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Review article

STEM professional development programs for science and mathematics primary school teachers: A systematic literature review

Afizal Abd Ghani [1]
0000-0001-6702-0864

Roslinda Rosli [1*]
0000-0001-7962-8420

Zanaton Iksan [1]
0000-0002-2798-3006

Lilia Halim [1]
0000-0003-2746-2021

Kamisah Osman [1]
0000-0003-4734-8031

Siti Mistima Maat [1]
0000-0002-5507-9081

Siti Nur Diyana Mahmud [1]
0000-0001-6398-1166

Muhammad Sofwan Mahmud [1]
0000-0002-0504-4622

Azmin Shah Rambely [2]
0000-0001-7541-7626

Ah Nam Lay [3]
0000-0003-2214-8252

[1] Faculty of Education, The National University of Malaysia, Bangi, MALAYSIA
[2] School of Mathematical Sciences, The National University of Malaysia, Bangi, MALAYSIA
[3] Ministry of Education Malaysia, Putrajaya, MALAYSIA
[*] Corresponding author: roslinda@ukm.edu.my

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ABSTRACT

In order to compete worldwide, the school system must be transformed by raising educational standards by implementing the science, technology, engineering, and mathematics (STEM) education approach. The purpose of the primary school curriculum is closely aligned with the teaching goals of STEM education, which is to develop each child's full potential, foster an interest in learning and promote children to develop skills in life. Training qualified science and mathematics primary teachers through professional development (PD) programs is necessary to raise young children who are knowledgeable and skilled in STEM. Therefore, a systematic literature review examined the significance and implementation of STEM PD programs for science and mathematics primary school teachers. The Scopus and Web of Science databases were utilized to find articles written and published between 2018 and 2022. This review gathered 22 articles and produced 14 subthemes under the main themes: Significance and the implementation of STEM PD for primary school teachers. Recommendations for further research are stated at the end of this paper.

Keywords: STEM education, primary school, professional development, systematic literature review, teacher education

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) education should start in primary school and prepare students for active engagement in the future (Kurup et al., 2019). This early experience is expected to influence and foster a deep and ongoing interest in STEM (Kurup et al., 2017). A new curriculum approach needs to be emphasized from the very beginning, especially in primary education, to produce students who are ready to face the challenges and demands of the global market that prioritizes STEM in the real world (Anagun et al., 2020; Corp et al., 2020).

Chai (2018) believes that primary education should prioritize STEM education since it may assist children in building their understanding and enthusiasm for STEM learning at a young age and overcoming misconceptions about STEM learning. Srikoom et al. (2017) stated that students begin to form perceptions and knowledge of STEM before and during their primary education. This shows the importance of STEM teaching; the learning process starts at the primary level. This is supported by Williams (2019), who contends that teaching STEM subjects in the primary grades offers a solid basis for middle and high school students to be prepared for STEM-related careers.

Teachers must make interdisciplinary connections by revising their teaching approach, such as inquiry-based teaching (D'Acunto et al., 2018), for students to understand multiple disciplines (Capone, 2021). However, integrating STEM into the primary school curriculum faces significant challenges as primary school teachers lack diverse knowledge and skills in various STEM disciplines apart from their subject knowledge (Corrigan, 2020; Wahono & Chang, 2019). For instance, an inadequate understanding of engineering and technology will affect their ability to carry out the integrated STEM activities (Corp et al., 2020), which would fail to promote STEM to primary school students (Anagun et al., 2020). It makes students disinterested in science and mathematics, as these subjects are often taught separately without being linked to real-world applications (English, 2017). Thus, primary school teachers require a strong foundation on how STEM integration should be introduced into existing primary school curriculum specifications (Delahunty et al., 2021).

Professional development (PD) has always been considered specialized instruction provided by some educational experts at a specific time and location (Guskey, 2002). Teacher PD is the primary key to improving the quality of education (Capone et al., 2022; Desimone, 2011). The role of teachers is not only to convey student performance information but also to decide the progress of the education transformation (Mohd Shahali et al., 2018). A significant focus in schools may occur through teams of teachers working together in an integrated strategy centered on teaching and learning across the curriculum to generate a motivated and talented generation in STEM (Kurup et al., 2019).

Teachers' meaningful experience can shape their knowledge and attitudes in applying STEM integration in the classroom (Burton, 2022; Wei & Maat, 2020). Therefore, there is a strong need for primary school teachers to engage in meaningful professional learning. Primary school teachers typically have less expertise and feel less prepared, especially involving subjects in the STEM disciplines (Goodnough, 2019).

According to Baker and Galanti (2017), there still needs to be more studies on the effectiveness of PD support required by science and mathematics primary school teachers in helping them carry out STEM integration in the classroom. This is supported by Chai (2018), who states that research on STEM PD for primary education still needs to be completed. Thus, in this present study, we aim to provide a systematic review of STEM research to understand the significance of STEM PD programs for science and mathematics teachers at the primary school level.

Table 1. Search strings

Database	Search strings
Scopus	TITLE-ABS-KEY (("professional development" OR "professional workshop" OR "professional growth" OR "workshop" OR "smart building" OR "resource* and support") AND ("stem" OR "science, technology, engineering and mathematics") AND ("primary school" OR "elementary school" OR "primary grade" OR "elementary grade" OR "elementary teacher*" OR "primary teacher*" OR "elementary education" OR "primary education"))
Web of Science	TS=(("professional development" OR "professional workshop" OR "professional growth" OR "workshop" OR "smart building" OR "resource* and support") AND ("stem" OR "science, technology, engineering and mathematics") AND ("primary school" OR "elementary school" OR "primary grade" OR "elementary grade" OR "elementary teacher*" OR "primary teacher*" OR "elementary education" OR "primary education"))

Table 2. Selection criteria

Criteria	Inclusion	Exclusion
Language	English	Non-English
Year of publication	Between 2018-2022	Before 2018
Type of paper	Journal (only research articles)	Journal (book chapter & conference proceeding)
Subject area	Science social & STEM education	Besides social science & STEM education

METHODOLOGY

This study utilizes a systematic literature review (SLR) as a research method, specifically consisting of a review protocol determining the topic to be investigated and the approach adopted during the subsequent review. An SLR is a form of research that requires generating clear research questions by using systematic and explicit methods in identifying, selecting, evaluating, collecting, and analyzing data from relevant past studies (Moher et al., 2009). The selection of this SLR method is based on the fact that it can help to synthesize all the academic literature related to the topic in depth. In selecting some empirical studies suitable for this report, a detailed and systematic review and analysis was carried out with the guidance of preferred reporting items for systematic reviews and meta-analyses (PRISMA). The PRISMA guidelines consist of a four-phase flow diagram that outlines essential items for transparency in conducting a literature review (Liberati et al., 2009).

This study examined, analyzed, and synthesized selected and relevant articles on STEM PD programs provided to science and mathematics primary school teachers. The chosen articles were analyzed in depth to achieve the research objective: examine available STEM PD programs. To aid science and mathematics primary school teachers in implementing STEM education, we also read how the programs were created and executed to help teachers integrate STEM content during classroom instruction. The review used the Scopus and Web of Science (WoS) databases. The use of these two databases is consistent with the recommendations by Xiao and Watson (2017), who state that another database will accommodate the lack of each database, which can also avoid committing retrieval bias if using only one database for a review (Durach et al., 2017).

Identification

In selecting suitable and appropriate articles for this study, a detailed and systematic review and analysis were carried out, consisting of three main phases. The first step was the identification of keywords and similar terms based on a thesaurus, dictionary, encyclopedia, and previous empirical research. Then, after all the relevant keywords were decided, search strings in the Scopus and WoS databases (see **Table 1**) were established. In the first step of the systematic review process, we successfully retrieved 185 articles from both databases.

Screening and Eligibility

The initial step in this phase was to identify articles with the same title and content from both the Scopus and WoS databases. From the 185 articles obtained in the first phase, only 121 unique and distinctive articles were used for further evaluation. In this eligibility phase, several criteria were set to ensure the acquisition of genuinely relevant articles coinciding with the study context. A summary of the article selection criteria is shown in **Table 2**.

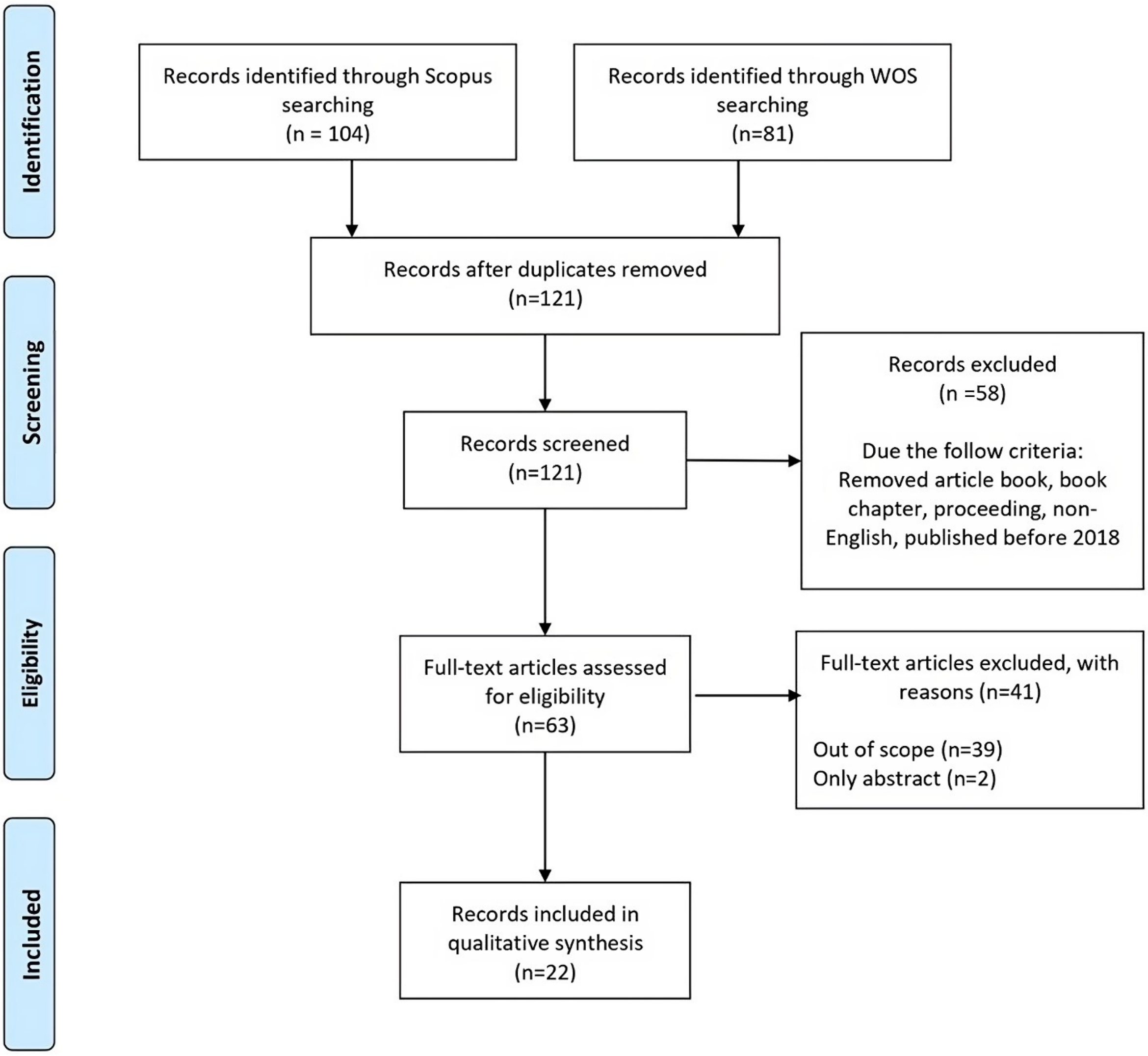

Figure 1. PRISMA flow diagram (Adapted from Moher et al., 2009)

First, the type of literature selected included articles from various indexed journals with empirical data, excluding systematic review articles, book series, books, book chapters, and conference proceedings. The second criterion, the focus of the systematic review, was on journal articles written in English to overcome any problems in the interpretation of meaning that could be clearer. Third, researchers must focus on publication timelines because we cannot review all articles published in an undefined timeline (Mohamed Shaffril et al., 2021). This review restricted the screening method only to include the publications published between 2018 and 2022 in consideration of the idea of "research field maturity" stressed by Kraus et al. (2020). This time frame was selected because there was enough published research for in-depth analysis. In the final part of the inclusion and exclusion process, the researchers focused on STEM PD programs involving in-service and pre-service science and mathematics teachers at the primary school level. In this final process, 41 articles were rejected, considering that the content was outside the scope of the study. This final phase produced 22 unique articles that were used in this study. The selection process is summarized in a PRISMA flow chart in **Figure 1**.

Data Abstraction and Analysis

A total of 22 gathered articles were studied and reviewed. To ensure quality in the article selection process and the themes set, the first researcher collaborated with one of the team members to evaluate the articles. After selecting 22 articles, a discussion was conducted to revise and ensure that the selection process coincided with and met the criteria related to the study context. Themes and subthemes were identified by

Table 3. Themes & subthemes of STEM professional development

Authors	Importance of STEM PD								Focus of STEM PD					
	SI	LK	MC	SKD	LR	TM	TAB	PL	PC	PjBL	PBL	IL	CT	IS
Araya (2021)				√									√	
Arrington and Willox (2021)		√			√	√			√		√			√
Capobianco et al. (2018)	√				√	√		√	√		√		√	√
Chen et al. (2020)	√	√	√	√	√		√	√	√	√		√		√
Correia and Baptista (2022)		√	√	√	√	√				√		√		√
Dailey et al. (2018)	√	√	√	√		√	√		√	√	√			√
DeCoito and Myszkal, 2018)	√	√	√	√	√	√	√		√			√		
Fernández-Limón et al. (2018)	√	√	√						√					
Goodnough (2019)		√	√	√			√		√		√	√		
Hamilton et al. (2021)	√	√		√	√	√	√		√	√				√
Havice et al. (2018)		√					√	√	√	√	√			√
Hourigan et al. (2021)		√	√						√			√		√
Kaderavek et al. (2020)	√	√		√		√		√	√			√		√
Lee et al. (2021)		√		√		√	√	√	√			√		
Mangiante and Gabriele-Black (2020)		√	√				√	√	√	√	√			√
Nesmith & Cooper (2019)	√	√	√	√			√		√	√		√		√
Pleasants et al. (2020)		√	√		√		√	√	√					√
Porter et al. (2019)		√		√	√	√	√	√	√				√	√
Rich et al. (2020)		√			√			√					√	
Silvestri et al. (2019)	√	√							√	√				√
Suebsing and Nuangchalerm (2021)		√			√	√	√	√						
Turner et al. (2021)	√	√		√	√	√	√	√	√			√		√

Note. SI: Student interest; LK: Lack of knowledge; MC: Misconception; SKD: Student knowledge development; LR: Lack of references & resources; TM: Time management; TAB: Teacher attitude & belief; PL: Preparing a lesson; PC: Partnership & collaboration; PjBL: Project-based learning; PBL: Problem-based learning; IL: Inquiry-based learning; CT: Computational thinking; & IS: Integrated skills

reviewing abstracts and in-depth reading of entire articles. Qualitative content analysis identified themes in all 22 articles related to PD programs for science and mathematics primary school teachers. To analyze these selected articles, we used Braun and Clarke's (2006) six-phase thematic analysis, namely:

(a) getting familiar with the data,

(b) generating initial codes,

(c) finding themes,

(d) reviewing themes,

(e) defining and naming themes, and

(f) producing reports.

Using the thematic analysis process allowed us to identify, analyze and report themes from within the data set to interpret various aspects of the research (Braun & Clarke, 2006).

We have used NVivo 12 as analytic software to conduct an inductive thematic analysis to identify themes compatible with the study objectives. We extracted the data, coded it into categories and subcategories, and then constructed a table to link them to produce related themes and subthemes. The coded themes and subthemes were compared between researchers regarding similarities and differences to achieve the study's objectives. A summary of the thematic analysis is shown in **Table 3**.

RESULTS

Significance of STEM Professional Development for Primary School Teachers

Develop students' interest in STEM

It is crucial to nurture primary school students' interest in STEM professions through STEM education (Chen et al., 2020). Consequently, 11 studies suggested that the formation of student interest is one of the factors that make STEM PD programs important for science and mathematics primary school teachers (Capobianco et al., 2018; Chen et al., 2020; Dailey et al., 2018; DeCoito & Myszkal, 2018; Fernández-Limón et al., 2018; Hamilton et al., 2021; Kaderavek et al., 2020; Lee et al., 2021; Nesmith & Cooper, 2019; Silvestri et al., 2019; Turner et al., 2021). Early engagement in STEM activities at primary school may promote study interest in STEM areas (Chen et al., 2020; Kaderavek et al., 2020), and it will support students as they go through school and make decisions about prospective STEM careers (Hamilton et al., 2021; Nesmith & Cooper, 2019). Additionally, STEM activities carried out by competent teachers can help form motivation among students to learn STEM subjects and further develop their interest in the STEM field (Hamilton et al., 2021; Silvestri et al., 2019).

Primary students' interest in STEM is often linked to their curiosity and participation in school activities, whether they consider these activities interesting, thrilling, or fun (Turner et al., 2021). Therefore, it is challenging for science and mathematics primary school teachers to plan STEM lessons and activities to attract interest and motivate students (Lee et al., 2021). Among the activities indicated that can assist teachers in raising students' interest in STEM are understanding STEM careers through the involvement of experts such as engineers and scientists (Dailey et al., 2018), organizing programs, courses, camps, or engineering clubs (DeCoito & Myszkal, 2018; Fernández-Limón et al., 2018; Silvestri et al., 2019); and collaborative projects with universities, schools, and industry (Capobianco et al., 2018). Primary school teachers should provide meaningful experiences related to theory and practicality within STEM so they can integrate the subjects effectively.

Lack of knowledge in STEM education

Primary students can participate in STEM activities directed by professional and informed teachers. Twenty of the research studies stated that many primary teachers, on the other hand, may lack knowledge in teaching STEM and genuinely require a PD program to expand their knowledge and abilities. Many primary school teachers lack the necessary skills and expertise to teach integrated STEM disciplines (Turner et al., 2021) since they usually receive separate training in science or mathematics teaching methods (Fernández-Limón et al., 2018). Several studies showed that primary school teachers are less qualified and knowledgeable, which might reduce their effectiveness in implementing STEM (DeCoito & Myszkal, 2018; Nesmith & Cooper, 2019). As a result, primary school teachers have difficulty accepting non-traditional teaching practices (Correia & Baptista, 2022) and organizing and designing their STEM lessons (Hamilton et al., 2021; Rich et al., 2020). Thus, primary school teachers require additional support in increasing their STEM knowledge and assisting them in implementing STEM integration in their lessons as well as developing their belief in teaching STEM (Arrington & Willox, 2021; Chen et al., 2020; Hamilton et al., 2021; Havice et al., 2018; Hourigan et al., 2021; Lee et al., 2021).

There is still a lack of PD or preparation programs for primary school teachers that will assist them in implementing STEM teaching practices (Dailey et al., 2018; Kaderavek et al., 2020; Pleasants et al., 2020; Silvestri et al., 2019). According to Mangiante and Gabriele-Black (2020), due to a lack of expertise and training in engineering design, primary school teachers need help in integrating engineering practices into their lessons. The engagement of primary school teachers in STEM PD programs can assist teachers in determining the best ways and processes for integrating STEM subjects into their lessons (Silvestri et al., 2019).

Furthermore, adopting a student-centered approach and inquiry-based learning in the teaching and learning of STEM subjects is perceived by primary school teachers as problematic due to a lack of knowledge and abilities (Goodnough, 2019; Porter et al., 2019). The experience gained in the PD program helps teachers see teaching as a holistic process that allows them to integrate disciplines without being bound by traditional education (Suebsing & Nuangchalerm, 2021). Since no certification is needed to teach STEM subjects, ongoing STEM PD is essential for enhancing teachers' understanding and ability to integrate STEM disciplines (Mangiante & Gabriele-Black, 2020).

Misconception and misunderstanding of STEM

Ten of the studies stated that many conceptual errors and misunderstandings in the learning of STEM education need to be overcome through STEM PD. Even though STEM education has advanced over the past ten years, many differences exist in conceptualizing it (Goodnough, 2019). Integrative STEM education and inquiry-based learning still need to be better understood today due to requiring more preparation or having limited knowledge of what interactive STEM learning entails (DeCoito & Myszkal, 2018). According to Hourigan et al. (2021), among the examples of misunderstanding is when a learning activity only uses one discipline, but the teacher interprets it as a STEM learning activity. These misconceptions and prejudices are incredibly harmful because they prevent STEM learning from happening effectively. After all, teachers who have such beliefs may have a detrimental impact on their pupils (Pleasants et al., 2020). The weak confidence and knowledge level among primary school teachers often causes misunderstandings involving the engineering discipline (Nesmith & Cooper, 2019), indirectly affecting students' understanding of those fields (Chen et al., 2020; Mangiante & Gabriele-Black, 2020).

The misconception and misunderstanding may be solved by having teachers participate in a meaningful PD program to gain accurate knowledge that can then be used to support students' learning about STEM (Correia & Baptista, 2022; Mangiante & Gabriele-Black, 2020). Engaging primary school teachers in STEM PD may provide them with skills for personal growth, improve their social environment and equip them to challenge traditional educational strategies (DeCoito & Myszkal, 2018; Fernández-Limón et al., 2018). Consequently, STEM activities created under the direction of experts through STEM PD will enable primary school teachers to acquire more accurate information about STEM (Chen et al., 2020). Like those in STEM PD, informal learning opportunities can address false ideas and stereotypes about STEM fields and offer rewarding experiences (Dailey et al., 2018).

Fostering primary school students' knowledge development

Twelve of the studies state the importance of STEM PD to the development of primary school students' knowledge (Araya, 2021; Chen et al., 2020; Correia & Baptista, 2022; Dailey et al., 2018; DeCoito & Myszkal, 2018; Goodnough, 2019; Hamilton et al., 2021; Kaderavek et al., 2020; Lee et al., 2021; Nesmith & Cooper, 2019; Porter et al., 2019; Turner et al., 2021). The development of STEM knowledge needs to start from the beginning of children's learning to reduce their knowledge gap (Kaderavek et al., 2020) and indirectly motivate them to learn STEM subjects more effectively (DeCoito & Myszkal, 2018; Hamilton et al., 2021; Turner et al., 2021). Exposure to STEM for students in primary school can help build a positive attitude toward STEM careers, allow them to reject stereotypes towards STEM professions, and inspire them to pursue STEM careers (Chen et al., 2020). For example, teaching primary school pupils about algorithms helps increase their understanding of the value of STEM applications in daily life and their applicability to real-world situations (Araya, 2021). Additionally, it can boost high-level thinking abilities, self-assurance, and competitiveness by emphasizing STEM skills like problem-solving and inquiry (Turner et al., 2021).

Therefore, primary school teachers are the critical support system for increasing children's knowledge and understanding of the value of STEM (Dailey et al., 2018; Lee et al., 2021; Porter et al., 2019). The practice is significant since there is a growing need for STEM-qualified workers globally (Correia & Baptista, 2022; Dailey et al., 2018). STEM learning objectives may be easily attained with the help of experienced and skilled teachers and various teaching techniques, including inquiry-based learning, hands-on activities, and more (DeCoito & Myszkal, 2018; Porter et al., 2019). Consequently, participation in a STEM PD program by primary school teachers can boost their expertise, which in turn will increase the children's understanding, effectiveness, and engagement in STEM (Turner et al., 2021), which will lead to more significant development in STEM careers (Lee et al., 2021). With the experience gained in STEM PD, teachers will also be more committed to helping students and planning more meaningful STEM learning for their students (Goodnough, 2019; Nesmith & Cooper, 2019).

Lack of resources and references

Eleven of the studies discussed the importance of STEM PD programs to overcome the problem of a lack of resources and reference materials for primary school teachers to carry out STEM education in schools (Arrington & Willox, 2021; Capobianco et al., 2018; Chen et al., 2020; Correia & Baptista, 2022; DeCoito & Myszkal, 2018; Hamilton et al., 2021; Pleasants et al., 2020; Porter et al., 2019; Rich et al., 2020; Suebsing & Nuangchalerm, 2021; Turner et al., 2021). Lack of reference resources and support materials for primary school teachers is one of the barriers to STEM implementation, which makes STEM PD crucial for teachers (Arrington & Willox, 2021; Capobianco et al., 2018; Correia & Baptista, 2022; DeCoito & Myszkal, 2018; Hamilton et al., 2021; Porter et al., 2019; Turner et al., 2021). Primary school teachers should be given high-quality teaching resources to help implement STEM instruction due to their need for knowledge and expertise in other disciplines, such as technology and engineering (Correia & Baptista, 2022).

Primary school teachers require reference sources and instructional tools to satisfy the demands of teaching STEM disciplines that require integration. For example, many primary teachers must learn about engineering and pedagogical approaches to include engineering in their lessons (Porter et al., 2019). In addition, the reference resources that present a more complex and in-depth picture of engineering work, on the other hand, can be a reliable source to promote teacher learning (Pleasants et al., 2020). Furthermore, Rich et al. (2020) stated that the lack of reference sources might also cause teachers to have less knowledge in teaching STEM involving computational thinking (CT). In addition, primary school teachers noted a need for reference resources and learning materials to support them in integrating STEM-based education, which brings science, technology, engineering, and mathematics together in an acceptable way (Suebsing & Nuangchalerm, 2021). Primary school teachers may construct and obtain the necessary reference tools and materials to design their STEM lessons by participating in meaningful PD activities (Chen et al., 2020).

Time management in STEM teaching

Ten studies discuss the importance of STEM PD in helping teachers plan and manage time well. Among the challenges primary school teachers face is insufficient teaching time to plan STEM lessons (Capobianco et al., 2018; Correia & Baptista, 2022; Lee et al., 2021; Porter et al., 2019; Turner et al., 2021). As they needed help controlling their time while designing STEM classes, teachers were found to refuse to implement the STEM integration strategy (Arrington & Willox, 2021; Hamilton et al., 2021; Porter et al., 2019). In addition, the challenge in applying STEM is also seen through the limited amount of instructional time (Capobianco et al., 2018; DeCoito & Myszkal, 2018; Hamilton et al., 2021; Suebsing & Nuangchalerm, 2021).

Therefore, Hamilton et al. (2021) and Kaderavek et al. (2020) suggested increasing teaching time involving STEM disciplines to help teachers plan STEM lessons better. Integrating STEM disciplines in primary schools requires sufficient time so that the understanding students should receive is not affected (Dailey et al., 2018). With adequate knowledge and the correct information, teachers can plan and design meaningful STEM lessons for students (Porter et al., 2019). Participation in STEM PD programs can help primary school teachers become better time managers so they can integrate STEM into their lessons (Arrington & Willox, 2021; Hamilton et al., 2021; Porter et al., 2019)

Development of attitudes and beliefs of primary school teachers

The attitudes and beliefs of primary school teachers are among the ambiguous factors that may make it challenging to ensure that the objectives of STEM education are achieved. Thirteen of the studies argue about the attitudes and beliefs of primary school teachers towards the implementation of STEM and that this needs to be addressed through the involvement of teachers in STEM PD programs (Chen et al., 2020; Dailey et al., 2018; DeCoito & Myszkal, 2018; Goodnough, 2019; Hamilton et al., 2021; Havice et al., 2018; Lee et al., 2021; Mangiante & Gabriele-Black, 2020; Nesmith & Cooper, 2019; Pleasants et al., 2020; Porter et al., 2019; Suebsing & Nuangchalerm, 2021; Turner et al., 2021).

Many primary school teachers have weak knowledge, attitudes, and beliefs about teaching subjects in the STEM disciplines (Dailey & Robinson, 2017; Goodnough, 2019; Nesmith & Cooper, 2019) because they did not get enough knowledge during their undergraduate studies (Turner et al., 2021). Access to PD programs throughout their teaching career may also contribute to the unpreparedness of primary school teachers to teach STEM (Goodnough, 2019). Porter et al. (2019) stated that many primary school teachers know the importance of integrating engineering into the curriculum. However, many still need to become more familiar with engineering and feel less confident in their ability to teach it.

A teacher must not only be an expert in their subject area but also have faith in their capacity to teach STEM to achieve the goal of STEM education (DeCoito & Myszkal, 2018). Support such as a STEM PD program needs to be given to primary school teachers to help them design STEM learning through increased knowledge and integration skills and eventually increase their confidence in involving students in STEM learning (DeCoito & Myszkal, 2018; Hammersley & Traianou, 2012; Nesmith & Cooper, 2019). In conjunction, effective STEM implementation calls on teachers to be prepared and able to employ STEM teaching strategies in the classroom, which is strongly impacted by the teacher's beliefs and experience (Mangiante & Gabriele-Black, 2020).

Primary school teachers' participation in STEM PD programs may foster the growth of their knowledge, attitudes, and beliefs about implementing STEM in their lessons (DeCoito & Myszkal, 2018; Hamilton et al., 2021; Lee et al., 2021; Porter et al., 2019). In addition, STEM PD is also seen to increase teachers' confidence and efficiency in designing meaningful STEM lessons for primary school students by implementing various STEM learning strategies (Havice et al., 2018; Turner et al., 2021). The STEM PD program's success also impacts primary school teachers' perceptions of STEM learning concepts and activities (Hamilton et al., 2021; Pleasants et al., 2020; Suebsing & Nuangchalerm, 2021). Participation in a STEM PD program also encourages the innovative thinking of primary school teachers in designing teaching and developing a positive attitude to create the best STEM lessons (Dailey et al., 2018).

Implementation of STEM Professional Development for Primary School Teachers

Planning and developing lessons based on STEM education

Primary school teachers need to know how to design their classroom activities to fit the nature of STEM learning. We found 11 studies that made the creation and development of lessons a goal in their STEM PD (Capobianco et al., 2018; Chen et al., 2020; Havice et al., 2018; Kaderavek et al., 2020; Lee et al., 2021; Mangiante & Gabriele-Black, 2020; Pleasants et al., 2020; Porter et al., 2019; Rich et al., 2020; Suebsing & Nuangchalerm, 2021; Turner et al., 2021). Havice et al. (2018) said that the Integrative STEM Education Institute organized a STEM PD program and carried out activities by assisting primary school teachers in developing integrative STEM lessons for use in the classroom. The practice is consistent with STEM PD in a study by Turner et al. (2021), which focused on assisting teachers in creating lessons for the existing curriculum incorporating the STEM field.

In addition, the STEM PD program by Kaderavek et al. (2020) focused on developing classroom teaching plans appropriate for the STEM curriculum with the assistance and support of scientists and university trainers. Meanwhile, in the STEM PD study by Chen et al. (2020), the teachers were guided to plan and design STEM integration activities and teaching aids based on the information and consultation they had collected from experts. Collaboration with experts in the field of engineering, for example, can help teachers build understanding to change and design their teaching to be integrated with engineering (Mangiante & Gabriele-Black, 2020). In Suebsing and Nuangchalerm's (2021) study, teachers constructed a STEM teaching manual guide based on relevant research materials. The experts evaluated and verified the manual to guarantee the content's correctness, the learning activities' structure, the content's validity, and editing. Furthermore, Pleasants et al. (2020) stated that the engineers involved in the STEM PD program in their study spent a day with teachers in the classroom to help plan and shape STEM integration lessons.

During the focused guiding session in the STEM PD research by Lee et al. (2021), there was a reflection session to review lesson planning and teaching, teaching tactics employed in lesson teaching, and student involvement and learning of the targeted topics. In the research by Capobianco et al. (2018), the first activity in the STEM PD concentrated on preparing for teaching by employing the concept of the 'big idea' in creating suitable activities for students. In the STEM PD conducted in the study by Rich et al. (2020), teachers were given teacher-facing tools to assist them in preparing lesson plans by connecting CT skills. Teachers have a real challenge when assessing and integrating many STEM disciplines into a single teaching session, according to Porter et al. (2019), and they often discover that lack of time is why their lesson plans fail. Teachers should know how to design classroom activities to meet the STEM approach's demands (Suebsing & Nuangchalerm, 2021).

Professional learning through partnership and collaboration

Most STEM PD programs strongly emphasize sharing and collaboration events involving teachers, administrators, universities, scientists, engineers, and other groups. According to Arrington and Willox (2021), they collaborated with local STEM non-profits and school district partners to coordinate a summer camp with a week of STEM PD programs. The activity was an excellent opportunity for teachers to collaborate, work and share ideas to teach STEM in their schools. In a study by Hourigan et al. (2021), three groups were involved in

STEM PD programs: three key stakeholders in STEM education, novice teachers, and experienced teachers who had participated in previous PD programs. These key stakeholders were selected based on their established roles in the well-developed landscape of integrated STEM education.

In a study by Mangiante and Gabriele-Black (2020), a teacher group professional learning communities program was utilized to perform teacher PD centered on assessing and analyzing student learning incorporating engineering issues. While in a study by Lee et al. (2021), the STEM PD program had two different trainers: elementary school teachers and secondary school science instructors. The participating primary school teachers discussed with their coaches after engaging in practical lesson modelling exercises. Additionally, primary school teachers and administrators collaborated in the PD program to create STEM-focused teaching and learning tools for their students (Havice et al., 2018; Turner et al., 2021).

Furthermore, the collaboration between the school and the university was vital to teachers' new learning. In a study by Kaderavek et al. (2020), university-based scientists and coaches helped teachers develop lessons based on STEM integration with various topics and pedagogical methods. There was also a STEM PD program for primary school teachers in collaboration with engineering graduate students from a local university (Pleasants et al., 2020), as well as collaboration from mathematics and science faculties from two local universities (Nesmith & Cooper, 2019). Similarly, Hamilton et al. (2021) reported a STEM PD program from the STEM faculty through School-University Partnerships with a small group of primary school teachers. In the study by Porter et al. (2019), the Ohio State University hosted an engineering education PD program for teachers from a low-income urban school district. Teachers were paid and received materials for participating in PD activities. In addition, a study by Silvestri et al. (2019) organized an after-school engineering club (EC) involving teachers, administrators, and engineering and literacy students from local universities to help teachers understand the engineering design process (EDP) teaching practice.

Through the collaboration with a local university in the study by Dailey et al. (2018), they provided opportunities for teachers and engineers to work together to make the subject matter more pertinent while adopting a co-teaching strategy to provide students with first-hand experiences from an engineer working in the field. In a study by Goodnough (2019), the university held a STEM PD program for teachers in collaboration with a local petroleum consortium. According to Chen et al. (2020), the STEM teacher PD program was successful with the involvement of four experts in specific fields such as water engineering, air engineering, and also computer science. PD program in DeCoito and Myszkal (2018) and Fernández-Limón et al. (2018) allowed teachers to connect with scientists and engineers, facilitating the dissemination of scientific information used in real-world contexts. While in the study by Capobianco et al. (2018), the STEM PD program was implemented with the cooperation of three parties: the university, industry, and schools. To ensure students were exposed to more accurate knowledge about various STEM careers, STEM professionals were involved as mentors to help teachers organize STEM activities by offering relevant information about their study fields (Chen et al., 2020).

Project-based learning

One of the approaches taught during the STEM PD program is project-based learning (PjBL). For example, teachers attended educational workshops on STEM-PjBL, where they built toys to address physics concepts with students: force, sound, thermodynamics, and electricity (Correia & Baptista, 2022). Meanwhile, there was STEM PD involving learning activities based on engineering projects as found in the Engineering is Elementary (EiE) curriculum (Chen et al., 2020; Dailey et al., 2018; Hamilton et al., 2021; Mangiante & Gabriele-Black, 2020; Nesmith & Cooper, 2019; Silvestri et al., 2019). For example, in a study by Nesmith and Cooper (2019), the teachers had to design and launch the farthest-traveling air-powered rocket, design and build a zipline carrier and use motion detectors to leverage vocal instructions and actual motions to produce precise time/distance graphs. During STEM PD in the study by Mangiante and Gabriele-Black (2020), teachers were given training and skills to handle several engineering projects, namely designing windmill blades and building bridges.

Teachers can participate in this PjBL activity to investigate and experience this integrated approach and better comprehend the procedure as a student (Mangiante & Gabriele-Black, 2020). In the study by Silvestri et al. (2019), teachers were taught about the engineering-related projects that would be carried out in the EC with the assistance of professionals in the area during the STEM PD program. Direction and teaching from qualified professionals in the STEM field can assist teachers in succeeding in PjBL based on engineering concepts and disciplines (Silvestri et al., 2019). 'Design a shoe' and 'Design a parachute' are two projects that primary school teachers completed while participating in a STEM PD program study (Hamilton et al., 2021). Both projects required engineering disciplines and the integration of science, mathematics, and other subjects into their project design.

Problem-based learning and design thinking

Along with the PjBL approach introduction in STEM PD, a program exposes teachers to problem-based learning (PBL). The opportunity to learn STEM science through PBL activities can stimulate interest and foster curiosity among young learners (Dailey et al., 2018). For example, the study by Havice et al. (2018) used the idea of PjBL and PBL to mix approaches, which allowed students to examine challenges and problems from the real world.

Teachers participating in STEM PD in the study by Mangiante and Gabriele-Black (2020) received instruction on the basics of engineering and technology to be prepared to lead PBL activities for students. For instance, in a study by Capobianco et al. (2018), the STEM PD activity employed a PBL strategy that incorporated real-life situations, requiring teachers to devise solutions and invent methods for slowing a boat down when attempting to catch a large fish. The preparation of real-world problem-solving activities can stimulate students' thinking power. Therefore, teachers should be more prepared to make teaching more meaningful.

Furthermore, in the study by Arrington and Willox (2021), they used the term design thinking approach in the STEM PD program for primary school teachers, where this approach is similar to PBL. In this PD, participants were exposed to a design thinking approach that focuses on problem-solving, including understanding problems, conducting research, brainstorming solutions, designing solution plans based on ideas, prototyping the design, redesigning the prototype, and sharing their progress and learning. Through the approach used in PD, teachers can effectively integrate STEM disciplines into a continuous problem-solving process that allows students to explore, think and learn from each other (Arrington & Willox, 2021). In the study by Goodnough (2019), teachers participating in an ongoing STEM PD program were introduced to a design thinking approach in the Design Thinking and Creativity for STEM workshop. This part of the second-year STEM PD aimed to generate opportunities for PBL, further strengthened by technology, to foster creativity and design thinking.

Inquiry-based learning

Among the approaches introduced and taught to primary school teachers in STEM PD programs was the inquiry-based learning approach. Ten STEM PD programs used an inquiry-based learning approach in their program activities. Hourigan et al. (2021) stated that the inquiry approach introduced to teachers with the involvement of STEM professionals could generate thoughts about STEM careers. For example, inquiry-based activities on nutrition, water, and science experts can help teachers design and implement STEM instruction involving investigative activities with expert guidance and further generate knowledge about how professionals work in the STEM field (Chen et al., 2020).

The inquiry approach introduced can also help teachers instill interest in primary school students to prepare them to continue learning STEM in secondary school (DeCoito & Myszkal, 2018). The inquiry-based approach used in the STEM PD study by Kaderavek et al. (2020) helped teachers experience how an investigation takes place and further helped to form students' high-level thinking. The inquiry approach taught to teachers by Goodnough (2019) helped teachers increase their confidence to teach STEM subjects and address stereotypes towards STEM teaching and learning.

In addition, the other four STEM PD programs used the engage, explore, explain, elaborate, and evaluate (5E) inquiry learning model (Correia & Baptista, 2022; Lee et al., 2021; Nesmith & Cooper, 2019; Turner et al., 2021). The activity in 5E can help teachers build learning activities systematically based on an inquiry-based constructivist approach (D'Acunto et al., 2018). Primary school teachers involved in STEM PD programs recognize the usefulness of 5E to help in the process of planning STEM activities (Correia & Baptista, 2022). Consequently, in the STEM PD program by Nesmith and Cooper (2019), the researchers linked EDP learning experience with the 5E inquiry model for meaningful STEM learning.

Computational thinking and mathematical modelling

One of the focuses in implementing STEM PD for primary school teachers is teaching CT. In the study by Rich et al. (2020), the STEM PD project focused on implementing four CT practices: abstraction, decomposition, debugging, and patterning. The primary school teachers involved in this STEM PD project were given two materials for use; the first was the CT Lesson Screener, created to help teachers recognize the CT components contained in the lesson. Second, the CT Lesson Enhancer was created to assist teachers in designing and implementing courses that would either integrate new possibilities for CT or make current CT concepts clearer (Rich et al., 2020).

Science learning partnership through engineering design program in the study by Capobianco et al. (2018) also used mathematical skills and CT in engineering activities when teachers performed the Door Alarm task. Furthermore, in the study by Araya (2021), a STEM PD workshop was conducted to test the implementation of the steepest descent algorithm in teaching at the primary school level to improve STEM integration and foster CT. The participants also examined whether it could be used to develop activities related to children's real-life experiences. In applied mathematics and STEM fields, the steepest descent algorithm is often utilized. It is also a frequently employed technique in engineering and mathematical modelling and has become a potent CT tool. In addition, it is significant in biology, physics, chemistry, and computer science (Araya, 2021).

Integrating knowledge and skills

Apart from the abovementioned approaches, several others are used in PD programs to apply STEM integration knowledge and skills for primary school teachers. Among others, the focus of STEM PD activities is interdisciplinary skills (Arrington & Willox, 2021; Chen et al., 2020; Correia & Baptista, 2022; Hamilton et al., 2021; Havice et al., 2018; Kaderavek et al., 2020; Turner et al., 2021). For example, using technacy genre theory, STEM PD in the study by Turner et al. (2021) promoted the concept of STEM integration involving all four STEM subjects in their lesson. In addition, the design thinking approach in the study of Arrington and Willox (2021) also provided opportunities for teachers to generate knowledge and skills in interdisciplinary subjects. In the study by Hourigan et al. (2021), the concept of STEM integration that was introduced emphasized the integration of two or more STEM disciplines applied in the STEM PD activities that were carried out. 'Design a parachute' project in the PD program in the study by Hamilton et al. (2021) also involved interdisciplinary skills, including integrating engineering, mathematics, and science.

Additionally, several STEM PD programs focused on integration involving engineering disciplines, among them introducing the concept of EDP to primary school teachers (Capobianco et al., 2018; Chen et al., 2020; Dailey et al., 2018; Nesmith & Cooper, 2019; Pleasants et al., 2020; Porter et al., 2019; Silvestri et al., 2019). In addition, introducing several units found in the EiE curriculum during the STEM PD program can help teachers integrate the engineering discipline into their teaching (Dailey et al., 2018; Mangiante & Gabriele-Black, 2020; Nesmith & Cooper, 2019; Porter et al., 2019).

DISCUSSION AND CONCLUSIONS

Although there is still a lack of STEM PD conducted involving primary school teachers, through the review conducted, efforts have been carried out in many countries by organizing STEM PD involving primary school teachers. We discovered seven subthemes from the review that address the significance of STEM PD for primary school teachers. From this review, the importance of STEM PD programs for primary school teachers is to increase interest in STEM among primary school students, increase teachers' knowledge of STEM and foster the development of primary school students. In addition, this STEM PD is also significant in correcting conceptual errors and misunderstandings about STEM, helping teachers with time management, and curbing the failure of STEM teaching due to a lack of reference resources or materials.

Teacher knowledge in STEM education is crucial for developing hands-on and meaningful activities, encouraging curiosity, and attracting students' interest (Rahman et al., 2021). Therefore, teachers should increase their understanding of teaching STEM education and integrate STEM disciplines involving problem-solving in the context of the real world. Since certification in STEM fields is not compulsory for primary school teachers, ongoing PD is crucial for educators to expand their subject and pedagogical skills as they integrate other STEM subjects into their classrooms (Mohd Shahali et al., 2015). Teachers with strong STEM knowledge and skills are able to develop effective STEM lessons by considering a variety of pedagogical approaches and encouraging students to explore greater depths of understanding (Hasim et al., 2022). Despite reports that primary teachers often lack knowledge and belief in integrating STEM into the classroom, professional learning opportunities can boost teacher assurance and the effectiveness of STEM initiatives.

Next, in the review conducted, we identified seven subthemes that discuss the implementation of STEM PD for primary school teachers. Among the implementation of STEM PD programs for primary school teachers is to help teachers plan STEM lessons, organize partnership and collaboration programs, and introduce inquiry-based learning approaches, PjBL PBL, CT mathematical modelling, and STEM integration skills. From this review, two focuses were often found in the STEM PD carried out: integration skills and partnership and collaboration programs. It has become a culture for PD programs to be conducted in cooperation with external agencies, professional bodies, and experts in the field to help teachers understand the implementation of STEM, develop trust in STEM teaching practices and further build a positive attitude towards STEM.

The skills applied in STEM education are necessary to meet the challenges of the twenty-first century. To ensure that a country can compete globally, many countries are taking action to continue improving the quality of their national education by refining the teaching of STEM education in all educational institutions. PD must be ongoing so that teachers not only put new abilities to use but are inspired to act as change agents. Teachers, as agents of change, need to be given real experience with experts in the field to dispel stereotypes about STEM education and indirectly be able to develop their faith in STEM further. Therefore, it is hoped that stakeholders in education can provide opportunities for meetings and interactions between primary school teachers and STEM experts such as scientists and engineers. The collaboration of STEM professionals and schools can support primary school teachers in addressing the challenges of designing real and practical STEM teaching. Hands-on activities taught to teachers through professional collaboration can provide opportunities for primary school teachers to experience and gain direct learning and obtain validation from actual field experts. The practice coincides with one of the principles for effective PD programs for mathematics teachers, which requires the involvement of experts who will help model effective teaching and become a source of professional reference.

For further research, we suggest studying primary school teachers' best approach to STEM integration. The teacher's expertise is limited to subjects in other STEM disciplines, so an approach to integrating the discipline needs attention. Time and schedule constraints for primary school subjects are also significant obstacles to realizing the objectives of STEM teaching. In addition, further research can be done to explore the effective implementation period of STEM PD in influencing the development processes of primary school teachers. According to Desimone (2011), practical teacher PD activities are usually conducted throughout one semester and should include 20 hours or more of contact time. Additional research may be done to examine the factors influencing STEM education practices at the primary school level and discuss teachers' needs for implementing STEM education. This point is supported by Goodnough (2019), who stated that many studies were conducted on teacher learning in STEM PD but did not examine the factors influencing changes in teachers' practices and activities. To ensure that the objective of introducing STEM for primary school students is achieved, teachers must first develop their knowledge, attitudes, and beliefs in teaching and implementing STEM education.

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