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STEM teacher professional development in pre-service teacher education: A literature review

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Abstract

Science, technology, engineering, and mathematics (STEM) education has recently been gaining popularity in a number of countries. This seems to have ramifications for increasing the intensity with which professional development programmes are implemented at both in-service and pre-service teacher levels. The present study provides a systematic literature review on scientific articles published between 2015 and 2021, examining how STEM teacher professional development programmes (STEM-TPD) led in the pre-service teacher corpus. Following a screening process, 66 studies were found to be eligible and in compliance with the review criteria. The review's findings indicate a positive trend in STEM-TPD scientific articles, with an increase in publications from year to year in many countries. The majority of studies were conducted in the United States and Turkey using various research methods. The STEM-TPD programme is carried out in three areas, namely, included in existing courses, conducted outside of lectures, and carried out on newly developed courses. We also ultimately discuss the seven most frequently used elements of STEM-TPD and the types of participant collaboration.

Keywords

STEM education; professional development; pre-service teacher

Introduction

Science, technology, engineering, and mathematics (STEM) education has received a lot of attention in the realm of education as a transformational paradigm. STEM education—also known as STEM integration or integrated STEM (Martín-Páez et al., 2019)—has been introduced in many countries lately. According to the National Research Council (U.S.) (2011, 2012), the United States is a pioneer in the field and has integrated science and engineering throughout its curriculum. STEM education's rise to prominence in the United States has been closely followed by other countries, such as Australia (Zhou et al., 2020), England (Skilling, 2020), Egypt (El Nagdi & Roehrig, 2020), Malaysia (Markus et al., 2021), South Korea (Kang, 2019), Thailand (Lin et al., 2020), and several other countries.

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(pp. 7–26)

The literary use of STEM is vastly different. Scientific discipline, interdisciplinary, multidisciplinary, and transdisciplinary are some of the terms used to describe it (Holbrook et al., 2020). In order to be more specific, integrating the STEM subjects, problem-based learning, inquiry-based learning, design-based learning, and cooperative learning are the guiding principles of STEM integration (Thibaut et al., 2018). STEM education, according to Sanders (2009), can only be defined as such if it encompasses at least two different fields of study. This definition of STEM was used in the writing of this review.

STEM education is seen as a way to help students develop their skills and prepare them for the workforce in the era of the Fourth Industrial Revolution. The ability to make decisions (Ortiz-Revilla et al., 2020), to think critically and creatively (Bybee, 2010; Kelley & Knowles, 2016; Sumarni, 2020) and to solve problems (Purwaningsih, et al., 2020) have all been proven in studies enhanced by STEM education. Although the effectiveness of STEM learning has been widely proven, the implementation of STEM education is not easy.

STEM implementation is highly dependent on the professionalism of teachers in schools. Several attempts have been made to develop teacher professionalism in the field of STEM education. Some of them were conducted through workshops/training related to STEM (Affouneh et al., 2020; Bergsten & Frejd, 2019; Gardner et al., 2019) as well as collaboration between teachers and STEM practitioners (Aslam et al., 2018; Yesilyurt et al., 2021). Many studies have shown that the STEM Teacher Professional Development (STEM-TPD) programme could improve teachers' capabilities, such as teachers' conceptions of STEM (Cavlazoglu & Stuessy, 2017; Suebsing & Nuangchalerm, 2021), STEM pedagogy (Aldahmash et al., 2019), technological pedagogical and content knowledge (Chaipidech et al., 2021), and attitude or motivation towards STEM education (Al Salami et al., 2017; Evans et al., 2019).

STEM-TPD programmes have been carried out not only at the in-service teacher level but also at the pre-service teacher level. For in-service teachers, Affouneh et al. (2020) did a qualitative investigation to determine how teachers see STEM learning. A total of 35 teachers participated in a two-day course on STEM learning for professional development. Using interview data-gathering techniques and focus group discussions, they discovered that the professional development of STEM teachers was influenced by a series of elements, including personality traits and internal factors, such as attitudes and views regarding STEM. Furthermore, Yesilyurt et al. (2021) conducted a study on 84 primary school teachers to investigate how engineering education can enhance the self-efficacy of future teachers. They discovered that participants' self-efficacy increased after receiving engineering instruction as an intervention. Two examples of this research showed that the programme positively impacts teacher professionalism.

Several studies related to STEM-TPD have also been carried out to develop the professionalism of pre-service teachers. For example, Aydin-Gunbatar et al. (2020) conducted professional development activities for 13 pre-service chemistry teachers in Turkey. Students learn STEM concepts and design STEM instruction. The programme that was carried out indicated that the pedagogical content knowledge of pre-service teachers could develop over time and the support provided. Another study was conducted by Navy and Kaya (2020) on 47 pre-service elementary teachers regarding PBL and integrated STEM. They conducted the programme for 15 weeks with 45 hours in class and 15 hours of fieldwork in elementary classrooms. The study results showed that pre-service teachers perceived that integrated STEM could help students relate real-life problems to classroom learning.

With the growth of STEM-TPD literature, a comprehensive review of existing findings becomes pivotal. Regarding participants in the STEM-TPD study, the review studies conducted can be grouped into two, namely participants who are in-service teachers and participants who consist of in-service and pre-service teachers. First, Margot and Kettler (2019) reviewed 25 articles with year coverage between 2000 and 2016 with in-service teacher participants. There are 17 findings in this review that can serve as a guide in conducting professional development in STEM education. This study also showed that teachers believe well-organised and frequently available professional learning opportunities will facilitate successful STEM initiatives. The studies reviewed included participants from the in-service teacher cluster. Lo (2021) conducted a systematic review with year coverage from January 2015 to June 2020 to obtain 48 empirical studies that match his set criteria. The important result shown in this review is that the most frequently reported professional development programmes include subject knowledge, pedagogical content knowledge, and the quality of teachers' STEM learning designs. Finally, Mesutoglu & Baran (2021) conducted a review involving 29 articles. The review was carried out to synthesise professional development studies related to the integration of engineering in K-12 education. They found that all studies used the face-to-face workflow approach to increase teacher capacity in three domains: integrating engineering concepts and practices, understanding and knowledge of engineering, and improving positive beliefs and attitudes.

Several STEM-TPD review studies were also carried out involving articles whose participants were not limited to in-service teachers but also pre-service teachers. First, Denton and Borrego (2021) conducted a scoping review to explore how funds of knowledge are used in STEM education. As a result, they found that most of the studies were conducted qualitatively in and after the classroom. In addition, this study shows that most studies focus on improving teaching, curriculum, or the relationship between the community and schools. This study does not fully focus on integrated STEM but involves individual STEM studies. Chai (2019) conducted a systematic review with databases from Scopus and World of Science. After reviewing 20 articles, he found that STEM-TPD was widely practised in the United States, focusing on in-service teachers. He also demonstrated in their review that STEM-TPD positively impacts teachers' pedagogical and content knowledge. Furthermore, Johari et al. (2022) reviewed articles published from 2017 to 2021 on the Scopus and World of Science databases. Based on the 20 reviewed articles, it was found that self-efficacy and commitment are factors that significantly determine the success of TPD. Although the review was conducted in the integrated STEM domain, participants in the reviewed study were only math teachers. Finally, Huang et al. (2022) also recently reviewed 76 studies. Participants involved in the reviewed studies were in-service and pre-service teachers. The most frequently reported approaches were related to three key themes: earning by design, scaffolding authentic experiences, and collaborating with peers. The STEM referred to in this study is diverse, ranging from individual to integrated STEM.

Although many studies have found beneficial results from STEM-TPD, a systematic review of the literature on professional development for pre-service teachers is rarely made available. Pre-service teachers have different characteristics from in-service teachers. For example, access to implementing classroom learning for pre-service teachers tends to be limited (Radloff & Guzey, 2017). In addition, in the initial phase, pre-service teachers sometimes have limited content knowledge (Purwaningsih et al., 2018) and the skills to apply reformative learning approaches (Mardiani et al., 2023). Thus, this study is expected to shed light on the current trends in STEM-TPD for pre-service teachers and identify best practices for pre-service teacher programmes.

Research questions

1. What are the publication year, countries, and research methods of selected STEM-TPD studies?
2. How does STEM-TPD fit into pre-service teacher education?
3. How do pre-service teachers collaborate in STEM-TPD?
4. What essential elements are employed in STEM-TPD for pre-service teachers?

Method

This research was a systematic literature review exploring the professional development activities of teacher candidates in the field of STEM education. Systematic literature review is a study conducted to synthesise research results comprehensively (Krille, 2020; Littell et al., 2008). With a systemic review, researchers could answer research questions, such as comparisons of interventions, diagnostic tests, and prognostic factors, to qualitative questions (Purssell & McCrae, 2020).

Literature search and selection

Google Scholar and Eric were used as databases because these databases are well established and are most recognised in the field of social sciences. To filter the grey literature, we use articles from Scopus and WoS indexed journals as eligibility criteria. Literature search is carried out using Boolean logic to capture more articles with the following keywords: ("professional development" OR "professional learning" OR "teacher education" OR "teacher training") AND "STEM education" AND integrat* AND ("pre service" OR "student teacher" OR "prospective teacher"). To accommodate most of the frequent expressions of integrated STEM education, an asterisk was utilised as a keyword (e.g., integrated STEM or STEM integration).

The search was carried out between January and February 2022. On the Google Scholar database, we collect articles using the Publish or Perish software (https://harzing.com/). Figure 1 shows the searching and screening process in this review.

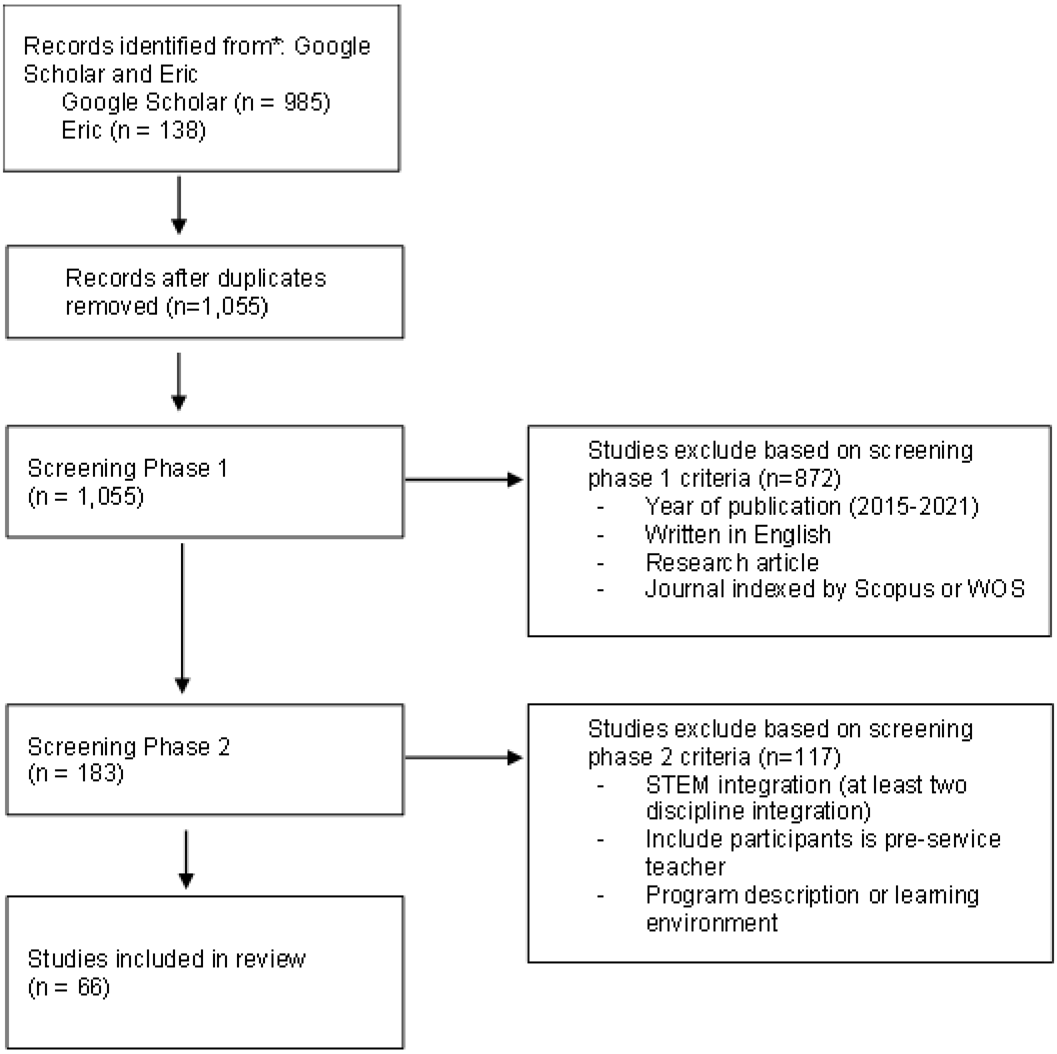

Figure 1. Diagram of the screening process.

Figure 1 shows the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) flowchart used in searching and refining articles. Based on the keywords used, there were 1,123 articles from Google Scholar (n=985) and Eric (n=138) searches with a 2015–2021 publication year limitation. Before doing a full reading, two researchers screened the title and abstract of the article. In cases in which the relevance of the study could not be inferred from the title or abstract, the researcher reviewed the full text to determine its feasibility. The following inclusion criteria were used:

1. Research article
2. Written in English
3. Year of publication (2015–2021)
4. Journal indexed by Scopus or WOS
5. STEM integration (at least two disciplines integration)
6. Participants are pre-service teacher
7. Include a programme description or learning environment

Quality assessment

To increase the trustworthiness of this study, screening phase 2 was carried out by two independent raters where a percentage agreement of 88.45% was obtained with a kappa coefficient value of 0.75 which was in the substantial category according to Belur et al. (2018). Disagreements between raters were discussed until a joint decision was reached.

Data analysis

Articles were thoroughly read one by one, then some general information was tabulated, such as publication year, where the study took place, methodology used, participants' backgrounds, etc. Furthermore, coding was carried out to answer the research questions pertaining to the position of STEM-TPD at the level of pre-service teacher education and related to the essential elements used in implementing/developing the STEM-TPD course.

Results

General characteristics of qualifying studies

There are currently 66 studies in our review study published between 2015 and 2021 in international publications indexed by Scopus or WOS. Figure 2 depicts the development of STEM-related professional development publications at the university level during the last seven years.

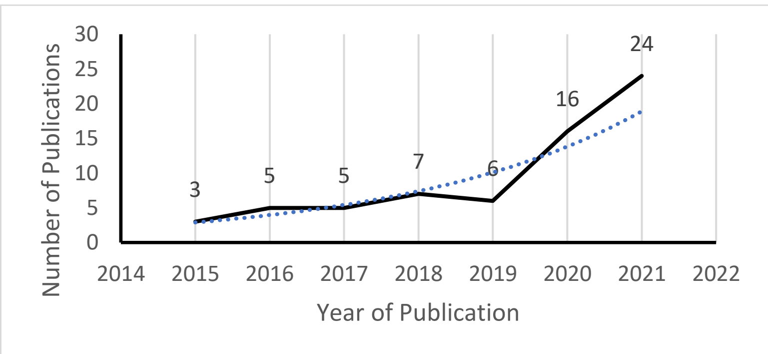

Figure 2. Distribution of STEM-TPD publications in pre-service teacher education (2015–2021).

As depicted in Figure 2, STEM-TPD activities at universities have increased year over year. In 2020 and 2021, there were significant rises. There was a two-and-a-half-fold rise from 2019 to 2020. A similar increase was seen in 2021. As evidenced by Figure 2, STEM-TPD has got a lot of attention recently. Research on STEM-TPD in pre-service teacher contexts is rapidly progressing, as shown by the trend line (see blue line in Fig. 2).

To obtain a comprehensive picture regarding the distribution of professional development programmes for pre-service teachers, we made a description of the country and the number of articles as shown in Table 1.

Table 1. ***Distribution of article publication is STEM-TPD from 2015–2021***

No.	Country	Number of articles	No.	Country	Number of articles
1	United States	21	10	Kazakhstan	1
2	Turkey	21	11	Cyprus	1
3	Spain	3	12	Sweden	1
4	Korea	3	13	Kosovo	1
5	China	2	14	Canada	1
6	Taiwan	2	15	Indonesia	1
7	Israel	2	16	Portugal	1
8	Australia	2	17	Thailand	1
9	United Kingdom	2	18	Malaysia	1

Table 1 shows the distribution of professional development programmes in various countries. This study explains that STEM-TPD is starting to be widely practised both in America and Europe. Professional development activities are concentrated in the United States and Turkey. Meanwhile, in Asian countries, the number of STEM-TPD publications at the level of pre-service teachers is still relatively limited. An overview of the methods used in the studies reviewed is presented in Figure 3.

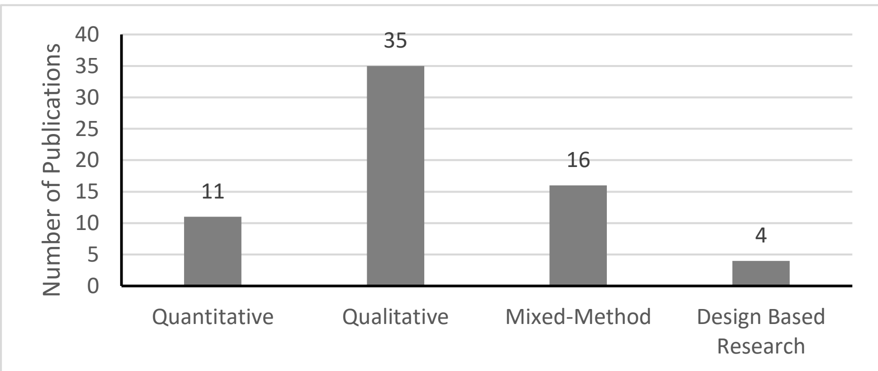

Figure 3. Distribution of articles based on research methods.

Figure 3 shows that there are a wide variety of approaches for conducting research. Most studies on STEM-TPD at the university level used qualitative approaches (n=35) for their research. At the same time, the number of mixed-method studies (n=16) and quantitative studies (n=11) is nearly the same. There are only a handful of design-based studies out there.

Position of STEM-TPD in pre-service teacher education

In general, the professional development programmes for aspiring teachers in STEM education are offered in a wide range of formats. STEM professional development for teacher candidates is portrayed in Figure 4.

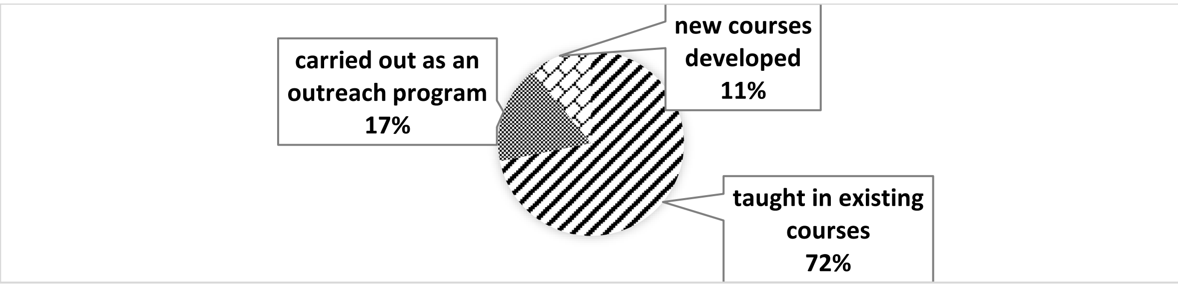

Figure 4. Position of STEM professionalism development at university level.

According to Figure 4, 72 percent of all studies are conducted in already-existing courses (48 out of the total 72 studies). The most commonly used courses are the Teaching Methods (n=13) (e.g. Buber & Unal Coban, 2020; Capobianco et al., 2021; Coppola, 2019; Navy & Kaya, 2020) and Educational Technology (n=12) (e.g. Anagün et al., 2020; Hanson et al., 2021; Kilty & Burrows, 2021; Moon et al., 2021). In addition to these two courses, several other courses are used, such as seminar courses (Bergsten & Frejd, 2019), laboratory courses (Ercan et al., 2016; Sari et al., 2020; Tezer et al., 2021), sound, waves, and communication systems (Awad & Barak, 2018), earth and space science (Van Eck et al., 2015), and mathematics course (Özçakır Sümen & Çalışıcı, 2021). This is being done in order to continue to prepare STEM teachers despite the lack of an existing curriculum.

Outside of the university curriculum, a number of professional development activities were also carried out (n=12 or 17 percent). The programme is implemented in two ways: either in collaboration with schools (e.g., Fernández-Martín et al., 2020; Küçük Demir, 2021) or on its own without partnering with schools (e.g., Dubek & Doyle-Jones, 2021; Estapa & Tank, 2017).

Although the number is still small, there are approximately 11% (n = 7) of studies that carry out professional development in special STEM learning courses. In this category, there is one programme that is reported in three different articles, namely the elective course developed by Aydin-Gunbatar et al. (2018). Furthermore, Altan et al. (2018) and Macalalag et al. (2020) focus on establishing STEM curricula that use socio scientific issues (SSI). Other courses were also developed by Pimthong and Williams (2021); Ryu et al. (2019); and Schmidt and Fulton (2016). Most of these courses are offered as electives.

Pre-service teacher collaboration in STEM-TPD

We also investigated the educational backgrounds of those who participated in the STEM-TPD study. The purpose of this part is to determine whether pre-service teachers collaborate across disciplines or departments. As a result, the maximum number of participants involved only came from two different majors. Most of the studies were conducted with participants who came from the same major. There are only four studies that prepare pre-service teachers to collaborate with other students with different majors.

Akaygun and Aslan-Tutak (2016) conducted a study on student mathematics and chemistry teacher candidates (N=38) with a focus on examining the STEM conception of chemistry and mathematics teacher candidates who have participated in a STEM professional development activity. The study was conducted at one of the universities in Istanbul, Turkey with the teaching method course. By examining posters made by pre-service teachers, they found that after participating in the activity, participants' conceptions of STEM became more detailed and more integrative.

During the 2017–2018 academic year, Berisha and Vula (2021) also held workshops for 22 aspiring mathematics teachers and 18 aspiring chemists. A qualitative content analysis study indicated that the workshops had a favourable impact on the STEM conceptualisation of future teachers. There are three key components to the PD activities: (1) collaboration between university professors to teach and integrate STEM in higher education, (2) a unique partnership between pre-service mathematics and chemistry teachers, and (3) professional development that is specialised and integrated into the study programme.

Lewis et al. (2021) conducted a study that included individuals from a variety of fields. Engineering students partnered up with 10 teaching applicants. Teachers-to-be will benefit from this pairing since it allows them to practise teaching science in an engineering setting. There was a considerable rise in the belief in topic understanding and teaching self-efficacy. The data suggested that the project's paired components were responsible for these results. They went on to say that future teachers can get a head start on their preparation by participating in collaborative projects as children.

Tank et al. (2020) conducted a study to determine how elementary school teachers implement engineering design-based learning and to determine whether or not there are any similarities or differences between the characteristics of engineering design and design when teachers implement learning. Classroom teachers, pre-service elementary teachers, and engineering graduate students are all involved. Many pre-service teachers included components of engineering design in their lesson plans, including context, restrictions, the exploration of materials and buildings, and the testing of solutions in their lesson plans using a qualitative approach to the study. But there are a few components that have a greater impact than others.

Summing up, the findings in these four studies show that collaboration between pre-service teachers from different disciplines has a positive impact on the competence and professionalism of teacher candidates. Increased understanding of STEM, the ability to design lesson plans, and skills in implementing STEM occur through collaborative activities carried out.

Essential elements of STEM-TPD in pre-service teacher education

When it comes to helping students become more proficient in STEM fields, there are a number of strategies that can be employed. Figure 5 shows the distribution of essential TPD elements.

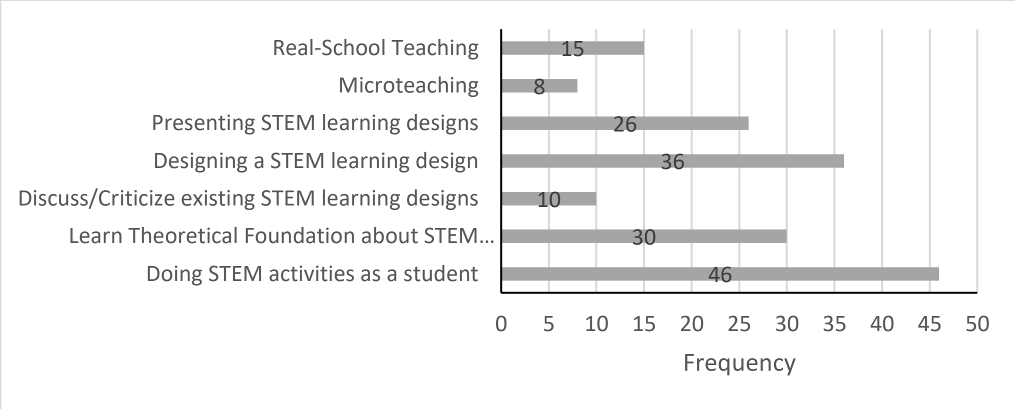

Figure 5. Instructional activities in the 66 TPD Programme (*Totals are greater than 66 because most TPD programmes provided multiple instructional activities).

Figure 5 shows the wide range of activities used to improve pre-service teacher professionalism in STEM education. Most of the learning activities carried out by pre-service teachers are by positioning them as students. In this activity, student teacher candidates are given STEM challenges like students. Furthermore, most studies have only reached the instructional design stage (e.g., Geiger et al., 2018; Vasconcelos & Kim, 2020). Student teacher candidates, however, are only asked to design and discuss the learning designs that have been made. Several studies have provided pre-service teachers up to the micro teaching (e.g., Alan et al., 2019; Çiftçi et al., 2020) or directly at the practice stage in schools (e.g., Capobianco et al., 2021; Coppola, 2019). We found that there was only one study whose professional development programme involved the seven elements (Lewis et al., 2021).

Discussion

What are the research trends for the professional development of teacher candidates in the field of STEM Education?

Empowering STEM teaching staff is one of the principles in supporting the success of STEM education (Murphy, 2022). Therefore, in many places, the preparation of teachers to teach STEM in schools is starting to be done a lot. This review shows a positive trend regarding STEM-TPD studies at the level of student teacher candidates. In recent years, publications related to the professional development of STEM teacher candidates have increased quite dramatically, although the number is still relatively small. In other words, it shows that this topic is getting more attention among educational researchers globally.

This study shows that STEM-TPD has been carried out in various countries around the world. America and Turkey are countries where STEM-TPD at the level of student teacher candidates is widely practised. These results are similar to Chai's (2019) findings that most STEM-TPD are found in America. There are many factors that can explain this. Some of them are policy factors. The Next Generation Science Standard (NGSS) curriculum explicitly raises the integration of science and engineering in the K-12 curriculum (National Research Council (U.S.), 2012). Clearly, there will be a lot of professional development for pre-service STEM teachers. For example, Capobianco et al. (2021) carried out professional development for 45 elementary pre-service teachers at Midwestern by providing provisions related to what engineering was to practise in classroom learning. They also emphasised that it is important in teacher preparation programmes to provide experience related to engineering design and its application in the classroom. This is also in line with the findings of Estapa and Tank (2017) in the Midwest suggesting that engineering design can help pre-service teachers find connections in STEM content.

Since 2017, there has been an upsurge in STEM-related publications in Turkey (Poyraz & Kumtepe, 2019). According to a 2016 report, The Turkish Ministry of Education has prioritised the implementation of STEM education at the primary, junior secondary, and senior secondary levels (Çiftçi et al., 2020). Therefore, several professional development initiatives have begun to be implemented, even at the level of pre-service teachers. Aydin-Gunbatar et al. (2018) pioneered this activity, which focuses on fostering STEM professionalism among chemistry education students. LESMR, which is an abbreviation for Learn, Experience, Study with Mentors, and Reflection, is one of the learning models developed to improve the professionalism of future STEM education teachers (Aydin-Gunbatar et al., 2020).

Professional development initiatives for aspiring STEM teachers are carried out not only in these two countries. However, it has been implemented in numerous European and Asian nations. For instance, the study undertaken by Lewis et al. (2021) in the United Kingdom by pairing engineering students with pre-service teachers improved both subject and pedagogical comprehension. In Taiwan, Kuo et al. (2019) are implementing interdisciplinary project-based learning (IPBL) to boost student STEM interest and creativity.

Moreover, in terms of research methodologies, this systematic review reveals that qualitative studies are utilised the most, followed by mixed-method and quantitative studies. In contrast, design-based studies are the least utilised technique. High levels of interest in STEM-TPD are demonstrated by the huge number of research methods employed concurrently. This difference is consistent with the variety of techniques found in Margot and Kettler (2019). In contrast to the literature examined by Denton and Borrego (2021) about the use of funds of knowledge by teachers in STEM education, qualitative studies predominate over other research methods. This might be related to the interpretive and organic nature of qualitative investigations that the gathered material can provide a precise depiction of the professional development programme undertaken by pre-service teachers. Moreover, the lack of development of courses designed to provide pre-service teachers with the skills to teach STEM subjects might be attributed to a variety of causes. A possible element is the curriculum. Future consideration may be given to revise the higher education curriculum to include STEM education courses as part of the preparation of pre-service teachers.

Where do we find pre-service teacher STEM-TPD implementation?

There are numerous ways to position the implementation of STEM-TPD for pre-service teachers. There are three positions of STEM-TPD at the university level: implementation of STEM-TPD inside of the current courses, implementation of STEM outside of the lectures, and implementation of STEM-TPD within newly offered courses.

STEM-TPD incorporated in existing course.

This systematic review shows that the majority of STEM-TPD implementations are carried out on existing courses. In other words, this review shows that STEM-TPD is flexible to implement. Teaching methods and educational technology are the most frequently used courses to implement STEM-TPD. The teaching method course is indeed suitable to be used because usually in this course, students will study learning theory and its practical application. This, of course, will have implications for the competence of pre-service teachers, such as understanding (Hanson et al., 2021), self-efficacy (Seung et al., 2019; Yurekli et al., 2020), belief (Yılmaz & Malone, 2020), and pedagogical content knowledge (Faikhamta & Clarke, 2013).

In addition to teaching methods, educational technology is also often used as a course to conduct STEM-TPD. STEM education involves at least two disciplines, where at least one of them is technology or engineering (Sanders, 2012). This is the logical reason why educational technology courses are ideal for STEM-TPD. In this course, students can complete STEM challenges or create technology designs enabling them to solve community problems. Nevertheless, it does not stop there. Student teacher candidates are also directed to use technology as a learning tool (Kilty & Burrows, 2021). In fact, there are studies applying this learning technology course to the stage where pre-service teachers apply the technology they have created in schools (Kilty & Burrows, 2021).

Implementation of STEM-TPD outside of lectures.

In addition to lectures, STEM-TPD is also done through other activities. Many of these activities are carried out by universities and schools having to work together. Cooperation between universities and schools can be good for both pre-service teachers and students at the school (Fernández-Martín et al., 2020). This is also in line with what Murphy (2022) found, suggesting that one of the benefits of STEM education is that people in the STEM community work together more. When universities and schools collaborate, the lack of role models, which is usually a problem in STEM education, can be coped with (Ryu et al., 2019). Furthermore, engineering, as an important part of STEM education, also needs attention. Collaboration between pre-service education and schools needs to be complemented by the involvement of engineers (Estapa & Tank, 2017). Tank et al. (2020) also did this study with three parts: pre-service teachers, graduate engineering students, and teachers. On top of that, an interesting study was done in which the teachers were treated as co-teachers from the planning stage to the actual teaching (Dubek & Doyle-Jones, 2021). As a result, they revealed that the co-teaching activities helped future teachers learn more about STEM and PCK.

Development of STEM-TPD course.

Several studies have developed specific courses for STEM-TPD, although there are still a few of these types. Offering STEM education courses in the teacher candidate curriculum is an alternative to generate teachers who are ready to teach STEM. Studies developing this learning state that attention regarding the preparation of pre-service teachers to carry out learning in schools is still minimal. According to records, in September 2005, the Technology Education faculty at Virginia Tech launched an innovative STEM education graduate programme that recruits science, technology, engineering, mathematics, and basic teachers/administrators to enrol and study related educational learning and research in Integrated STEM (Sanders, 2009). Furthermore, this literature study found several courses that provide opportunities for students to learn and practise STEM. For example, the integrated STEM course developed by Aydin-Gunbatar et al. (2020) for chemistry education students, and the integrated STEM teaching method course by Ryu et al. (2019) for secondary pre-service teachers. As a consequence, STEM courses like this have a positive impact on pre-service teachers, such as increasing STEM understanding (Pimthong & Williams, 2021), learning design skills (Altan et al., 2018; Macalalag et al., 2020), and integrating technology in learning (Schmidt & Fulton, 2016).

How do pre-service teachers collaborate in STEM-TPD?

This review found that very few studies involved participants with heterogeneous academic backgrounds. There are only four studies that conducted STEM-TPD activities with participants from more than one major. Seeing the curriculum structure existing in many places, conducting STEM-TPD activities that involve voluntary teacher candidates from various majors is not easy. Therefore, this activity is simpler to implement as an activity outside of lectures (e.g. Berisha & Vula, 2021; Lewis et al., 2021). Activities can be carried out through workshops by providing opportunities for pre-service teachers to complement others as a team. In this activity, each person does a cognitive apprenticeship with the others. This is a good thing as a simulation when facing a real school environment later.

Furthermore, assessing whether a STEM-TPD activity is oriented towards the outcomes of teachers who can teach STEM individually or as a team is certainly a complex matter. However, this review shows that the focus of TPD is more on the preparation of a single STEM teacher. This result is in accordance with the Ejiwale (2013) finding that one of the obstacles in implementing STEM is the lack of collaboration between STEM fields. Hence, in various ways that have been done, they try to develop various competencies needed by teachers in implementing STEM in schools later, in spite of the fact the participants have specific majors.

The nature of each discipline in STEM is certainly different but remains an important part of STEM education to know. Studies show that in implementing STEM by science teachers, they often encounter obstacles due to a lack of understanding related to engineering (Hammack & Vo, 2022) and technology (Purwaningsih et al., 2018). Therefore, various efforts were made to overcome this, starting from presenting experts (e.g Dubek & Doyle-Jones, 2021) to inviting participants to collaborate with friends from different majors (e.g., Tank et al., 2020).

Collaboration with heterogeneous disciplines can support the STEM reform agenda. Everyone, with their respective expertise, can support others in a collaborative activity. Highly collaborative activities can increase knowledge construction and reveal more metacognitive features and social interactions gradually (Leng et al., 2021). According to van Tryon and Schwartz (2012), the role of collaboration in a TPD must be determined based on skills and needs. For example, in STEM-TPD, if the participants are science students whose engineering design is no more than engineering students, then the role is to design a practical engineering challenge. On the other hand, the role of pre-service science teachers is to ensure that the engineering challenge can be explained scientifically and in accordance with the principles of science education.

What professional development elements are adopted to conduct STEM-TPD?

In evaluating the elements adopted in implementing STEM-TPD, it was interesting to note that the elements used were quite varied. There are seven elements that are considerably adopted in STEM-TPD reported in the studies we reviewed. Doing STEM activities as a student is the most extensively used strategy. Students are asked to complete various STEM challenges like high school students. Inviting students to student-centred pedagogies of STEM can significantly increase the attitudes and confidence of pre-service teachers to teach STEM (Nowikowski, 2017). This is in accordance with one of the elements of effective PD, namely engaging teachers in active learning (Roth et al., 2017). A STEM teacher is not only required to be practically trained to apply STEM, but it is also important to know the foundations and fundamental philosophies of STEM. This can assist pre-service teachers in designing and implementing STEM learning effectively. Furthermore, the self-efficacy of pre-service teachers in teaching STEM can increase (Yesilyurt et al., 2021).

Since most studies were explored with pre-service science teacher participants, the area of emphasis in many studies was related to the lack of understanding of other disciplines (Berisha & Vula, 2021), particularly engineering (Vasconcelos & Kim, 2020). Therefore, several efforts were applied to overcome the lack of knowledge in other disciplines. Pre-service teachers are provided the opportunity to carry out a series of activities that involve the engineering design process. Capobianco et al. (2021) found that when pre-service teachers were involved in engineering design activities, there was a positive change from pre-service teachers as learners to teachers. Such a role model is a serious challenge in STEM-TPD (Ryu et al., 2019).

Discussing/criticising existing learning designs is also done to develop the professionalism of pre-service teachers in teaching STEM. Through the model provided, pre-service teachers learn how to design and implement STEM learning. This model can be a learning design script, a video, or even a STEM learning expert. The cognitive apprenticeships that occur in this activity can raise the understanding of pre-service teachers regarding the concept of integrated STEM (Dubek & Doyle-Jones, 2021). Pre-service teachers, who in this case are still novices, do cognitive apprenticeships with the expert sources provided. Furthermore, this activity is also carried out in groups so that the principles of social learning can also emerge.

Good implementation starts with good design. Therefore, in the studies reviewed, teacher candidates are also guided to make STEM learning designs. This activity can provide information to lecturers or facilitators regarding the extent of practical understanding possessed by pre-service teachers. It examines how pre-service teachers apply the knowledge they have learned in the development of a learning design. Besides, in this section they are asked to present their designs in front of the class.

Many teachers are interested in implementing STEM but feel they are not ready and able to implement it (Shernoff et al., 2017). One of the efforts made by previous researchers is to invite pre-service teachers to carry out small teaching practices to teach in schools. Referring to the theory of situated cognition, which is one of the learning theories, learning is done by involving physical and social elements in the learning process. The context of learning becomes an important thing. To put it simply, if you want to be able to teach STEM, pre-service teachers must learn how to teach STEM in the right context.

Conclusion

This systematic literature review shows that STEM-TPD activities at the university level are increasing every year. In other words, STEM-TPD is getting more and more attention from lecturers, researchers, and educational stakeholders around the world. Most STEM-TPD initiatives take place in the US and Turkey. STEM-TPD is most prevalent in the United States and Canada for a variety of reasons, but curriculum and national policy appear to be two of the most significant. STEM-TPD in the future, especially at the level of pre-service teacher education, should be increasingly more widespread because of the increased dissemination of the benefits of STEM education for students' 21st-century abilities.

It's not uncommon for researchers to employ a variety of techniques. Qualitative research is the most frequent method utilised in university-level studies on STEM-TPD The design-based research field is still underrepresented, with only a handful of studies currently being conducted. Considering the existing curricula, there is a lot of space for further research and development in order to better prepare future educators to teach in the STEM subject areas in particular.

STEM-TPD implementation in existing courses, implementation outside of lectures, and implementation in new courses are all examples of STEM-TPD jobs at the university level, according to this study. Most of the study is done on already-existing courses and facilities. This is the right choice as long as the lecture activities carried out are still in accordance with the goals set by the institution.

Seven elements are commonly used in STEM-TPD, according to the studies we looked at. Doing STEM activities as a student, learning the theoretical foundation of STEM education, discussing/critiquing existing STEM learning designs, developing a STEM lesson plan, presenting a STEM learning design, microteaching, and real-school teaching are the seven components of the programme. These choices fit with the goal of the lecture, the mood of the audience, and the amount of time given for it.

This study reveals that the literature on STEM-TPD activities involving students from varied disciplinary backgrounds is still very much in its infancy. The majority of research is conducted in conjunction with other researchers in the same field or with schoolteachers. As a future integrative learning method integrating four distinct fields, PD with a diverse range of participants would be an intriguing endeavour.

Future direction

Following the analysis, there are numerous options for further investigation. Most studies look at existing courses both qualitatively and quantitatively. New courses involving design-based research are still restricted. This might serve as both an opportunity and a roadmap for future research. With the introduction of unique courses that equip future teachers to teach STEM, faculty can build lectures that are flexible and adaptable to the STEM education agenda. In addition, this study found that critiquing current STEM learning designs, microteaching, and real-school teaching is still a rare practice. Future STEM-TPD research should concentrate on these three key components. Real-school teaching may be demanding since it involves solid relationships and cooperation between colleges and schools. However, this component is still required in order to fully prepare future educators in STEM subjects. The lack of professional activities for pre-service teachers from a variety of disciplines is another fascinating area for further study. In numerous studies, conceptual mastery has been identified as a barrier to integrating integrative STEM. Volunteers are hard to find for these kinds of events, but it would be interesting to study how activities that bring together people from different fields could help train future STEM teachers.

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References

References marked with an asterisk indicate studies included in the systematic literature review.

Affouneh, S., Salha, S., Burgos, D., Khlaif, Z. N., Saifi, A. G., Mater, N., & Odeh, A. (2020). Factors that foster and deter STEM professional development among teachers. *Science Education, 104*(5), 857–872. https://doi.org/10.1002/sce.21591

*Akaygun, S., & Aslan-Tutak, F. (2016). STEM images revealing STEM conceptions of pre-service chemistry and mathematics teachers. *International Journal of Education in Mathematics, Science and Technology, 4*(1), 56. https://doi.org/10.18404/ijemst.44833

Al Salami, M. K., Makela, C. J., & de Miranda, M. A. (2017). 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

*Alan, B., Zengin, F. K., & Keçeci, G. (2019). Using STEM applications for supporting integrated teaching knowledge of pre-service science teachers. *Journal of Baltic Science Education, 18*(2), 158–170. https://doi.org/10.33225/jbse/19.18.158

Aldahmash, A. H., Alamri, N., M., & Aljallal, M. A. (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*(1), 1580852. https://doi.org/10.1080/2331186X.2019.1580852

*Altan, E. B., Ozturk, N., & Turkoglu, A. Y. (2018). Socio-scientific issues as a context for STEM education: A case study research with pre-service science teachers. *European Journal of Educational Research*, *7*(4), 805–812. https://doi.org/10.12973/eu-jer.7.4.805

*Anagün, Ş. S., Karahan, E., & Kiliç, Z. (2020). Primary school teacher candidates' experiences regarding problem-based stem applications. *Turkish Online Journal of Qualitative Inquiry, 11*(4), 571–598. https://doi.org/10.17569/tojqi.793820

Aslam, F., Adefila, A., & Bagiya, Y. (2018). STEM outreach activities: An approach to teachers' professional development. *Journal of Education for Teaching*, *44*(1), 58–70. https://doi.org/10.1080/02607476.2018.1422618

*Awad, N., & Barak, M. (2018). Pre-service science teachers learn a science, technology, engineering and mathematics (STEM)-oriented program: The case of sound, waves and communication systems. *EURASIA Journal of Mathematics, Science and Technology Education, 14*(4), 1431–1451. https://doi.org/10.29333/ejmste/83680

*Aydin-Gunbatar, S., Ekiz-Kiran, B., & Oztay, E. S. (2020). Pre-service chemistry teachers' pedagogical content knowledge for integrated STEM development with LESMeR model. *Chemistry Education Research and Practice*, *21*(4), 1063–1082. https://doi.org/10.1039/D0RP00074D

*Aydin-Gunbatar, S., Tarkin-Celikkiran, A., Kutucu, E. S., & Ekiz-Kiran, B. (2018). The influence of a design-based elective STEM course on pre-service chemistry teachers' content knowledge, STEM conceptions, and engineering views. *Chemistry Education Research and Practice, 19*(3), 954–972. https://doi.org/10.1039/C8RP00128F

Belur, J., Tompson, L., Thornton, A., & Simon, M. (2018). Interrater reliability in systematic review methodology: Exploring variation in coder decision-making. *Sociological Methods and Research*, *50*(2). https://doi.org/10.1177/0049124118799372

*Bergsten, C., & Frejd, P. (2019). Preparing pre-service mathematics teachers for STEM education: An analysis of lesson proposals. *ZDM*, *51*(6), 941–953. https://doi.org/10.1007/s11858-019-01071-7

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

*Buber, A., & Unal Coban, G. (2020). From modeling to STEM: A predictor activity of volcanic eruption. *Science Activities: Projects and Curriculum Ideas in STEM Classrooms*, *57*(3), 111–121. https://doi.org/10.1080/00368121.2020.1814193

Bybee, R. W. (2010). What is STEM education? *Science, 329*(5995), 996–996. https://doi.org/10.1126/science.1194998

*Capobianco, B. M., Radloff, J., & Clingerman, J. (2021). Facilitating preservice elementary science teachers' shift from learner to teacher of engineering design-based science teaching. *International Journal of Science and Mathematics Education*, 20, 747–767. https://doi.org/10.1007/s10763-021-10193-y

Cavlazoglu, B., & Stuessy, C. (2017). Changes in science teachers' conceptions and connections of STEM concepts and earthquake engineering. *The Journal of Educational Research, 110*(3), 239–254. https://doi.org/10.1080/00220671.2016.1273176

Chai, C. S. (2019). Teacher professional development for science, technology, engineering and mathematics (STEM) education: A review from the perspectives of technological pedagogical content (TPACK). *The Asia-Pacific Education Researcher, 28*(1), 5–13. https://doi.org/10.1007/s40299-018-0400-7

Chaipidech, P., Kajonmanee, T., Chaipah, K., Panjaburee, P., & Srisawasdi, N. (2021). Implementation of an andragogical teacher professional development training program for boosting TPACK in STEM education: The essential role of a personalized learning system. *Educational Technology & Society, 24*(4), 220–239.

*Çiftçi, A., Topçu, M. S., & Foulk, J. A. (2020). Pre-service early childhood teachers' views on STEM education and their STEM teaching practices. *Research in Science & Technological Education*, 1–27. https://doi.org/10.1080/02635143.2020.1784125

*Coppola, M. P. (2019). Preparing preservice elementary teachers to teach engineering: Impact on self-efficacy and outcome expectancy. *School Science and Mathematics, 119*(3), 161–170. https://doi.org/10.1111/ssm.12327

Denton, M., & Borrego, M. (2021). Funds of knowledge in STEM education: A scoping review. *Studies in Engineering Education, 1*(2), 93. https://doi.org/10.21061/see.19

*Dubek, M., & Doyle-Jones, C. (2021). Faculty co-teaching with their teacher candidates in the field: Co-planning, co-instructing, and co-reflecting for STEM education teacher preparation. *Teacher Educator, 56*(4), 445–465.

Ejiwale, J. A. (2013). Barriers to successful implementation of STEM education. *Journal of Education and Learning (EduLearn), 7*(2), 63–74. https://doi.org/10.11591/edulearn.v7i2.220

El Nagdi, M., & Roehrig, G. (2020). Identity evolution of STEM teachers in Egyptian STEM schools in a time of transition: A case study. *International Journal of STEM Education, 7*(1), 41. https://doi.org/10.1186/s40594-020-00235-2

*Ercan, S., Altan, E., Taştan, B., & Dağ, I. (2016). Integrating GIS into science classes to handle STEM education. *Journal of Turkish Science Education, 13*, 30–43.

*Estapa, A. T., & Tank, K. M. (2017). Supporting integrated STEM in the elementary classroom: A professional development approach centered on an engineering design challenge. *International Journal of STEM Education, 4*(1), 6. https://doi.org/10.1186/s40594-017-0058-3

Evans, P. K., Dillard, K. C., Rodriguez-Wilhelm, D., & McAlister-Shields, L. (2019). Like-minded people: University-based interdisciplinary collaborations in STEM teacher preparation programs. *Journal for STEM Education Research, 2*(1), 35–54. https://doi.org/10.1007/s41979-019-00011-0

Faikhamta, C., & Clarke, A. (2013). A self-study of a Thai teacher educator developing a better understanding of PCK for teaching about teaching science. *Research in Science Education, 43*(3), 955–979. https://doi.org/10.1007/s11165-012-9300-7

Fernández-Martín, F.-D., Arco-Tirado, J.-L., Carrillo-Rosúa, F.-J., Hervás-Torres, M., Ruiz-Hidalgo, J.-F., & Romero-López, C. (2020). Making STEM education objectives sustainable through a tutoring program. *Sustainability, 12*(16), 6653. https://doi.org/10.3390/su12166653

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

Geiger, V., Mulligan, J., Date-Huxtable, L., Ahlip, R., Jones, D. H., May, E. J., Rylands, L., & Wright, I. (2018). An interdisciplinary approach to designing online learning: Fostering pre-service mathematics teachers' capabilities in mathematical modelling. *ZDM, 50*(1–2), 217–232. https://doi.org/10.1007/s11858-018-0920-x

Hammack, R., & Vo, T. (2022). A mixed methods comparison of elementary preservice teachers' conceptualization of teaching engineering. *Research in Science Education, 52*(4), 1335–1353. https://doi.org/10.1007/s11165-021-10013-x

*Hanson, J. R., Hardman, S., Luke, S., & Lucas, B. (2021). Developing pre-service primary teachers' understanding of engineering through engineering habits of mind and engagement with engineers. *International Journal of Technology and Design Education, 32*, 1469–1494. https://doi.org/10.1007/s10798-021-09662-w

Holbrook, J., Rannikmäe, M., & Soobard, R. (2020). STEAM education—A transdisciplinary teaching and learning approach. In B. Akpan & T. J. Kennedy (Eds.), *Science education in theory and practice* (pp. 465–477). Springer. https://doi.org/10.1007/978-3-030-43620-9_31

Huang, X., Erduran, S., Luo, K., Zhang, P., & Zheng, M. (2022). Investigating in-service teachers' STEM literacy: The role of subject background and gender. *Research in Science & Technological Education*, 1–21. https://doi.org/10.1080/02635143.2022.2153243

Johari, M. I., Rosli, R., Maat, S. M., Mahmud, M. S., Capraro, M. M., & Capraro, R. M. (2022). Integrated professional development for mathematics teachers: A systematic review. *Pegem Journal of Education and Instruction*, *12*(4), 226–234. https://doi.org/10.47750/pegegog.12.04.23

Kang, N.-H. (2019). A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea. *Asia-Pacific Science Education*, *5*(1), 6. https://doi.org/10.1186/s41029-019-0034-y

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 11. https://doi.org/10.1186/s40594-016-0046-z

*Kilty, T. J., & Burrows, A. C. (2021). Secondary science preservice teachers: Technology integration in methods and residency. *Journal of Science Teacher Education*, *32*(5), 578–600. https://doi.org/10.1080/1046560X.2021.1907514

Krille, C. (2020). *Teachers' participation in professional development*. Springer. https://doi.org/10.1007/978-3-030-38844-7_2

*Küçük Demir, B. (2021). The opinions of mathematics teacher candidates who have received a STEM training on STEM and the activities they designed in the class. *Athens Journal of Educaiton*, *8*(4), 401–416. https://doi.org/10.30958/aje.8-4-4

*Kuo, H.-C., Tseng, Y.-C., & Yang, Y.-T. C. (2019). Promoting college student's learning motivation and creativity through a STEM interdisciplinary PBL human-computer interaction system design and development course. *Thinking Skills and Creativity*, *31*, 1–10. https://doi.org/10.1016/j.tsc.2018.09.001

Leng, J., Yi, Y., & Gu, X. (2021). From cooperation to collaboration: Investigating collaborative group writing and social knowledge construction in pre-service teachers. *Educational Technology Research and Development*, *69*(5), 2377–2398. https://doi.org/10.1007/s11423-021-10020-9

*Lewis, F., Edmonds, J., & Fogg-Rogers, L. (2021). Engineering science education: The impact of a paired peer approach on subject knowledge confidence and self-efficacy levels of student teachers. *International Journal of Science Education*, *43*(5), 793–822. https://doi.org/10.1080/09500693.2021.1887544

Lin, P.-L., Chien, Y.-T., & Chang, C.-Y. (2020). Teachers' responses to an integrated STEM module: Collaborative curriculum design in Taiwan, Thailand, and Vietnam. In J. Anderson & Y. Li (Eds.), *Integrated approaches to STEM education* (pp. 491–509). Springer. https://doi.org/10.1007/978-3-030-52229-2_26

Littell, J. H., Corcoran, J., & Pillai, V. K. (2008). *Systematic reviews and meta-analysis*. Oxford University Press.

Lo, C. K. (2021). Design principles for effective teacher professional development in integrated STEM education: A systematic review. *Educational Technology & Society*, *24*(4), 136–152.

*Macalalag, A. Z., Johnson, J., & Lai, M. (2020). How do we do this: Learning how to teach socioscientific issues. *Cultural Studies of Science Education*, 15(2), 389–413. https://doi.org/10.1007/s11422-019-09944-9

Mardiani, A., Wilujeng, I., & Zulaikha, D. F. (2023). Exploring teachers' perspectives on implementation of STEM-inquiry integrated with disaster mitigation. *Jurnal Ilmu Pendidikan Fisika*, *8*(1), 18–29.

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

Markus, L., Sungkim, S., & Ishak, Mohd. Z. B. (2021). Issues and challenges in teaching secondary school quantum physics with integrated STEM education in Malaysia. *Malaysian Journal of Social Sciences and Humanities*, *6*(5), 190–202. https://doi.org/10.47405/mjssh.v6i5.774

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education*, 103(4), 799–822. https://doi.org/10.1002/sce.21522

Mesutoglu, C., & Baran, E. (2021). Integration of engineering into K-12 education: A systematic review of teacher professional development programs. *Research in Science & Technological Education*, *39*(3), 328–346. https://doi.org/10.1080/02635143.2020.1740669

*Moon, J., Lee, S., & Xu, X. (2021). Exploring pre-service teachers' technology-integration belief and scientific inquiry in a teacher-development course. *International Journal of Technology and Design Education. 32*, 1777–1798. https://doi.org/10.1007/s10798-021-09672-8

Murphy, S. (2022). Leadership practices contributing to STEM education success at three rural Australian schools. *The Australian Educational Researcher*. https://doi.org/10.1007/s13384-022-00541-4

National Research Council (U.S.). (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. National Academies Press. https://doi.org/10.17226/13158

National Research Council (U.S.) (Ed.). (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* The National Academies Press.

*Navy, S. L., & Kaya, F. (2020). PBL as a pedagogical approach for integrated STEM: Evidence from prospective teachers. *School Science and Mathematics, 120*(5), 221–232. https://doi.org/10.1111/ssm.12408

*Nowikowski, S. (2017). Successful with STEM? A qualitative case study of pre-service teacher perceptions. *The Qualitative Report, 22*(9), 2312–2333. https://doi.org/10.46743/2160-3715/2017.2893

Ortiz-Revilla, J., Adúriz-Bravo, A., & Greca, I. M. (2020). A framework for epistemological discussion on integrated STEM education. *Science & Education*, *29*(4), 857–880. https://doi.org/10.1007/s11191-020-00131-9

*Özçakır Sümen, Ö., & Çalışıcı, H. (2021). The effects of STEM activities applied in mathematics courses for elementary pre-service teachers in Turkey. *International Journal of Mathematical Education in Science and Technology*, 3352–3376. https://doi.org/10.1080/0020739X.2021.1944679

*Pimthong, P., & Williams, P. J. (2021). Methods course for primary level STEM preservice teachers: Constructing integrated STEM teaching. *Eurasia Journal of Mathematics, Science and Technology Education, 17*(8), em1996. https://doi.org/10.29333/ejmste/11113

Poyraz, G. T., & Kumtepe, E. G. (2019). An example of STEM education in Turkey and distance education for sustainable STEM learning. *Journal of Qualitative Research in Education, 7*(4), 1–20. https://doi.org/10.14689/issn.2148-2624.1.7c.4s.2m

Purssell, E., & McCrae, N. (2020). *How to perform a systematic literature review*. Springer. https://doi.org/10.1007/978-3-030-49672-2_3

Purwaningsih, E., Sari, S. P., Sari, A. M., & Suryadi, A. (2020). The effect of STEM-PjBL and discovery learning on improving students' problem-solving skills of the impulse and momentum topic. *Indonesian Journal of Science Education, 9*(4), 65–476. https://doi.org/10.15294/jpii.v9i4.26432

Purwaningsih, E., Wasis, Suyatno, & Nurhadi, D. (2018). Innovative lesson study (LS) to improve the pedagogical content knowledge (PCK) of STEM teacher candidates in Indonesia. *Global Journal of Engineering Education, 20*(1), 39–47.

Radloff, J., & Guzey, S. (2017). Investigating changes in preservice teachers' conceptions of STEM education following video analysis and reflection: STEM conceptions following video reflection. *School Science and Mathematics, 117*(3–4), 158–167. https://doi.org/10.1111/ssm.12218

Roth, K. J., Bintz, J., Wickler, N. I. Z., Hvidsten, C., Taylor, J., Beardsley, P. M., Caine, A., & Wilson, C. D. (2017). Design principles for effective video-based professional development. *International Journal of STEM Education, 4*(1), 31. https://doi.org/10.1186/s40594-017-0091-2

*Ryu, M., Mentzer, N., & Knobloch, N. (2019). Preservice teachers' experiences of STEM integration: Challenges and implications for integrated STEM teacher preparation. *International Journal of Technology and Design Education, 29*(3), 493–512. https://doi.org/10.1007/s10798-018-9440-9

Sanders, M. (2009). STEM, STEM Education, STEMmania. *The Technology Teacher, 68*(4), 20–26.

Sanders, M. (2012). Integrative STEM education as best practice. In H. Middleton (Ed.), *Explorations of best practice in technology, design, & engineering education* (vol. 2, pp. 103–117). Griffith Institute for Educational Research.

*Sari, U., Duygu, E., Şen, Ö. F., & Kirindi, T. (2020). The effects of STEM education on scientific process skills and STEM awareness in simulation based inquiry learning environment. *Journal of Turkish Science Education., 17*(3), 19.

*Schmidt, M., & Fulton, L. (2016). Transforming a traditional inquiry-based science unit into a STEM unit for elementary pre-service teachers: A view from the trenches. *Journal of Science Education and Technology, 25*(2), 302–315. https://doi.org/10.1007/s10956-015-9594-0

Seung, E., Park, S., & Lee, M.-A. (2019). The impact of a summer camp-based science methods course on preservice teachers' self-efficacy in teaching science as inquiry. *Journal of Science Teacher Education, 30*(8), 872–889. https://doi.org/10.1080/1046560X.2019.1635848

Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education*, *4*(1), 13. https://doi.org/10.1186/s40594-017-0068-1

Skilling, K. (2020). Student STEM beliefs and engagement in the UK: How they shift and are shaped through integrated projects. In J. Anderson & Y. Li (Eds.), *Integrated approaches to STEM education* (pp. 251–270). Springer. https://doi.org/10.1007/978-3-030-52229-2_14

Suebsing, S., & Nuangchalerm, P. (2021). Understanding and satisfaction towards STEM education of primary school teachers through professional development program. *Jurnal Pendidikan IPA Indonesia, 10*(2), 171–177. https://doi.org/10.15294/jpii.v10i2.25369

Sumarni, W. (2020). Ethno-stem project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia, 9*(1), 11–21. https://doi.org/10.15294/jpii.v9i1.21754

*Tank, K. M., DuPont, M., & Estapa, A. T. (2020). Analysis of elements that support implementation of high-quality engineering design within the elementary classroom. *School Science and Mathematics, 120*(7), 379–390. https://doi.org/10.1111/ssm.12432

*Tezer, M., Orekhovskaya, N. A., Shaleeva, E. F., Knyazeva, S. A., & Krokhina, J. A. (2021). The effectiveness of STEM education applied with a distance education approach. *International Journal of Emerging Technologies in Learning (IJET), 16(*19), 180. https://doi.org/10.3991/ijet.v16i19.26061

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., De Cock, M., Hellinckx, L., Knipprath, H., Langie, G., Struyven, K., Van de Velde, D., Van Petegem, P., & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3(*1). https://doi.org/10.20897/ejsteme/85525

Van Eck, R. N., Guy, M., Young, T., Winger, A. T., & Brewster, S. (2015). Project NEO: A video game to promote STEM competency for preservice elementary teachers. *Technology, Knowledge and Learning*, *20(*3), 277–297. https://doi.org/10.1007/s10758-015-9245-9

van Tryon, P. J. S., & Schwartz, C. S. (2012). A pre-service teacher training model with instructional technology graduate students as peer coaches to elementary pre-service teachers. *TechTrends*, *56*(6), 31–36. https://doi.org/10.1007/s11528-012-0611-3

*Vasconcelos, L., & Kim, C. (2020). Preparing preservice teachers to use block-based coding in scientific modelling lessons. *Instructional Science*, *48(*6), 765–797. https://doi.org/10.1007/s11251-020-09527-0

*Yesilyurt, E., Deniz, H., & Kaya, E. (2021). Exploring sources of engineering teaching self-efficacy for pre-service elementary teachers. *International Journal of STEM Education*, *8*(1), 42. https://doi.org/10.1186/s40594-021-00299-8

Yılmaz, Ö., & Malone, K. L. (2020). Preservice teachers perceptions about the use of blended learning in a science education methods course. *Smart Learning Environments*, *7*(1), 18. https://doi.org/10.1186/s40561-020-00126-7

Yurekli, B., Bostan, M. I., & Çakıroğlu, E. (2020). Sources of preservice teachers' self-efficacy in the context of a mathematics teaching methods course. *Journal of Education for Teaching, 46*(5), 631–645. https://doi.org/10.1080/02607476.2020.1777068

Zhou, D., Gomez, R., Wright, N., Rittenbruch, M., & Davis, J. (2020). A design-led conceptual framework for developing school integrated STEM programs: The Australian context. *International Journal of Technology and Design Education*, *32*, 383–411. https://doi.org/10.1007/s10798-020-09619-5