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Integrated Professional Development for Mathematics Teachers: A Systematic Review

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Abstract

An effective professional program can enhance the integrated knowledge and skills of Science, Technology, Engineering, and Mathematics (STEM) among mathematics teachers. Nevertheless, the strategies for STEM integration in teaching and learning taught in many professional programs have proven impractical for many teachers. Thus, a systematic literature review is presented to investigate the characteristics of successfully implemented professional programs for STEM education for mathematics teachers. Twenty research articles published from 2017 to 2021 were obtained from the Scopus and Web of Science databases. The results show that of six interdisciplinary concepts, the integration of mathematics and science content was the one most employed in professional programs. In addition, the workshop design type was found to be popular for STEM professional programs, and it impacted teachers' teaching practices in the classroom, student learning outcomes, and knowledge and skills. The results suggest that the self-efficacy of mathematics teachers and their commitment to the programs were significant factors contributing to the effectiveness of the programs. When planning STEM professional development programs, organizers need to think about the needs of teachers and students, the length of the programs, practical activities, STEM concepts, follow-up actions, and so on in order to meet the goals of these programs

Keywords: Professional development, mathematics teachers, systematic literature review, STEM concepts, teacher education

Introduction

Professional development is widely implemented as part of an educational policy agenda in the United States to equip teachers with the most recent educational knowledge and practices (Gardner et al., 2019). Each year, extensive innovations in the fields of Science, Technology, Engineering, and Mathematics (STEM) have led to an increased demand for teacher professional programs for STEM education. Such programs are essential for improving teachers' knowledge of the content, pedagogical knowledge, and understanding of changes in the educational system (Brown & Bogiages, 2017; Nesmith & Cooper, 2019). Currently, the educational system's goal tends to focus on student engagement in STEM-related learning and activities, which in turn increases their interest in STEM-related career paths (Velasco et al., 2022), and teachers must understand how to encourage such engagement. In addition, teacher professional programs can increase the competence of the teachers and further the development of the teaching profession (Thomson et al., 2020). These programs should be expanded to benefit teachers and educational organizations (Brown & Bogiages, 2017; Chai et al., 2020). The most important thing is that effective professional development programs can help students, teachers, and the whole educational system do well, which is why they are so important.

Educators and policymakers in recent years have begun to realize the importance and many benefits of integrating STEM subjects into teaching and learning. Effective mathematics teaching, in particular, is crucial for the successful integration of STEM education in schools (Siregar et al., 2019). However, most teachers still tend to teach mathematics in isolation and procedurally (Srikoom et al., 2017). As a result, student understanding and mastery of mathematical concepts across the curriculum and STEM disciplines cannot be established, often thwarting the goals of STEM education (Ng & Park, 2021). To prevent this, teachers should have a clear vision and direction in assisting students to develop their mastery of mathematics and STEM integration, which necessitates a change in the traditional curriculum. Al Salami et al. (2015) and Erdogan and Stuessy (2022) asserted that transformation in the curriculum requires teachers to constantly change their teaching strategies and approaches to be in line with global developments. Teachers

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need effective professional development to equip themselves with the latest knowledge and skills in the curriculum, use of technology, and teaching practices. There have been many studies conducted to figure out which STEM professional programs are best for mathematics teachers (e.g., Maass & Engeln, 2019; Nesmith & Cooper, 2019), but but this research is still ongoing Mathematics is a subject related to numbers, measurements, quantities, and shapes. Araya (2021) described mathematics as the focal point of all professions, but it is considered a difficult subject by many students, thus resulting in their not pursuing STEM-related career pathways. Previous studies have also shown that mathematics and other subjects tend to be taught in isolation (Srikoom et al., 2017). In addition, there are inequitable representations of disciplines in STEM education, in that the central focus is mostly on science (Bybee, 2013; English, 2016, 2017), and mathematics is often not emphasized or is only given a supporting role (Stohlmann, 2019). These issues may limit the opportunities for incorporating mathematical ideas and concepts into STEM.

Nevertheless, implementing STEM curricula in neither an interdisciplinary nor transdisciplinary way in mathematics classrooms without profound content understanding and effective pedagogical knowledge is another common issue (e.g., Beswick & Fraser, 2019; Margot & Kettler, 2019; York, 2018). For instance, York (2018) contended that many teachers' STEM content and pedagogy are not integrated. Similarly, scholars have argued that many mathematics teachers fail to emphasize STEM connections more prominently (English & King, 2019) and ignore providing adequate scaffolding in developing students' 21st-century competencies (Beswick & Fraser, 2019). Previous studies showed that mathematics teachers lack knowledge of the content and pedagogical knowledge in STEM integration, which results in low self-confidence in facilitating instruction in the classroom (e.g., Gardner et al., 2019). As such, the approaches and strategies of mathematics teachers need to be improved to be in line with global technological advancements and educational requirements (Prodromou & Lavicza, 2017). The initiatives of providing continuous STEM professional programs need to be appropriately implemented to prepare mathematics teachers with sufficient knowledge to integrate STEM into their classrooms (Kareemee et al., 2019).

Professional programs are not a "one-size-fits-all" solution, however. Gardner et al. (2019) suggested that professional programs for mathematics teachers should be designed based on teachers' specific needs and experiences. Professional programs for STEM education among mathematics teachers should include a range of skills and knowledge involving STEM pedagogy to create a purposeful classroom environment. An effective professional program needs to consider features such as activity format, collaborative teacher participation, and the appropriate duration for program implementation (Aguirre-Muñoz & Pando, 2021; Baker & Galanti, 2017). This statement is also supported by Lynch et al. (2019), who argued that an effective professional program could change teachers' instructional approaches and practices, improving student achievement. Effective professional programs can also increase teacher self-efficacy, discipline, and satisfaction in implementing STEM-related teaching and learning (Al Salami et al., 2015; Saadati et al., 2021). The effectiveness of the professional programs conducted can also be seen by how they improve teachers' knowledge and skills in STEM curriculum innovation (Nesmith & Cooper, 2019). In addition, Thibaut et al. (2018) described how to implement professional development that can change teachers' views and practices in STEM education by focusing on specific teaching topics during the program's implementation.

The impacts that professional programs have on teacher disposition and instructional strategies directly affect student learning. Baker and Galanti (2017) and Mohammad Hasim et al. (2022) claimed that a better designed and practical STEM professional program could change teachers' ways of thinking and enhance student learning. Saadati et al. (2021) conducted a study related to STEM professional programs and emphasized the relationship between quality teaching and student learning outcomes. Gardner et al. (2019) and Saadati et al. (2021) observed improved student performance after teachers attended professional programs to enhance STEM integration practices. As a result, knowledge in integrating STEM based on 21st-century learning can be developed in schools to serve as a model for other teachers. There is evidence from previous studies that teachers' knowledge and skills in delivering STEM content have influenced students' interest and achievement in mathematics within STEM (Moh'd et al., 2021; Rahman et al., 2021). Thus, teachers should attend professional programs to improve their teaching methods in the following learning session to impact students positively.

Factors involving the teacher that influence the effectiveness of professional programs for STEM education have been discussed in numerous studies (e.g., Mohammad Hasim et al., 2022; Owens et al., 2019; Thibaut et al., 2018; Velasco et al., 2022). Researchers have noted some of these important factors, such as teacher involvement and motivation (Maass & Engeln, 2019; Saadati et al., 2021; Velasco et al., 2022), teacher commitment during activities (Al Salami et al., 2015; Owens et al., 2019; Thomson et al., 2020), teacher attitudes during and after professional programs (Aldahmash et al., 2019; Chai et al., 2020; Gardner et al., 2019), and teachers' self-efficacy regarding their ability to implement teaching based on knowledge and skills learned during a professional program (Aguirre-Muñoz & Pando, 2021; Al Salami et al., 2015; Nesmith & Cooper, 2019), but this list is not all-inclusive. In addition, the designed activities implemented during STEM professional programs must improve self-efficacy and teaching practices and support teachers' ability to integrate

STEM education in line with the goals of the curriculum. For example, Ng and Park (2021) conducted a study on video technology to support the integration of mathematics and technology, which assisted teachers in planning further learning sessions. Nesmith and Cooper (2019) also noted that STEM programs with mathematics and engineering concepts proved to have a positive influence on the effectiveness of teachers in implementing lessons involving engineering activities in their classrooms.

Method

Based on the issues presented, the current study intends to produce a critical review and analysis of previous studies about STEM professional programs for mathematics teachers at the primary and secondary school levels. In general, all types of research need clearly stated goals to determine the direction of a study. Thus, the research questions that guided this study are as follows:

a) What are the interdisciplinary concepts used in STEM professional programs?
b) What are the different design types of STEM professional programs?
c) What are the impacts of the STEM professional programs?
d) What teacher factors influence the effectiveness of STEM professional programs in the classroom?

Research Design

A survey study was conducted to critically synthesize the findings of empirical studies related to STEM professional programs involving mathematics teachers. The results of this study are reported based on guidelines for conducting systematic surveys in the social sciences as proposed by Petticrew and Roberts (2006). The guidelines cover four primary steps, including keyword searching, selecting the studies, extracting the data, and analyzing the data.

Population and Sample

Step 1: Keyword search

Some specific aspects need to be considered when selecting an article. Only studies that met the criteria were selected as articles to be included in the sample. Two databases, namely Scopus and Web of Science (WoS), were used to obtain empirical studies published in mathematics education (Table 1). The databases were selected due to their collection of articles with high-impact reputations. The search parameters were based on the research questions and involved multiple terms and keywords. In the search process, Boolean operators were used to search for the appropriate study.

Data Collection Tools

Step 2: Selection process

Several criteria were selected as specific conditions for the inclusion or exclusion of each empirical journal article. The inclusion criteria were as follows: (a) the article is in English, (b) published between 2017 and 2021, (c) related to professional programs for STEM education covering the primary and secondary school levels, (d) available in full text as well as indexed in Scopus and WoS, and (e) the study participants were mathematics teachers. As for the exclusion criteria, journal articles that were not empirical studies, namely chapters in books, reviews, dissertations, theses, and proceedings, were not selected for analysis. In the study, the selection process from Scopus ($n = 518$) and WoS ($n = 342$) utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analysis procedure developed by Moher et al. (2015).

Data Collection

Step 3: Data extraction

Relevant data were identified and extracted using a structured coding form to evaluate the quality of the articles. The article evaluation process was conducted using a rubric adapted from Margot and Kettler (2019), covering seven evaluation criteria: (1) objectives and purposes, (2) literature review, (3) theoretical or conceptual framework, (4) participants, (5) methods, (6) results and conclusions, and (7) interests. Each criterion was rated on a 4-point scale: 1 = *not achieving quality*, 2 = *nearly achieving quality*, 3 = *achieving quality*, and 4 = *highly achieving quality*. Articles receiving a total score of 14 points or less were excluded from this study for not achieving the minimum level of quality, and only 20 were identified to have met the quality requirements. Then, data for each article were extracted using the coding scheme proposed by Gast et al. (2017):

a) General information (title, author, year of publication, research context, and type of publication);
b) Research design (research questions or objectives, background information, and layout); and
c) Overall research findings (findings relevant to the research question).

Table 1: Keywords for literature search

Database	*Keyword*
Scopus	TITLE-ABS-KEY ((“professional development” OR “professional development for mathematics teacher*” OR “mathematics teacher programme*”) AND (STEM OR “STEM education”) AND (“mathematics” OR “mathematics teacher*”))
Web of Science	TS= ((“professional development” OR “professional development for mathematics teacher*” OR “mathematics teacher programme*”) AND (STEM OR “STEM education”) AND (“mathematics” OR “mathematics teacher*”))

Data Analysis

Step 4: Data analysis

In this study, thematic analysis was used to examine selected articles, as this can assist in exploring data more broadly by categorizing them into specific themes (Miles et al., 2019). Data extracted from the studies was collected and synthesized to answer the research questions. Each article's results and discussion sections were evaluated to determine the overall research outcomes.

Findings and Discussion

The present systematic literature review aimed to synthesize empirical research related to STEM professional programs among mathematics teachers. The results of this study are discussed in terms of appropriate research themes based on the research questions, namely the interdisciplinary concept of STEM, program design types, the impacts, and the teachers' factors that influence the effectiveness of STEM professional programs. Figure 1 shows the flow diagram of the systematic review to answer the guiding research questions.

The interdisciplinary concept of STEM

This section answers the first research question and demonstrates the interdisciplinary concept of STEM that was emphasized during professional programs. Table 2 summarizes six dominant STEM interdisciplinary concepts that were identified from the selected empirical studies, which were mathematics-science ($n = 6$), mathematics-engineering ($n = 2$), mathematics-technology ($n = 4$), mathematics-science-engineering ($n = 5$), mathematics-science-technology ($n = 1$), and mathematics-science-engineering-technology ($n = 2$). Specifically, Aldahmash et al. (2019) stated that STEM is an approach that explores classroom instruction of any two or more STEM subject areas within one STEM subject. Maass et al. (2019) further argued that interdisciplinary concepts in STEM are connected to 21st-century competencies and skills that support student learning. Skills such as analyzing, problem-solving, and critical thinking are features needed for the workforce in the future (Academy of Sciences Malaysia, 2018).

The interdisciplinary nature of mathematical modelling provides a clear opportunity to link mathematics with STEM educational goals when learning how to solve real-world problems through STEM knowledge (Baker & Galanti, 2017). For example, Berisha and Vula (2021) discussed the relationship between mathematics and engineering in STEM education, while Gardner et al. (2019) stressed the importance of mathematics, science, and engineering domains when implementing STEM professional programs. To support meaningful student learning in STEM and the development of 21st-century skills, mathematics teachers must master the knowledge of their field and equip themselves with the knowledge of other STEM disciplines, and STEM professional

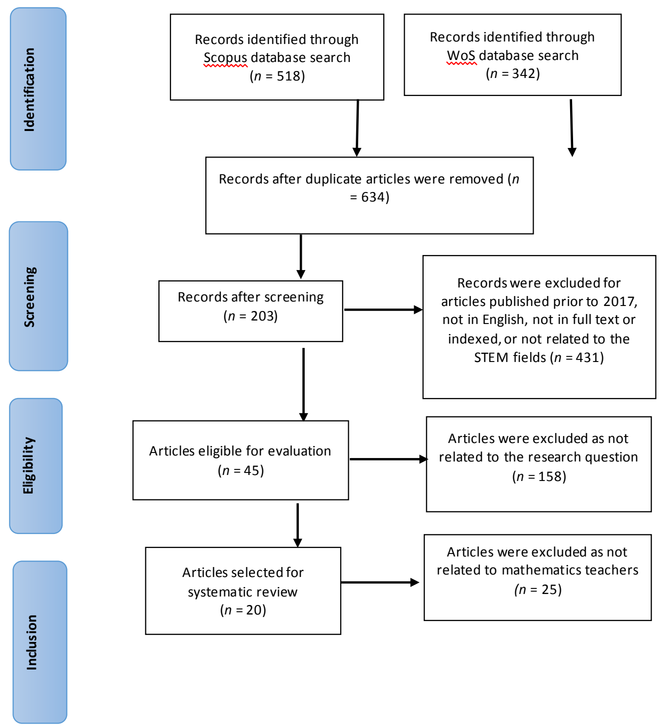

Fig. 1: The flow diagram of the systematic review

Table 2. The interdisciplinary concepts of STEM

STEM Concept	*Frequency*	*Article*
Mathematics and science	6	Aguirre-Muñoz and Pando (2021); Araya (2021); Brown et al. (2018); Brown and Bogiages (2017); Owens et al. (2019); Velasco et al. (2022)
Mathematics and engineering	2	Baker and Galanti (2017); Berisha and Vula (2021)
Mathematics and technology	4	Asempapa and Love (2021); Kareemee, Suwannatthachote, and Faikhamta (2019); Ng and Park (2021); Prodromou and Lavicza (2017)
Mathematics, science, and engineering	5	Aldahmash et al. (2019); Diego-Mantecon et al. (2021); Maass and Engeln (2019); Nesmith and Cooper (2019); Thomson et al. (2019)
Mathematics, science, and technology	1	Gardner et al. (2019)
Mathematics, science, engineering, and technology	2	Chai et al. (2020); Thibaut, et al. (2017)

programs provide opportunities for mathematics teachers to do so. Although various interdisciplinary concepts of STEM have been implemented during professional programs, teachers need to further adapt different interpretations of the STEM content presented for effective classroom instruction (Chai et al., 2020). This is because teachers face difficulty understanding and mastering all the interdisciplinary concepts of STEM simultaneously that can be utilized in mathematics teaching. We strongly believe teachers need sufficient time to understand and adapt the instruction related to STEM activities they engage in during professional programs to their specific classroom's needs (Maass & Engeln, 2019). Furthermore, the STEM concept highlighted in every professional program should focus on an interdisciplinary STEM concept so that there is no misinterpretation of the concept among teachers, especially concepts involving the integration of science and engineering into mathematics. Thus, the development of integrated STEM teaching skills and knowledge should include a number of program stages to make sure that teachers understand the relevant STEM concepts that they will be teaching.

Design types of STEM professional programs

This section presents an overview of the design types of professional programs for STEM education. It is also important to note that the design implemented influences the effectiveness of the STEM professional program (Aguirre-Muñoz & Pando, 2021). Although there are various design types, their purposes are similar: to effectively ease the traditional knowledge transfer process, which seeks to provide relevant knowledge and skills to teachers for fulfilling the needs and demands of the current STEM trend (Aldahmash et al., 2019). There is no specific design that works for all teachers, as the key to success is dependent on teacher involvement (Owens et al., 2019).

As shown in Table 3, various design types of STEM professional programs have been implemented, such as workshops (n = 12), short-term courses (n = 2), online courses (n = 2), model usage (n = 2), professional learning community (n = 1), and reflective practice and exploration (n = 2). Out of the 20 articles, 12 utilized the workshop design type, which was the most often implemented for STEM professional programs. According to Velasco et al. (2022), STEM professional programs conducted as workshops can impart direct experience to teachers and promote hands-on learning through exposure to STEM educational activities that support teaching in the classroom. Along the same line, Berisha and Vula (2021) argued that the design of professional development programs should be appropriate, focused, and geared toward developing teachers' knowledge and skills in STEM integration, as many teachers still lack the pedagogical knowledge and skills needed to integrate STEM into the classroom. Furthermore, Baker and Galanti (2017) stated that integrating STEM into mathematics classroom contexts is challenging and complex because many teachers have traditionally utilized the conventional instructional method and focused solely on routine algorithms and procedural understanding. Darling-Hammond et al. (2017) said that professional development programs for mathematics teachers can be improved when the design and implementation take into account the teachers' needs when they teach in the classroom.

Impacts of STEM professional programs

Table 4 shows the impacts of STEM professional programs that are divided into three main categories: teachers' knowledge and skills (n = 11), teaching practices (n = 6), and student learning outcomes (n = 3). The results showed that 11 of the 20 articles focused on the impact of STEM professional programs on teachers' knowledge and skills, and six articles discussed the effects on teaching practices. Chai et al. (2020) found that teachers who attended STEM professional programs improved their content knowledge and skills in integrating technology into mathematics teaching in the classroom. Similarly, Baker and Galanti (2017) found that professional programs for STEM education enhance the knowledge and skills of mathematics teachers and their pedagogical content knowledge of mathematics within STEM. Based on this review, we strongly believe teachers' knowledge and skills in STEM play a key role in making programs more effective and sustainable in the long run.

Table 3. Design types of professional programs for STEM education

Design type	*Frequency*	*Article*
Workshop	12	Aguirre-Muñoz and Pando (2021); Berisha and Vula (2021); Brown et al. (2018); Brown and Bogiages (2017); Chai et al. (2020) Gardner et al. (2019); Diego-Mantecon et al. (2021); Maass and Engeln (2019); Nesmith and Cooper (2019); Owens et al. (2019); Prodromou and Lavicza (2017); Velasco et al. (2022);
Short-term courses	2	Aldahmash et al. (2019); Thomson et al. (2019)
Online courses	2	Araya (2021); Ng and Park (2021)
Model usage	2	Asempapa and Love (2021); Baker and Galanti (2017)
Professional learning community	1	Kareemee et al. (2019)
Reflective practice and exploration	1	Thibaut et al. (2017)

Table 4: Impacts of STEM professional programs

Impact category	*Frequency*	*Article*
Teachers' knowledge and skills	11	Aguirre-Muñoz and Pando (2021); Aldahmash et al. (2019); Asempapa and Love (2021); Brown and Bogiages (2017); Berisha and Vula (2021); Chai et al. (2020); Thomson, et al. (2019); Maass and Engeln (2019); Nesmith and Cooper (2019); Thibaut et al. (2017); Velasco et al. (2022);
Teaching practices	6	Brown et al. (2018); Diego-Mantecon et al. (2021); Gardner et al. (2019); Kareemee et al. (2019); Owens et al. (2019); Prodromou and Lavicza (2017);
Student learning outcomes	3	Araya (2021); Baker and Galanti (2017); Ng and Park (2021)

Furthermore, teachers' teaching practices in integrating STEM in schools improved when teachers participated in professional programs that focused on pedagogical approaches (Velasco et al., 2022). The ability of teachers to utilize all the required expertise in evaluating mathematics teaching and improving their teaching practices regarding STEM education significantly improves after participating in professional programs focusing on STEM integration. Effective programs should be designed to help teachers improve their teaching skills and help students learn about STEM in the classroom.

In comparison, student learning outcomes were the least focused on by researchers, as only three articles discussed this. The selected empirical studies found that not all programs were designed for student learning outcomes. However, Kareemee et al. (2019) determined that professional programs can have a significant impact on student learning outcomes in STEM if teachers acquire new knowledge and skills in the programs. Specifically, they found that STEM professional programs have a significant effect on teachers' teaching practices, contributing to improved student performance. These findings suggest that professional development programs for STEM education among mathematics teachers can influence and improve mathematics achievement (Asempapa & Love, 2021; Berisha & Vula, 2021) and assist teachers in being able to understand students' ways of thinking (Aldahmash et al., 2019; Velasco et al., 2022). In addition, teachers can build meaningful STEM content knowledge (Berisha & Vula, 2021; Gardner et al., 2019) and support other teachers in improving their mathematics teaching practices (Brown et al., 2019; Saadati et al., 2021).

We also found several studies focused on two categories of effect; for instance, Gardner et al. (2019) concentrated on teachers' knowledge, skills, and teaching practice, while Baker and Galanti (2017) centred their STEM professional development on improving teachers' knowledge and skills and on student learning outcomes. Teachers can better support their students in achieving their learning objectives when they attend professional programs for STEM education that are organized in a planned and orderly manner (Aldahmash et al., 2019). In addition, professional programs combined with meaningful teacher experience can influence teachers' instructional styles (Araya, 2021) and student learning outcomes (Maass & Engeln, 2019). Thus, Gardner et al. (2019) contended that teachers need to transform their teaching practices into meaningful learning based on the needs of the students.

Influence of teacher factors

This section describes four factors involving the teacher that influence the effectiveness of STEM professional programs, namely the teacher's motivation, attitude, commitment, and self-efficacy (Table 5). The analysis showed that four articles focused on teachers' motivation when participating in STEM professional programs and its relationship with their learning (Aguirre-Muñoz & Pando, 2021; Asempapa & Love, 2021; Berisha & Vula, 2021; Ng & Park, 2021). Berisha and Vula (2021) stated that teachers' motivation regarding professional programs is crucial, as it can influence their enthusiasm and intent to implement the skills and strategies learned throughout the program. Highly motivated teachers are more likely to apply knowledge gained through such programs to help their students overcome the challenges in learning mathematics within STEM (Aldahmash et al., 2019).

An additional four articles discussed teacher attitudes during STEM professional development programs (Aldahmash et al., 2019; Brown et al., 2019; Maass & Engeln, 2019; Thibaut et al., 2018). We strongly believe teachers' attitudes play an essential role in implementing effective professional development programs. For instance, Thibaut et al. (2018) argued that positive changes in teachers' attitudes towards STEM professional programs could contribute to better outcomes, and teachers' perceptions before attending the program would be an indicator that might influence the effectiveness of these programs. Moreover, six articles discussed teachers' commitment to implementing in their classrooms what they learned during STEM professional programs (Araya, 2021; Brown & Bogiages, 2017; Diego-Mantecon et al., 2021; Kareemee et al., 2019; Owens et al., 2019; Prodromou & Lavicza, 2017). Along the same lines, Owens et al. (2019) argued that teachers must be committed to changing teaching practices to improve student learning. Six articles highlighted the teachers' self-efficacy when teaching STEM (Baker & Galanti, 2017; Chai et al., 2020; Gardner et al., 2019; Nesmith & Cooper, 2019; Thomson et al., 2020; Velasco et al., 2020; Velasco et al., 2020; Velasco et al., 2020) According to Gardner et al. (2019) and Saadati et al. (2021), self-efficacy refers to teachers' perceptions of their ability to deliver STEM

Table 5: Teacher factors that influence STEM professional programs

Factor	*Frequency*	*Article*
Motivation	4	Asempapa and Love (2021); Aguirre-Muñoz and Pando (2021); Berisha and Vula (2021); Ng and Park (2021);
Attitude	4	Aldahmash et al. (2019); Brown et al. (2018); Maass and Engeln (2019); Thibaut et al. (2017);
Commitment	6	Araya (2021); Brown and Bogiages (2017); Diego-Mantecon, et al. (2021); Owens et al. (2019); Prodromou and Lavicza (2017); Kareemee et al. (2019);
Self-efficacy	6	Baker and Galanti (2017); Chai et al. (2020); Gardner et al. (2019); Nesmith and Cooper (2019); Thomson et al. (2019); Velasco et al. (2022)

teaching due to effective professional development programs, which also influences student learning goals.

An effective professional program also requires teachers to integrate the relevant STEM education strategies into their teaching practice (Owens et al., 2019). Committed teachers realize that professional programs will help them improve their students' mathematical achievement and always implement meaningful learning sessions in the classroom. The success and effectiveness of a professional program is also highly dependent on the positive attitude of teachers towards developing their knowledge and skills during the program (Chai et al., 2020; Darling-Hammond et al., 2017). A positive attitude will boost teachers' confidence in becoming committed mathematics teachers capable of implementing integrated STEM education.

Teacher self-efficacy in integrating STEM in the classroom is another factor that should be considered when designing a teacher professional program. Gardner et al. (2019) claimed this factor is very important because teachers with a high level of self-efficacy allow themselves to gain confidence to facilitate their learning during a program. In other words, when teachers are confident in their potential to teach and acquire knowledge that can improve and develop their teaching practices, they will be motivated to participate in professional development programs (Thomson et al., 2020). New approaches to teaching and learning mathematics within STEM in the classroom are only effective when a teacher desires to transform their teaching practices, and professional programs only affect a teacher's knowledge and skills to the extent that they will allow this.

Conclusions

The integration of STEM into mathematics teaching and learning is dependent on motivated, committed, and positive teachers who have high self-efficacy. To improve the quality of mathematics teachers, professional programs specific to STEM need to be implemented and developed comprehensively. Teacher professional development, especially in mathematics education, is one of the major routes for teachers to innovate in teaching practices. Professional development should be an ongoing process that seeks to meet the latest student learning needs in the 21st century. The results of professional programs for STEM education in most developed countries indicate that quality STEM teaching connects mathematics with meaningful daily life scenarios. However, the success of integrated STEM not only depends on improving the quality of education alone: every student must be committed and strive to form a positive identity in all aspects. This systematic literature review demonstrated that professional programs for STEM education among mathematics teachers significantly affect teachers' knowledge and skills, teachers' teaching practices, and student learning outcomes. We also urge stakeholders, such as policymakers or school administrators, to pay more attention to the impact and factors that contribute to teacher learning outcomes by considering the design types of professional programs.

There should be future studies that conduct more extensive and in-depth analyses of various professional programs for STEM education involving mathematics teachers, such as teacher group-based programs, teacher collaboration programs, or professional development in teacher communities. Additional factors other than those examined in this review also need to be explored to determine their significance. Thus, it is suggested that a more detailed analysis should be conducted to understand the impact of the factors influencing the effectiveness of STEM professional programs on mathematics teachers. In addition, future studies should also focus on the measurable increases and improvements in teacher knowledge in STEM that professional programs provide. Moreover, most studies only reported general findings of teacher learning outcomes after implementing the programs. Therefore, future researchers should investigate the nature of teachers' practices by examining the impact of STEM professional programs on individuals, groups of teachers, and schools.

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References

*(*References marked with an asterisk indicate the study was included in the systematic literature review)*

Academy of Sciences Malaysia. (2018). *Science outlook: Converging towards progressive Malaysia 2050* (Version 2).

*Aguirre-Muñoz, Z., & Pando, M. (2021). Conceptualizing STEM teacher professional knowledge for teaching ELs: Initial impact of subject matter and disciplinary literacy PD on content knowledge and practice. *Bilingual Research Journal*, *44*(3), 335–359. https://doi.org/10.1080/15235882.2021.1970654

*Aldahmash, A. H., Alamri, N. M., Aljallal, M. A., & Bevins, S. (2019). Saudi Arabian science and mathematics teachers' attitudes toward integrating STEM in teaching before and after participating in a professional development program. *Cogent Education*, *6*, Article 1580852. https://doi.org/10.1080/2331186X.2019.1580852

Al Salami, M. K., Makela, C. J., & de Miranda, M. A. (2015). Assessing changes in teachers' attitudes toward interdisciplinary STEM teaching. *International Journal of Technology and Design Education*, *27*(1), 63–88. https://doi.org/10.1007/s10798-015-9341-0

*Araya, R. (2021). Enriching elementary school mathematical learning with the steepest descent algorithm. *Mathematics*, *9*, Article 1197. https://doi.org/10.3390/math9111197

*Asempapa, R. S., & Love, T. S. (2021). Teaching math modeling through 3D-printing: Examining the influence of an integrative professional development. *School Science and Mathematics*, *121*(2), 85–95. https://doi.org/10.1111/ssm.12448

*Baker, C. K., & Galanti, T. M. (2017). Integrating STEM in elementary classrooms using model-eliciting activities: Responsive professional development for mathematics coaches and teachers. *International Journal of STEM Education*, *4*(10), 1–15. https://doi.org/10.1186/s40594-017-0066-3

*Berisha, F., & Vula, E. (2021). Developing pre-service teachers conceptualization of STEM and STEM pedagogical practices. *Frontiers in Education*, *6*, Article 585075. https://doi.org/10.3389/feduc.2021.585075

Beswick, K., & Fraser, S. (2019). Developing mathematics teachers' 21st-century competence for teaching in STEM contexts. *ZDM – Mathematics Education*, *51*(6), 955–965. https://doi.org/10.1007/s11858-019-01084-2

*Brown, B. A., Boda, P., Lemmi, C., & Monroe, X. (2019). Moving culturally relevant pedagogy from theory to practice: Exploring teachers' application of culturally relevant education in science and mathematics. *Urban Education*, *54*(6), 775–803. https://doi.org/10.1177/0042085918794802

*Brown, R. E., & Bogiages, C. A. (2017). Professional development through STEM integration: How early career math and science teachers respond to experiencing integrated STEM tasks. *International Journal of Science and Mathematics Education*, *17*(1), 111–128. https://doi.org/10.1007/s10763-017-9863-x

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. National Science Teachers Press.

*Chai, C. S., Rahmawati, Y., & Jong, M. S. Y. (2020). Indonesian science, mathematics, and engineering preservice teachers' experiences in STEM-TPACK design-based learning. *Sustainability (Switzerland)*, *12*, Article 9050. https://doi.org/10.3390/su12219050

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017, June 5). Effective teacher professional development. *Learning Policy Institute*. https://learningpolicyinstitute.org/product/teacher-prof-dev

*Diego-Mantecon, J. M., Prodromou, T., Lavicza, Z., Blanco, T. F., & Ortiz-Laso, Z. (2021). An attempt to evaluate STEAM project-based instruction from a school mathematics perspective. *ZDM – Mathematics Education*, *53*(5), 1137–1148. https://doi.org/10.1007/s11858-021-01303-9

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education, 3*(1), 1–8. https://doi.org/10.1186/s40594-016-0036-1

English, L. D. (2017). Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education, 15*(1), 5–24. https://doi.org/10.1007/s10763-017-9802-x

English, L. D., & King, D. (2019). STEM integration in sixth grade: Designing and constructing paper bridges. *International Journal of Science and Mathematics Education, 17*(5), 863–884. https://doi.org/10.1007/s10763-018-9912-0

Erdogan, N., & Stuessy, C. L. (2022). Applying an ecology metaphor in a mixed methods analysis of high school science program infrastructure. *Journal of Education in Science, Environment, and Health*, *8*(1), 86–97. https://doi.org/10.21891/jeseh.1029468

*Gardner, K., Glassmeyer, D., & Worthy, R. (2019). Impacts of STEM professional development on teachers' knowledge, self-efficacy, and practice. *Frontiers in Education*, *4*, Article 26. https://doi.org/10.3389/feduc.2019.00026

Gast, I., Schildkamp, K., & van der Veen, J. T. (2017). Team-based professional development interventions in higher education: A systematic review. *Review of Educational Research*, *87*(4), 736–767. https://doi.org/10.3102/0034654317704306

*Kareemee, S., Suwannatthachote, P., & Faikhamta, C. (2019). Guidelines for online PLC with a lesson study approach to promote STEM education. *Journal of Behavioral Science*, *14*(3), 32–48.

Lynch, K., Hill, H. C., Gonzalez, K. E., & Pollard, C. (2019). Strengthening the research base that informs STEM instructional improvement efforts: A meta-analysis. *Educational Evaluation and Policy Analysis*, *41*(3), 260–293. https://doi.org/10.3102/0162373719849044

*Maass, K., & Engeln, K. (2019). Professional development on connections to the world of work in mathematics and science education. *ZDM – Mathematics Education*, *51*(6), 967–978. https://doi.org/10.1007/s11858-019-01047-7

Maass, K., Geiger, V., Ariza, M. R., & Goos, M. (2019). The role of mathematics in interdisciplinary STEM education. *ZDM – Mathematics Education*, *51*(6), 869–884. https://doi.org/10.1007/s11858-019-01100-5

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, *6*(1), 1–16. https://doi.org/10.1186/s40594-018-0151-2

Miles, M. B., Huberman, M. A., & Saldana, J. (2019). *Qualitative data analysis: A methods sourcebook* (4th ed.). SAGE.

Mohamad Hasim, S., Rosli, R., Halim, L., Capraro, M. M., & Capraro, R. M. (2022). STEM professional development activities and their impact on teacher knowledge and instructional practices.

Mathematics, *10*(7), Article 1109. http://doi.org/10.3390/math10071109

Moh'd, S. S., Uwamahoro, J., Joachim, N., & Orodho, J. A. (2021). Assessing the level of secondary mathematics teachers' pedagogical content knowledge. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(6), 1–11. https://doi.org/10.29333/ejmste/10883

*Nesmith, S. M., & Cooper, S. (2019). Engineering process as a focus: STEM professional development with elementary STEM-focused professional development schools. *School Science and Mathematics*, *119*(8), 1–12. https://doi.org/10.1111/ssm.12376

*Ng, O. L., & Park, M. (2021). Using an enhanced video-engagement innovation to support STEM teachers' professional development in technology-based instruction. *Educational Technology and Society*, *24*(4), 193–204.

*Owens, D. C., Herman, B. C., Oertli, R. T., Lannin, A. A., & Sadler, T. D. (2019). Secondary science and mathematics teachers' environmental issues engagement through socioscientific reasoning. *Eurasia Journal of Mathematics, Science and Technology Education*, *15*(6), 1–27. https://doi.org/10.29333/ejmste/103561

Petticrew, M., & Roberts, H. (2006). *Systematic reviews in the social sciences: A practical guide*. Blackwell Publishing. https://doi.org/10.1002/9780470754887

*Prodromou, T., & Lavicza, Z. (2017). Integrating technology into mathematics education in an entire educational system – Reaching a critical mass of teachers and schools. *International Journal of Technology in Mathematics Education*, *24*(3), 192–135. https://doi.org/10.1564/tme

Rahman, N. A., Rosli, R., & Rambely, A. S.. (2021). Mathematical teachers' knowledge of STEM-based education. *Journal of Physics: Conference Series*, *1806*(1), Article 012216. https://doi.org/10.1088/1742-6596/1806/1/012216

Saadati, F., Chandia, E., Cerda, G., & Felmer, P. (2021). Self-efficacy, practices, and their relationships; the impact of a professional development program for mathematics teachers. *Journal of Mathematics Teacher Education*. Advance online publication. https://doi.org/10.1007/s10857-021-09523-2

Siregar, N. C., Rosli, R., Maat, S. M., & Capraro, M. M. (2019). The effect of science, technology, engineering and mathematics (STEM) program on students' achievement in mathematics: A meta-analysis. *International Electronic Journal of Mathematics Education*, *15*(1), 1–12. https://doi.org/10.29333/iejme/5885

Srikoom, W., Hanuscin, D., & Faikhamta, C. (2017). Perceptions of in-service teachers toward teaching STEM in Thailand. *Asia-Pacific Forum on Science Learning and Teaching*, *18*(2), 1–24.

Stohlmann, Micah (2019). Three modes of STEM integration for middle school mathematics teachers. *School Science and Mathematics*. *119*(5), 287–296. doi:10.1111/ssm.12339

*Thibaut, L., Knipprath, H., Dehaene, W., & Depaepe, F. (2018). How school context and personal factors relate to teachers' attitudes toward teaching integrated STEM. *International Journal of Technology and Design Education*, *28*(3), 631–651. https://doi.org/10.1007/s10798-017-9416-1

*Thomson, M. M., Walkowiak, T. A., Whitehead, A. N., & Huggins, E. (2020). Mathematics teaching efficacy and developmental trajectories: A mixed-methods investigation of novice K-5 teachers. *Teaching and Teacher Education*, *87*, Article 102953. https://doi.org/10.1016/j.tate.2019.102953

*Velasco, R. C. L., Hite, R., & Milbourne, J. (2022). Exploring advocacy self-efficacy among K-12 STEM teacher leaders. *International Journal of Science and Mathematics Education*, *20*(3), 453–457. https://doi.org/10.1007/s10763-021-10176-z

York, M. K. (2018). STEM content and pedagogy are not integrated. Grand Challenges White Papers. https://bit.ly/34Akc33lor.pdf