 2020; Yang et al., 2020; Yoder et al., 2015).

Technological integration

All 19 studies discussed the integration of technology concerning teaching STEM disciplines. Different technologies are utilized as tools to support student learning, enable various activities, and enhance collaboration. Teachers are encouraged to provide activities that benefit students in using technology outside school (Ajmain et al., 2020; Chacko et al., 2015; Sanders, 2012; Stohlmann, 2020).

Research Question 3: What is the type of implementation enhancing the outreach activities?

The third theme that emerged from the content analysis was STEM implementation, which has seven sub-themes: (a) accessibility, (b) alignment with the local context, (c) professional development and learning support, (d) evidence of effectiveness, (e) access to materials and support, and (f) scalability (GSA-NYAS, 2016).

Accessibility

For implementing STEM learning meaningfully, teaching activities should be developed and planned to involve students from various backgrounds, abilities, and experiences. All materials and support should adhere to universal learning design principles to meet students' and teachers' needs as mentioned in all the articles (Archer, 2020; Freitas & Carvalho, 2020).

Alignment with the local context

The STEM implementation also considers the aspect of alignment with the local context. All the designed materials should be tailored by stakeholders to match their teaching contexts, such as local or national education policies, assessment goals, and accountability frameworks (Archer, 2020; Freitas & Carvalho, 2020; Peterson & Hipple, 2020; Yang et al., 2020). Support for such adaptation, such as content coordinated with a relevant regional teaching framework or a set of frameworks representing various international approaches, should be provided (Archer, 2020;

Freitas & Carvalho, 2020; Yang et al., 2020). We found all selected studies in this review discussed the significant role of accessibility and alignment of the local context to STEM activities.

Professional development and learning support

Besides practitioner support, the continuous implementation of professional development and learning support in STEM for mathematics teachers is also essential. During interactive professional development, teachers are involved with lesson content, pedagogy, and discussion of student work samples to make observations or exercises for future STEM learning (Baker & Galanti, 2017; Hill et al., 2020; Johnson & Sondergeld, 2015; Wells, 2016). Learning support should be provided for pre-service teachers and in-service teachers, and school administrators, including opportunities to prepare before implementation, ongoing support, individual support for planning and reflection, and training, guidance, and cooperation throughout their work (Chowdhury et al., 2020; Freitas & Carvalho, 2020; Hill et al., 2020; Nepeina et al., 2020; Shernoff et al., 2017). All the selected studies in this review supported the need for professional development and learning support for pre-service teachers (PST) and in-service teachers (IST) as both are in continuous process of education. The PST is a professional preparation consisting of a collection of unrelated courses and field experience, and induction process before they enter into service as different types of teachers. Programs offered are intended to support and enhance PST teacher learning and build a deeper level of confidence (Burton et al., 2020). The difference with IST is portrayed by in service education being a continuous professional development process throughout IST's teaching career. The job of teaching continues well if IST continue studying every day in and out of classroom situations (El-Deghaidy et al., 2017; Liu, 2020). From time to time, formal and informal programs are organized to ensure that the standards of education are properly maintained among ISTs (El-Deghaidy et al., 2017; Song, 2019; Wienhandl et al., 2020).

Evidence of effectiveness

In relation, evidence of program effectiveness could be used to enhance STEM implementation. The evidence of a sustained program is collected through rigorous evaluation methods, and the results are accessible to all stakeholders for guiding their instructional practices (Wahono et al., 2020; Robatzek et al., 2020). Support is provided for continuous data collection and analysis to measure impact and support data-based decision-making processes (Milner-Bolotin, 2018; Robatzek et al., 2020; Stohlmann, 2020; Wahono et al., 2020). All of the studies discussed the importance of using evidence from successful STEM program implementation.

Access to materials and support

On the other hand, accessing materials and practitioner support is considered one way of implementing best practices in STEM education. User support is limited by the time, location, language, provision, or technology expertise of the stakeholders. That is, there are no significant barriers to stakeholder involvement in the materials that are designed. Any placement of the required materials is inexpensive and straightforward. Restrictions on technology access for stakeholders, such as internet speed issues, should be addressed in the best possible way, by, for example, giving the option to download material in the form of small individual files (Silva et al., 2020). Any technological requirements should be well documented and easily accessible has been discussed in all the relevant articles (Ajmain et al., 2020; Silva et al., 2020).

Scalability

Finally, mathematics teachers would also need scalability in terms of computer application or product (hardware or software) to function well. All materials and support should be available online locally or through flexible distribution channels. There are proven mechanisms to evaluate professional development and learning support, such as models or modules to train coaches or teachers (Baker & Galanti, 2017; Gardner et al. 2019; Hill et al., 2020; Johnson & Sondergeld, 2015; Nadelson et al., 2012; Nadelson & Seifert, 2013; Nepeina et al., 2020). The content for this is reviewed and updated periodically to ensure that real-world examples and applications remain relevant (Anderson et al., 2020; Nepeina et al., 2020; Silva et al., 2020). Discussions on scalability were found in 19 studies, as displayed in Table 2.

Discussion

The research of STEM education has increased globally, as it is inherent to economic growth and competitiveness, national development productivity, and human well-being (Allam, 2020; Attard et al., 2020; Freeman et al., 2019; Schwab, 2019). A thorough review sourced from two databases resulted in 19 articles related to mathematics teachers' STEM practices across different countries. The results indicated that mathematics teachers at the secondary school level engaged in STEM practices and continuously implemented it into their teaching perspectives. The scope of this review led to three emergent themes, and 21 sub-themes, determining STEM practices among mathematics teachers: Core competencies encompassed 21st century teaching, instructional designs, and requisite STEM execution.

Core competencies encompass 21st century teaching skills

Levy and Murnane (2004) indicates that individuals learn and apply broad 21st century skills within the context of specific bodies of knowledge. Development of 21st century skills corresponded with development of technical content knowledge (Penprase, 2020). Similarly, in STEM education, students may develop cognitive skills while engaged in the study of specific STEM-related social or global situations (Attard et al., 2020; Brahier, 2020; Bybee, 2013; Freeman et al., 2019; Penprase, 2020). Previous studies have shown that teachers who lack expertise in STEM disciplines would affect students' attitudes and involvement in related subjects (Gardner et al., 2019; Yıldırım & Turk, 2018; York, 2018). Thus, to meet the demand for producing a STEM workforce grounded in technological advances, mathematics teachers must collaboratively embrace and increase emphasis on 21st century essential competence during instruction (Bowen & Shume, 2020; Dong et al., 2020; English, 2017). The governments must provide opportunities to mathematics teachers to acquire extensive knowledge in STEM and teachers need to progressively shift in developing the skills to facilitate student learning (Beswick & Fraser, 2019). In facilitating students learning, teachers' skills in communication and collaboration were the most common practices used. Educators' complex communications and social skills in processing and interpreting both verbal and nonverbal information motivates the students to respond appropriately (Bybee, 2013). In addition, essential requirement to implement integrated STEM education need communication and cooperation between educators. When educators work together, they create a better learning experience. In today's educational mores, being a part of a professional learning center (PLC) and pursuing professional learning scenarios enable progressing advancement for students and teachers (Freeman et al., 2019).

However, due to an ever-increasing workload and fixed schedules, teachers face limited free time to engage in gainful communication and beneficial collaboration with their compeers (Song, 2019). Critical thinking and problem-solving skills are the other practices mentioned. Students can develop 21st century skills such as adaptability, complex communication, social skills, non-routine problem solving, self-management or self-development, and systems thinking to compete in the modern economy (NRC, 2010). Non-routine problem solving includes creating new and innovative solutions, integrating seemingly unrelated information, and entertaining possibilities (Levy & Murnane, 2004). Teachers' critical thinking include examining a broad span of information, recognizing patterns, and narrowing the information to diagnose problem solving, which helps students to cope with STEM activities (Abdallah, 2020; Bybee, 2010b; Hafni et al., 2020; NRC, 2010; Priatna et al., 2020). Exposing students to STEM programs, incorporating group activities, investigations, and projects provide opportunities for teachers to help students develop 21st century skills (Archer, 2020; Bybee, 2010a; Freitas & Carvalho, 2020; Penprase, 2020; Wells, 2016). In addition, teachers' creativity in suggesting students' mode of presentation through STEM activities involving data literacy, digital literacy and knowledge of computer science enhanced teaching competencies towards 21st century skills (Chacko et al., 2015; Changpetch & Seechaliao, 2020; Fuller & Deshler, 2020; Mandinach & Gummer, 2016; Nouri et al., 2020; Penprase, 2020; Silva et al., 2020).

Instructional designs

Engagement of students with a challenge or problem begins with the teacher's instructional approach. The appropriateness of the challenges depends on the students' age, grade and developmental stage. Accordingly, mathematics teachers should restructure their instructional designs to cater to students' learning needs (Brahier, 2020). Beswick and Fraser (2019) contend that the present mathematics instruction design does not encourage students to pursue or equip their studies, thereby stopping many future STEM graduates from pursuing these areas. The challenge for mathematics teachers lies in integrating the STEM disciplines effectively (English, 2017; Madani, 2020). Nevertheless, using a variety of instructional approaches appropriately could create a meaningful learning environment that could enhance students' attitudes and motivation in knowledge acquisition of STEM subjects (Kelley et al., 2020; Kennedy & Odell, 2014). Integrated STEM approaches that applied real-world problems and projects could create the experience of learning (Archer, 2020; English & King, 2019; Wells, 2016). Teaching and learning using the integrated STEM approach is an alternative for encouraging students' interest in mathematics (English, 2016, 2017). The highlighted practices under instructional designs are research-based pedagogy technological integration and project-based learning/ problem-based learning (PBL). STEM education is being implemented in terms of information technology (IT) usage and technology tools, aligned with the 4IR (Ajmain et al., 2020; Archer, 2020; Kennedy & Odell, 2014; Wells, 2016). Teaching integrated S, T, E, M not only content integrated but also integrated through processes, such as engineering design-based process and technology design-based by using PBL. According to Kelley and Knowles (2016), the analytical element of the engineering design process allows students to use mathematics and science inquiry to produce and do experiments that will familiarize the learner about the operation and scope of attainable design solutions before a final prototype is built. This approach to engineering design enables students to rely on their own experiences and equips learners to build new science and math knowledge through design analysis and scientific investigation. From the analysis review, integration of mathematics and technology is the most common practices other than science but none from engineering domain. However, the products of technology and engineering greatly influenced everyday life. Engineering is directly involved in problem solving and innovation and by improving technology usage students increase their understanding of how things work (Bybee, 2010b). According to Kennedy and Odell (2014), STEM education programs of high quality should include (a) integration of technology and engineering into science and math curriculum at a minimum; (b) promote scientific inquiry and engineering design; and (c) include rigorous mathematics and science instruction. Bybee (2013) asserted one of the components of STEM literacy was the willingness to engage in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen.

Requisite STEM execution

The purpose of requisite STEM execution or STEM implementation in schools is to prepare the students for the future work demand in STEM which is related to 21st century skills (English, 2016, 2017). Therein lie many challenges for teachers to integrate STEM within mathematics classrooms, yet excellence in STEM implementation requires necessary support and resources from stakeholders. The review of 19 journal articles identified all the sub-themes under STEM implementation were the most common STEM practices among mathematics teachers. In specific, scholars agreed on the importance of STEM continuous professional learning for mathematics teachers to enhance their content knowledge, pedagogical content knowledge, and instructional practices (Dong et al., 2020; Gardner et al., 2019; Hill et al., 2020; Weinhandl et al., 2020; Yıldırım & Turk, 2018; York, 2018). The increase in teacher knowledge could potentially increase students' learning outcomes in STEM and develop students' 21st century skills (Abdallah, 2020; Capraro et al., 2016; Gardner et al., 2019; Han et al., 2015; Penprase, 2020; Weinhandl et al., 2020). Aslam et al. (2018) reveal the teachers' role as a driving force through STEM professional refinement to upgrade teachers' understanding of STEM subjects in the real world. Kennedy and Odell (2014) noted that high quality STEM education programs included collaborative approaches to learning, connecting students and educators with STEM field and professionals, and provided global and multi-stance interpretations. Thus, requisite STEM execution in providing model STEM units, professional development, and ideal evaluation at the elementary, middle, and high school levels would have a significant influence on the STEM education system. In addition, this enhances understanding and support of STEM practitioners, increases support by policy makers and administrators, and promotes understanding by the public (Aslam et al., 2018).

Conclusion

The STEM practices involved the core competencies encompassed by 21st century teaching skills, instructional designs, and STEM implementation. The core competencies encompassed 21st century teaching skills are creativity, data literacy, and digital literacy and computer science. The most common practices determined were critical thinking, communication, collaboration, and problem-solving skills. Identification of common practices in delivering mathematics teaching process enabled the teachers to be prepared mentally and to physically use the STEM approach. The instructional designs involved STEM content integration, real-world application, scaffolding, assessment, and cultural relevance and sensitivity. The frequent practices highlighted under instructional designs are research-based pedagogy, project-based learning/ problem-based learning (PBL), and technological integration. To ensure the integrated STEM approach is sustained in the secondary mathematics classroom, the aspects of accessibility, professional development and learning support, evidence of effectiveness, access to materials and practitioner support, and scalability must be addressed in the future. Maintaining STEM practices in every educational level in most countries will attract more students to venture into STEM fields, fill the STEM workforce gap, and eventually achieve IR4.0.

Recommendations

There are several suggestions for future studies. First, a mixed-methods investigation offers a strong understanding of problem research. We suggest mixed methods to explore best practices in STEM education, as it is the approach that is least often used (Chowdhury et al., 2020). Moreover, mixed methods research is new in the social and human sciences (Creswell & Creswell, 2017). The mixture of qualitative data, which is open-ended, and quantitative data, which is closed, provides different information types (Creswell & Creswell, 2017). Second, the reviewers suggest that the combination of four domains in STEM education should be explored. The result of systematic literature review discovered only three out of nineteen studies discussed the integrative STEM education with all four STEM disciplines addressed. Most articles discussed the integration between mathematics and technology. Third, an analysis of the integration between engineering and mathematics is still lacking. None of the articles integrated engineering and mathematics, thus, the engineering domain is considered less and given little attention (Bybee, 2010a). Fourth, the required skills to integrate engineering into teaching and learning is also a problem among secondary mathematics teachers wishing to implement the STEM approach. The difficulties of integrating engineering with mathematics should be highlighted in future research works. Emphasis is given to engineering because the strongest feature in engineering studies illustrates a good knowledge of mathematics and natural sciences (Pohjolainen, 2018).

According to Sosnovsky (2018), countries that have not invested in STEM education and do not possess strong enough engineering workforce will be forced to pay other countries for engineering problems by outsourcing. In order to win the future, we should invest in STEM education to increase engineering literacy to enable the next generation of innovators. Fifth, in order to requisite STEM execution necessary at the secondary school level, teacher training programs, PST education and related educational policies regarding STEM are recommended. Reviewers agreed with

Song's recommendations (2019) towards the incorporation of blended STEM education training courses to be included as compulsory courses for the PST in college education programs. For IST, STEM training courses which are now optional and in progress along with online and offline, are suggested to be completed as a mandatory training course for all STEM-related teachers. It is also beneficial to create an intensive training center by the propagation of integrated STEM education to develop integrated STEM programs and to produce integrated STEM experts. In addition, ICT integration knowledge acquisition should be made accessible via training opportunities for a professional development arrangement for IST and PST. Teachers should continuously refresh their knowledge and maintain digital and scientific proficiency and literacy. Finally, in the future, researchers should apply a longer timeline of at least 10 years of research instead of 5 years to gain more articles to study. Researchers also should look for patterns in the literature relevant to the study objectives.

Limitations

This article only focused on secondary school mathematics teachers who used the STEM approach in the mathematics teaching and learning process. It was identified mathematics and technology were dominant practices in the STEM approach compared to the other two disciplines. Fewer articles were obtained due to using only two search engines of Scopus and Web of Science (WoS) databases to search for literature within 5 years of recent research.

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Authorship Contribution Statement

Rahman: Drafting manuscript, conceptualization, design, data acquisition, analysis, & writing manuscript. Rosli: Editing, reviewing, securing funding, supervision, & approval. Rambely: Reviewing, supervision, & approval. Halim: Supervision & final approval.

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