Science, Technology, Engineering, and Mathematics Professional Development on Science Learning: A Review

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Abstract

The STEM professional development (STEM PD) programs are important in improving teacher competence in developing STEM-integrated science learning. This study aims to determine the progress of STEM PD programs and effective STEM PD programs in science learning. The methodology used in this study is a systematic literature review conducted through 3 main stages: planning, conducting, and reporting the review. The results of the study stated that the progress of the STEM PD program can be seen in teacher participation, changes in teacher competencies, integration of STEM in the curriculum, improved student skills, and resource enhancement. Furthermore, an effective STEM PD program can be seen from the STEM approach, collaboration and partnerships, use of media and technology, stakeholder support, and sustainability. This study concludes that implementing STEM PD in science learning should be carried out sustainably so that teachers will continue to be exposed to the integration of STEM in science learning. STEM PD implemented with commitment and appropriate efforts will improve teacher competence and student interest in STEM-based science learning.

Keywords: Effective, Progress, Science learning, STEM, STEM professional development.

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INTRODUCTION

STEM learning calls for integrating concepts and skills in Science, Technology, Engineering, and Mathematics (Bybee, 2010; Parmin & Sajidan, 2019). The integration in STEM learning is expected to develop students' critical thinking, problem-solving skills, creativity, and collaboration to overcome all complex and relevant challenges in daily life. A balance between knowledge and practical skills in STEM learning is necessary. Students often struggle to connect STEM learning and application in everyday life. This is because their knowledge and practical skills are not balanced and still abstract (Hiğde & Aktamış, 2022; Tan et al., 2023). STEM learning requires students to be actively involved in experiments, projects, exploration, and problem-solving to have perseverance, curiosity, and confidence in learning (Conchas et al.; Lombardi et al., 2021; Murphy et al., 2019). The approach entails an integrated method of instructing several fields, specifically emphasizing practical applications in the actual world and links between different disciplines.

Teachers have the primary role in implementing learning in the classroom. They are the best profile in the teaching and learning process and have the best capacity to develop appropriate learning tools for students to achieve the desired competencies (Jimenez, 2020). Most teachers lack professional development opportunities (Agustina & Saxena, 2022; Tedia & Redda, 2022). This is due to teachers' high teaching loads, lack of readiness and desire from teachers, lack of support from the school and surrounding areas, and lack of training opportunities or workshops attended by teachers to improve their competence (Al-Thani et al., 2021; Tahir et al., 2020).

A teacher's professional competence includes a combination of skills, knowledge, attitudes, and behaviors required by teachers to develop effective and quality learning for students (Murkatik et al., 2020; Sancar et al., 2021). On the other hand, teachers also hope to improve their thinking and innovation in their learning by developing new ways of thinking (Androutsos & Brinia, 2019). STEM learning requires an understanding and ability to integrate several scientific disciplines. Teachers who will teach STEM need to develop their competencies to equip students with STEM literacy that reflects 21st-century skills so that they can face the challenges of globalization and involvement in modern science (Suwarma & Kumano, 2019).

In some countries, STEM is usually not explicitly listed in a particular subject matter (Suwarma & Kumano, 2019; Yata et al., 2020). One subject matter that is closely related to STEM is science (Margot & Kettler, 2019). In science learning, science concepts are integrated with other scientific disciplines, such as technology, engineering, and mathematics, to prepare students to face all everyday life challenges (Permanasari et al., 2021). Science teachers in Indonesia do not specifically teach STEM in their lessons. Therefore, these teachers must be equipped to have a strong understanding and good skills in teaching STEM to students. STEM professional development is a program that assists science teachers in incorporating STEM principles into the science curriculum (Affouneh et al., 2020; Du et al., 2019; Guzey et al., 2019; Margot & Kettler, 2019; Morrison et al., 2021; Permanasari et al., 2021).

STEM PD for science teachers is an ongoing program to improve science teachers' ability to integrate STEM concepts into the science curriculum. Apart from that, STEM PD is also expected to improve the pedagogical skills of a science teacher in carrying out effective teaching in the classroom. STEM PD invites teachers to encourage maximum student involvement in conducting investigations and understanding the interrelationships of various fields of science. This aims to encourage students to apply their scientific knowledge and skills to overcome challenges in their science learning. STEM PD is a key indicator in improving the quality of STEM-based science learning in schools. Having the readiness and motivation of teachers to enhance their competence, as well as getting support from the school and the surrounding environment, can be a determinant in the success of the STEM PD program (AlAli et al., 2023; Fakcharoenphol et al., 2022; Zhou et al., 2023).

Science teachers who teach STEM to students must be provided with programs or training to determine their readiness to teach STEM in science learning. The success of STEM education depends on the teacher's perspective and readiness to implement integrated STEM learning in learning. It is necessary to understand the abilities and professionalism of teachers who teach STEM and continuously provide support for the implementation of STEM learning. The program is called STEM Professional Development (STEM PD). The STEM PD program is designed to support science teachers in developing the skills, knowledge, and attitudes necessary to teach science with an effective STEM approach. Therefore, the focus of this study is to investigate the progress of the STEM PD program and the effective implementation of STEM PD.

METHOD

The review method used in this research is a systematic literature review (SLR) using a qualitative approach. SLR was chosen as the method used in this study because this method can help researchers find out the progress and effective implementation of STEM PD. SLR is a methodology to systematically collect, identify, and critically analyze a research study (Peters et al., 2015; Xiao & Watson, 2019). The research studies used are articles published by Scopus-indexed publishers, such as Elsevier, Sage, Springer, Taylor & Francis. The keywords used are: "science learning", "STEM", "professional development", and "STEM professional development". Based on these keywords, hundreds of documents found articles within five years (2018-2023). However, only 34 articles met the criteria corresponding to this article.

The steps in the research include three main stages: planning the review, conducting the review, and reporting the review (Xiao & Watson, 2019). The steps can be seen in the figure 1.

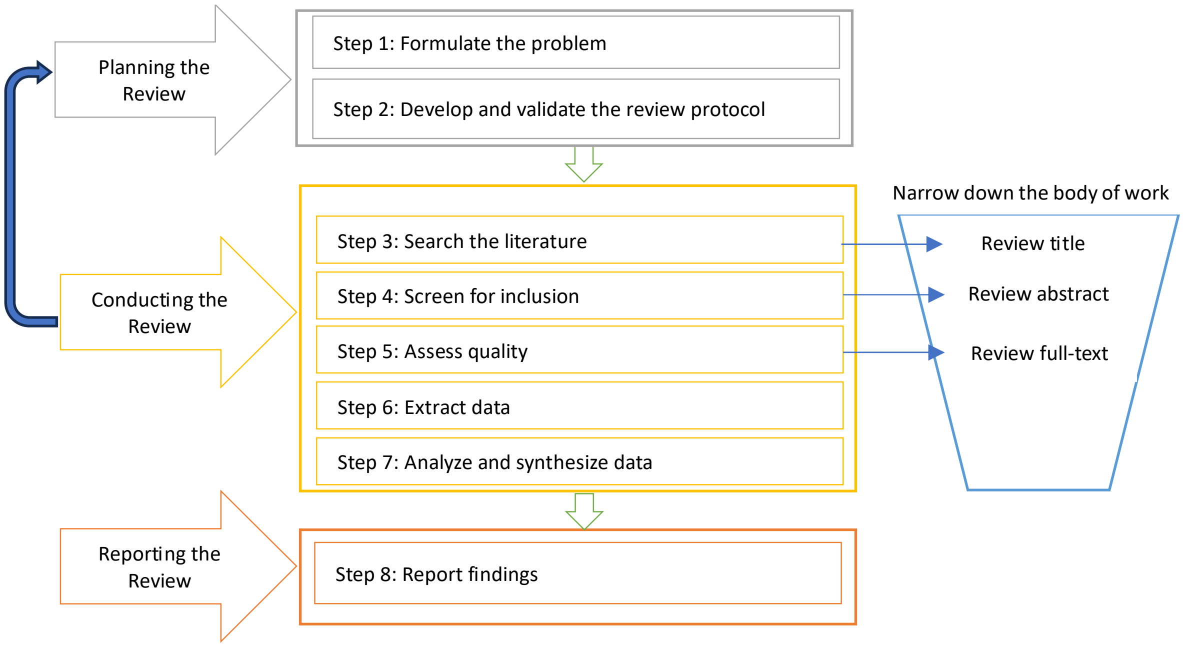

Figure 1: The systematic literature review process (Xiao & Watson, 2019)

As a result of stage 1, the researchers then conducted a review that began with searching for appropriate literature using specific keywords. The next stage is for researchers to extract, analyze, and synthesize data (Xiao & Watson, 2019). In this second stage, researchers can determine the title, describe the abstract, and present the paper.

The final stage is reporting, where the researcher writes a report on the literature review results to disseminate the findings (Xiao & Watson, 2019). This literature review process is iterative. When conducting the review, the researcher encountered a problem because the research question was too broad, and the researcher wanted to narrow the topic and adjust the inclusion criteria. Based on the whole process carried out by the researcher, the review results in this study draw some information related to the progress of the STEM PD program and the effective implementation of STEM PD in science learning.

RESULT AND DISCUSSION

Studies on STEM professional development have long been published in education, educational technology, teacher training, and professional development journals. While there is a wealth of literature on STEM PD today, there has been limited effort to review the progress of STEM PD and the effective implementation of STEM PD. This review lasted eight weeks, from July 5 to August 31, 2023. Based on the results of the review that researchers have carried out, two findings will be presented, namely regarding the progress of the STEM PD program and the effective implementation of STEM PD in science learning.

The progress of STEM PD programs

Research on STEM PD programs in the last five years has received particular attention, but it has not been possible to identify its progress systematically. Implementing STEM PD is usually done through training, workshops, and mentoring models. Training and seminars usually emphasize appropriate learning design. Meanwhile, mentoring emphasizes aspects of knowledge, including content, pedagogy, and collaboration.

According to the literature review, the implementation of STEM PD has increased every year in the last five years. Global trends and the application of STEM education at all levels of education influence this increase. The need to meet the demands of global trends impacts the application of STEM PD. STEM teachers are essential in directly influencing the implementation and quality of STEM education. Leveraging STEM education to increase students' knowledge and understanding (Huang et al., 2022; Oztay et al., 2022).

The development of STEM PD implementation over the last five years can be seen in the program's implementation and the competency achievements of teachers participating in the STEM PD program. The implementation of the STEM PD program in terms of the subjects (teachers) who took part in it can be seen in Table 1.

Table 1. Distribution of STEM-PD participants in 2018-2023

Educational Level	STEM-PD Participant 2018-2020	STEM-PD Participant 2021-2023
Early childhood teachers	V	V
Elementary school teachers	V	V
Secondary school teachers	V	V
Pre-service teachers	V	V
Library STEM facilitators	V	V
K-12 level teachers	V	V
University teachers		V

Table 1 shows that the implementation of STEM-PD has been implemented by teachers at all levels of education. This indicates that all levels of education can implement STEM learning from early childhood to adulthood. Increased teacher competence in teaching STEM through play and independent exploration can improve young children's STEM skills and knowledge (MacDonald et al., 2020; Suebsing & Nuangchalerm, 2021). Implementing STEM-PD also positively impacts the implementation of STEM learning at the university level. Students taught by lecturers who have participated in STEM-PD are given experience in preparing STEM learning materials and strategies (Du et al., 2020; Macaluso et al., 2020).

This research will identify the progress of STEM PD implementation. Various ways can assess the progress of STEM PD in science learning. Based on the review results, some indicators that can measure the progress of the STEM PD program are presented in Table 2.

Table 2. Indicators of progress of STEM PD program in science learning

Indicator	Description
Teacher's participation	The progress of the STEM PD program can be seen from the level of teacher participation in the program. The more actively participating teachers, the more significant the potential impact on science learning. Based on the review results, the STEM PD program was followed by teachers with a variety of numbers, including STEM TPD through STSP (19 teachers) (Saat et al., 2021), STEM PD for teachers' knowledge, and others (8 teachers) (Du et al., 2019), STEM PD with FGD (35 teachers) (Mumcu et al., 2022; Mumcu et al., 2023), The PD use of STEM-based 5E inquiry learning (78 teachers) (Ong et al., 2020), and others. Teachers' desire to participate in STEM PD is a key support to help teachers apply STEM concepts and teaching strategies in their classrooms (Shernoff et al., 2017). Teachers realize that STEM PD does not only focus on STEM learning materials but also includes pedagogical knowledge (Affouneh et al., 2020; Chiu et al., 2021; Gardner et al., 2019; Shernoff et al., 2017; Stohlmann et al., 2012).

Indicator	Description
Changes in teacher competencies	The progress of STEM PD can be seen through an instrument to determine teachers' initial and final competence regarding STEM learning in science learning (Gardner et al., 2019; Thi To Khuyen et al., 2020). One of the competencies that can be developed from the application of STEM PD is technological pedagogical content knowledge (TPACK). Teachers who actively participate in STEM PD are expected to be able to integrate science learning with STEM (Aldahmash et al., 2019; Chai, 2019; Thi To Khuyen et al., 2020).
Integrating STEM into science curriculum	Curriculum development is a crucial factor in implementing STEM integration in science learning. Teachers must be able to design and modify the science lesson plans that they will implement by including STEM components. An important sign is how well science and STEM subjects are taught (Aldahmash et al., 2019; Brown & Bogiages, 2019).
Improved student competence	Student competencies in this indicator include improved learning outcomes after STEM learning and student engagement in learning (Struyf et al., 2019; Triana et al., 2020). The primary desired impacts of the STEM PD program on science learning are improvements in engineering skills, project design, creativity, increased interest, and student engagement in STEM-based science learning (Baharin et al., 2018; Bicer & Lee, 2023; Hiğde & Aktamış, 2022).
Resource enhancement	Science and STEM learning is synonymous with experimentation, exploration, and the development of learning projects (Jesionkowska et al., 2020; Vennix et al., 2018). This calls for improved equipment and infrastructure to support learning. The progress of the STEM PD program can also be seen in the availability of adequate resources for teachers to manage their knowledge (Affouneh et al., 2020; Clair et al., 2020).

The progress of the STEM PD program shown by the indicators above requires time and results that are not immediately visible. These indicators should be used as a reference by researchers and organizers of STEM PD in science learning so that the program can take place optimally. Overall, progress in the implementation of STEM PD over the past five years has focused on meeting the specific needs of teachers, encouraging and supporting teachers, and fostering the identity of STEM teachers (Ahmed et al., 2023; Kleinschmit et al., 2023; Mumcu et al., 2022).

Implementing STEM PD is expected to develop the competence of teachers in determining strategies and material content, as well as integrating both (Widodo & Riandi, 2013). The competence of teachers attending the STEM-PD program has evolved from year to year. The period 2018-2023 showed the competence of measured teachers that not only looked at the components of pedagogical knowledge (PK), content knowledge (CK), and pedagogical content knowledge (PCK) but also technological pedagogical contents knowledge (TPACK), ability to collaborate, metacognitive awareness, self-efficacy, computational thinking, and other competences (Adebusuyi et al., 2022; Chai et al., 2020; Gardner et al., 2019; Hughes & Partida, 2020; Kelley et al., 2020; Richmond et al., 2017). These efforts aim to increase the implementation of integrated STEM approaches and improve the overall quality of STEM education. Based on the review that has been conducted, STEM PD in Indonesia, especially in science learning, has not been widely carried out, so the program's progress cannot be observed in more detail.

The effective STEM PD programs

The effective implementation of STEM PD programs in the last five years can be seen in some literature. The literature suggests that teachers often struggle to effectively implement new, learner-centered approaches to STEM education, even after participating in PD (Affouneh et al., 2020; Brown & Bogiages, 2019). However, several studies highlight the positive impact of PD programs on teachers' attitudes towards integrated STEM teaching. This shows that participation in PD can increase teacher confidence and competence in teaching STEM (Chiu et al., 2021; Saat et al., 2021).

Several factors contribute to the success of a STEM PD program in science education, including:

1. The approach based on STEM: the STEM approach to education is a holistic and interdisciplinary methodology that seeks to strengthen students' readiness for future professions, enhancing their ability to solve problems and fostering a deeper understanding of the practical applications of science, technology, engineering, and mathematics in the real world. Science learning taught using a STEM approach can improve students' critical thinking. This approach shows the connection of science subjects with a STEM approach and encourages teachers to create meaningful connections between various scientific disciplines. Using this approach in science learning, students can increase their understanding of science concepts and apply them in real situations. This effort fosters innovative science and technology talents with interdisciplinary knowledge, literacy, and problem-solving abilities. Thus, professional development is essential to develop teachers' knowledge and skills in STEM teaching, resulting in better STEM outcomes (Baharin et al., 2018; Dare et al., 2018; DeCoito & Myszkal, 2018; Hamad et al., 2022; Reynders et al., 2020).
2. Collaboration and partnerships: collaboration and partnerships can occur between schools, communities, experts, and industry professionals who can access resources, expertise, and real-world applications of STEM concepts. Collaborative activities allow teachers to benefit from working in teams and being involved in activities. This collaborative and partnership approach is a place to share good practices, share ideas, and be creative in implementing innovative STEM learning (Kelley et al., 2020; Saat et al., 2021; So et al., 2021; Zizka et al., 2021).
3. Media and technological usage: media and technology relevant to STEM-based science learning can help students more easily understand science concepts through visualization, simulation, and interactive exploration. Applying STEM PD integrated with technology can provide ideas for teachers to develop science learning (Chiang & Liu, 2023; Nasir et al., 2022).
4. Stakeholder support: an effective STEM PD program must provide support from within and outside the school environment (Aslam et al., 2020; Lynch et al., 2019). This support consists of appropriate curriculum, learning facilities, school leaders who support teachers' professional development activities, and other teachers' professional development support activities related to STEM.
5. Sustainability: effective STEM PD programs require ongoing support. This aims to ensure that teachers want to maximize their competencies. This support can include coaching, mentoring, and a constant professional learning community. The sustainability of the implementation of STEM education in science learning is greatly influenced by the sustainability of the STEM PD program (Conradty & Bogner, 2020; Havice et al., 2018).

Professional development programs provide teachers with the knowledge and skills to effectively integrate STEM into their teaching. This highlights the importance of opportunities to develop professional development programs with specific objectives primarily for STEM-based science learning. Several factors mentioned above prove that with the support of these factors, STEM-focused professional development programs that use several approaches can make the implementation of STEM education more effective (Heba et al., 2017; Nesmith & Cooper, 2019).

The implementation of STEM PD is carried out using various approaches, strategies, and methods adapted to the teacher competency objectives to be achieved. The strategies and methods that are often used are collaborative. Collaboration is usually carried out with colleagues and teachers or involves other parties. The results of the collaboration are in the form of creating discussions between teachers and allowing teachers to obtain input from colleagues, the community, the public, experts, and other parties who participate in the STEM PD program (Baker-Doyle & Yoon, 2011; Kelley et al., 2020; Richmond et al., 2017; So et al., 2021).

The inquiry method is a method that is also often used in the application of STEM PD. STEM PD using the inquiry method gives teachers the confidence to manage learning. This is because the inquiry method provides opportunities for teachers to investigate and find appropriate strategies for implementing STEM-based science learning in their classes. Teachers who have found the right teaching strategies will have confidence when carrying out learning and can increase students' understanding and motivation (DeChenne et al., 2015; Gardner et al., 2019; Kelley et al., 2020; Nadelson et al., 2013; Nasir et al., 2022; Ong et al., 2020; Schallert et al., 2021; Wang et al., 2015).

A strategy that is also widely used in implementing STEM PD is the use of technological assistance. The technology used can be in the form of websites, videos, applications, and other technologies (Hennessy et al., 2022; Kim et al., 2020; Wang et al., 2015). STEM education cannot be separated from technology because STEM learning requires the integration of various fields of science. Implementing STEM-PD that utilizes technology aims to facilitate and identify appropriate and effective technology in helping achieve STEM PD goals. Effective STEM PD is a series of structured PD that results in changes in teacher practices and improved student learning outcomes related to STEM learning.

STEM PD in science learning aims to develop teachers' professionalism competencies in STEM-integrated science learning (Aldahmash et al., 2019; Brown & Bogiages, 2019). These competencies are expected to help improve students' critical, creative, and analytical thinking skills. Integrating science learning with STEM is needed to strengthen direct learning opportunities for students to gain learning experiences so that they can solve problems faced by the surrounding community and the whole world. The basis for successfully implementing STEM-integrated science learning includes fostering student engagement and participation, improving teacher capability, and supporting STEM learning practices (Chiu et al., 2021; Roehrig et al., 2021). These three things are interrelated elements and focus on the ability of science teachers to implement STEM-integrated science learning. Thus, science teachers must develop professional competencies to create practical STEM-integrated science learning through STEM PD. In Indonesia, STEM learning is generally only implemented in science and mathematics. The effective implementation of STEM PD for science teachers is expected to create teachers who can implement STEM learning well so that it can encourage other subject teachers to collaborate in implementing STEM learning in their curriculum.

CONCLUSION

STEM PD in science learning is one of the programs expected by most teachers to improve their competence in STEM learning. This study states that in the last five years, the progress of the STEM PD program has been implemented to facilitate teachers from primary to tertiary levels. In addition, the progress of STEM PD can be seen from several aspects, including: teacher's participation, changes in teacher competencies, STEM integration in the science curriculum, improved student competence, and resource enhancement. In addition, implementing an effective STEM PD program must meet several factors: STEM approach, collaboration and partnerships, use of media and technology, stakeholder support, and sustainability. Based on the literature study conducted by the author, it is recommended to develop a STEM professional development program that includes current trends and global perspectives in science education. This approach will ensure educators have the knowledge and skills to deliver high-quality STEM teaching.

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