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STEM professional development: A decade of progress

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ABSTRACT
Along with the development of STEM education at all levels of education, STEM teacher professional development (TPD) has become an important topic. This study aims to provide a comprehensive picture of the progress of STEM PD over a decade in terms of the characteristics of STEM PD publications, developments in STEM PD research, and trends in STEM PD research topics. This research presents a bibliometric analysis of STEM PD topics using VOSviewer and Microsoft Excel. Seven hundred and sixty four publications were retrieved from Scopus and used in this study. The characteristics of STEM publications show that the author who is most influential as measured by citations regarding STEM PD is Moore, T.J., the country with the most publications is the US, and the International Journal of STEM Education is the source of the journal with the highest citations. Data shows increased research development regarding STEM PD from one year to the next. The implementation of STEM PD is carried out using various methods and objectives. Trends in STEM PD research topics are associated with the keywords found. Some of these keywords show that STEM PD is closely related to the learning process, curriculum, teacher competency, and educational development. This research examines STEM PD programmes for instructors from various disciplines, their techniques, and their impacts. This study's findings can be utilised to determine the trajectory of future research in the implementation of STEM PD and as a guide for the development of future research.

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Introduction

STEM education helps learners become problem-solvers, innovators, inventors, logical thinkers (Ammar et al., 2024; Hou et al., 2020), and technologically literate by using science, technology, engineering, and mathematics (Gil-Doménech et al., 2020; Septiyanto et al., 2024; Takeuchi et al., 2020). They can apply their knowledge in pertinent real-world contexts, promoting independent thought and responsible behaviour (Dare et al., 2021; Muhfahroyin et al., 2023). Moreover, it strengthens their engagement with technological and social change, and enables them to implement sustainable development practices in their local and global communities (Gamage et al.,

2022; Kamarrudin et al., 2022). STEM provides opportunities for hands-on investigation, experimentation, inquiry, and the formation of rational responses (Zhai, 2019). In addition to solving problems, learners develop a proper understanding of natural phenomena (minds on) through the in-depth study of the issues, just as scientists do (Akiri et al., 2020; Parmin et al., 2020); therefore, STEM is effective at fostering positive changes in learners' perceptions to predict future societies and sustainable development and to make decisions that promote harmony among environmental, economic, and social domains (Gamage et al., 2022; Suh & Han, 2019).

STEM is an integrative learning model that combines science, technology, mathematics and engineering. STEM education can increase learners' interest and engagement with STEM fields and better prepare them for a future STEM workforce where disciplines are interrelated and integrated. This attention to integrating STEM fields of study has led to the developing and implementation of integrated STEM programmes in real classrooms (Nadelson, 2017; Xue et al., 2023). Many educational institutions have begun to emphasise STEM education early on by training science teachers to implement STEM education in their classrooms (Kelley et al., 2020; Kelley & Knowles, 2023). The purpose of STEM training for teachers is to instil a solid conceptual understanding of STEM learning and practise it optimally (Kelley et al., 2020; Lin et al., 2021; Sari et al., 2020). However, since STEM education emerged, there has been little research on teacher professional development in integrated STEM education.

The literature provides reasoned and comprehensive answers about the essential characteristics of effective teacher professional development (PD) and its effects on teachers' beliefs and classroom practices (Boz, 2023). Providing professional development is one way to support teachers in implementing STEM learning. The implementation of learning will not run effectively without continuous support from teachers. Therefore, addressing teachers' learning needs through professional development is crucial, as teachers are the primary vehicle for delivering STEM education to school learners (Bouwma-Gearhart, 2012; Clair et al., 2020; Farrow et al., 2022).

Effective professional development is continuous and collaborative. Professional development is a variety of learning activities that support teachers in applying what they learn to their practice and in solving classroom problems (Clair et al., 2020; Du et al., 2019; Farrow et al., 2022; Nesmith & Cooper, 2019; Ufnar & Shepherd, 2019). PD is usually carried out in the form of training activities (Aydin-Gunbatar et al., 2020; Du et al., 2019; Farrow et al., 2022) and workshop activities (Clair et al., 2020; Nesmith & Cooper, 2019; Ufnar & Shepherd, 2019). Variations in PD implementation are tailored to the objectives and teacher competencies to be achieved

STEM professional development (STEM PD) has been conducted by Nesmith & Cooper (2019) in the form of a 2-year workshop with three sessions each year, each containing significant group discussion activities, interactive, and small group work. STEM PD has been implemented by Du et al. (2019) in the form of a three-year training with a total duration of 195 stages, which consists of training on engineering design, STEM modelling, and problem- and project-based learning. Several researchers have conducted studies on the implementation of STEM PD. It can help teachers develop their understanding in the classroom (Hasim et al., 2022; Johari et al., 2022a). Bibliometric research on STEM PD has been conducted by Ahmed et al. (2023), but this study only discussed the expansion of STEM PD research. Further studies are also needed to analyse development in this area and identify the challenges of STEM PD implementation for future development.

Based on the explanation above, research on STEM PD has been carried out using specific strategies and methods. This research aimed to determine the progress of STEM PD over the last decade regarding publication characteristics, research developments, and trends in research topics regarding STEM PD using quantitative methods with a descriptive approach in bibliometric analysis. Based on the research background that has been stated, the problems studied can be formulated in research questions as follows:

1. What are the characteristics of STEM PD publications in the last decade?
2. How has research on STEM PD evolved in the last decade?
3. What is the trend in STEM PD research topics over the last decade?

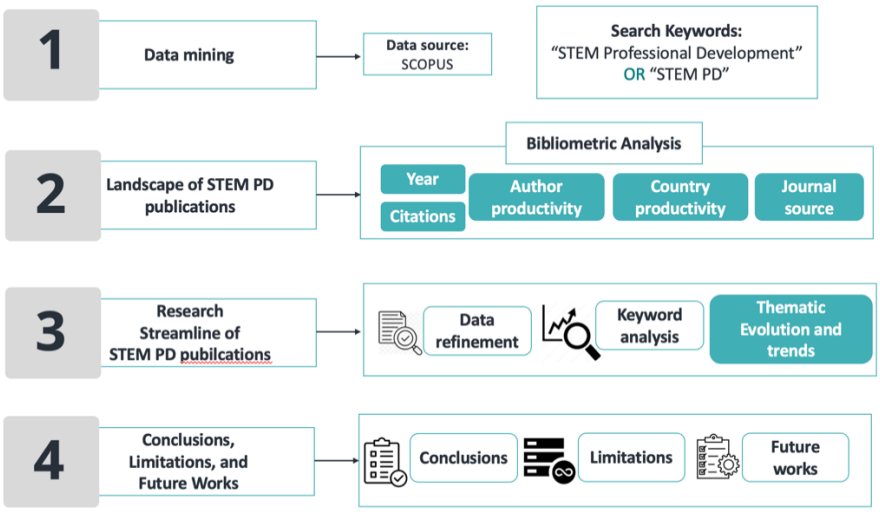
The problem limitation in this study is the data used in English-language journal articles with publication restrictions in 2013-2023. The data used comes from the Scopus database. The data used is based on the keyword "STEM Professional Development". This research uses VOSviewer software to map the results of publication development. VOSviewer was chosen because this software has been well-developed and well-documented in many fields.

Methods

This research methodology is quantitative utisiling a bibliometric analysis technique. Bibliometrics is the quantitative and descriptive statistical analysis of publications, including journal articles, proceedings and books (Raman et al., 2021). This type of analysis generates valuable data for evaluators of scholarly activity (Castillo-Vergara et al., 2018; Rey-Martí et al., 2016). The data in this study were obtained from research publications based on the Scopus database in English-language journal articles within the publication period from 2013 to 2023. Bibliometric analysis using data from Scopus is highly favoured because the quality and reputation of journals indexed in Scopus are high and go through a rigorous peer-review process. Hence, the data obtained is more credible and reliable than data obtained from other sources that are not indexed or less verified, and do not go through a strict peer-review process, databases that do not have the same standards in selecting articles, or publications that are not indexed in reputable academic databases. The data provided by Scopus is well structured, making it easier for researchers to perform various types of analysis, such as citation analysis and collaboration networks. In addition, Scopus has powerful internal analysis tools, such as Scopus Analytics, which make it easier for researchers to conduct in-depth and comprehensive analyses (Baas et al., 2020), Figure 1 details the research procedure (Abdullah et al., 2023).

Figure 1

Research methodology



The first step, as depicted in Figure 1, is data mining. The author relies on Scopus. Scopus was chosen because it is one of the most comprehensive indexes of published documents, incorporates metadata from respectable publications, and is used for bibliometric research out of place here – amalgamate all material of Scopus (Abdullah et al., 2023; Bahri et al., 2022). On the 2nd of June, 2024, a document search using the keywords "STEM professional development" or "STEM PD" yielded 4040 results. In addition, the authors selected relevant documents using inclusion and exclusion criteria. Document type (article), publication stage (final), language (English), source type (journal), and publication year (2013-2023) are the inclusion criteria for this study.

The authors utilised only articles published in reputable international periodicals. After applying the inclusion and exclusion criteria, 764 documents were used in this investigation. In comma-separated values (CSV) format, 764 documents' metadata were downloaded. The second phase of this research was to conduct a bibliometric analysis to determine the state of STEM PD research. This study utilised VOSviewer and Microsoft Excel for bibliometric analysis. Annual publication trends, citations, author productivity, country productivity, and journal articles on STEM PD are among the factors considered.

The third step was to downsize the data and identify keywords. Identification was by checking how often the keywords are used and the relationship between one keyword and another. Decreasing the data is done to reduce bias - the counting of keywords with the same meaning separately. The outcomes of this analysis were subsequently used to ascertain thematic evolution and current research trends within the STEM PD theme. Based on the data analysis, the final stage of this study is to determine the study's limitations and future research projects.

Findings and Discussion

Bibliometric analysis is a quantitative study of bibliographic materials that overviews publications on a particular subject, identifies changes in specific scientific research topics, and determines trends in a discipline (Hebebci, 2021; Pham et al., 2023). Analysing STEM PD publications using bibliometrics effectively determines conclusions, limitations, and recommendations for developing research on STEM PD.

This study uses bibliometric analysis to track the evolution of STEM PD research over the last ten years. More research has been conducted on STEM PD every year during the past ten years. Because STEM education has recently become crucial in many nations and the focus of policymakers' attention, there has been an increase in the number of articles on STEM-PD (Assefa, 2013; Aydin-Gunbatar et al., 2020; Byars-Winston, 2014; Ha et al., 2020). The development of STEM learning needs to be balanced with the development of students' knowledge abilities. The development of teachers' abilities must accompany the development of students' abilities, so teachers need to develop their professionalism in implementing STEM learning (Bouwma-Gearhart, 2012; Chai, 2019; Hancock, 2016; Pham et al., 2023).

The results of this study explain the progress of STEM PD in terms of several things, namely, the characteristics of STEM PD publications, the development of research on STEM PD, and trends in STEM PD research topics. The characteristics of STEM PD publications in this study are reviewed based on author productivity, number of citations, countries, and journal sources. The development of research on STEM PD can be seen from the development of the number of publications on STEM PD and the development of STEM PD methods conducted in the last decade. Trends in STEM PD research topics can be seen through keywords often used and the relationship between these keywords.

Characteristics of STEM-PD Publications

This study investigated STEM PD publication author productivity, citations, country, and journal source. The authors who have received the most citations impact a particular field of study (Abdullah et al., 2023; Sánchez-Roldán et al., 2022).

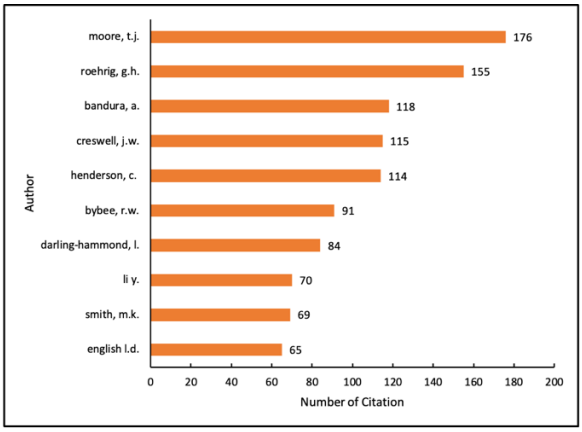
Characteristics of STEM-PD Publications by Author Productivity and Number of Citations

When analyzing a research topic, it is necessary to discuss the analysis of author productivity and the number of citations (Abdullah et al., 2023; Barbosa et al., 2022). We can quickly search for documents on a topic if we know its most prominent authors. According to the database, 758 authors have published documents on STEM-PD. Figure 2 represents the top ten STEM-PD authors with the most citations, whereas Figure 3 illustrates the top ten STEM-PD authors with the most significant

number of publications. Authors with the most citations are the most influential on the research topic (Abdullah et al., 2023; Sánchez-Roldán et al., 2022).

Figure 2

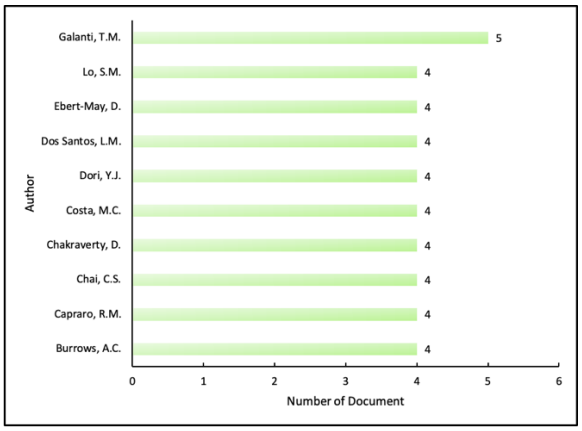
The top ten authors with the most citations



Moore, T.J. has the most citations with 176 citations, making him the most influential author in STEM-PD research. The many citations indicate that Moore, T.J.'s research is widely regarded as being of high quality, and relevant. Articles that have a large number of citations make a significant contribution to the development of knowledge, especially in STEM PD research (Istyadji & Sauqina, 2023; Wang et al., 2019).

Figure 3

The top ten authors with the most works published



Based on Figure 3, Galanti T.M. is considered a prolific author of articles on STEM PD, so he can be considered an expert in STEM PD research. In the last decade, Galanti T.M. has focused on publications on STEM PD in reputable journals. One of his articles is related to measuring teachers' competencies in teaching STEM, and the article states that to develop their competencies, teachers not only need the implementation of PD but also need agencies or institutions that can help them develop their competencies through various competency development activities (Galanti & Holincheck, 2022).

Characteristics of STEM-PD Publications by Country

Analysing STEM-PD papers from different nations helps establish which nations have published the most and highest-impact articles on this issue. Figure 4 shows the top ten countries, out of 40, with the most publications on STEM-PD topics. Figure 4 displays the ten nations with the most STEM PD publications. The United States (US) ranks first based on the number of citations of publications that examine STEM PD studies.

Figure 4

The ten nations with the most publications

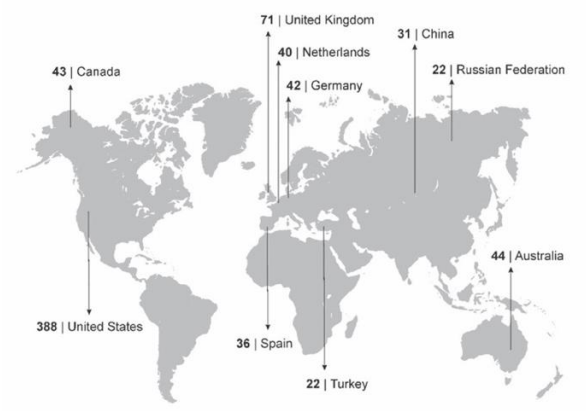
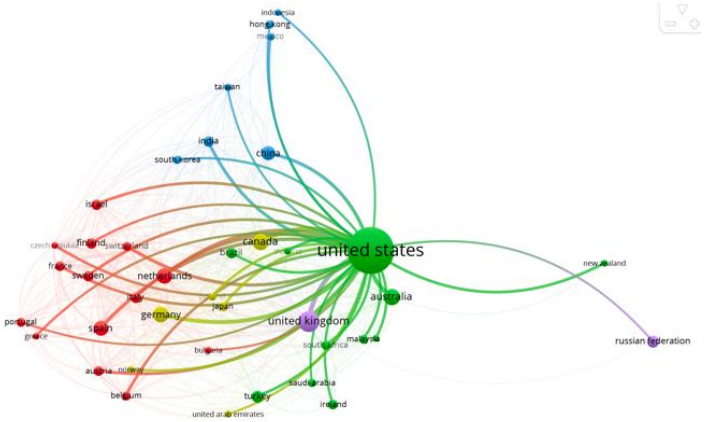


Figure 4 shows the 10 countries with the most publications on STEM PD topics. The United States (US) is the first country based on the number of citations of publications examining studies on STEM PD. The next ranking based on the number of publications is the United Kingdom (71), Australia (44), Canada (43), Germany (42), Netherlands (40), Spain (36), China (31), Russian Federation (22) and Turkey (24).

Next, we analysed the characteristics of STEM PD publications using the international research cooperation map. Using VOSviewer software, Figure 5 represents a map of international cooperation between nations.

Figure 5

Country collaboration on publications



The network visualisation map in the number of publications per country is shown in Figure 5. The collaborative interconnections in these publications explain the interconnection links between

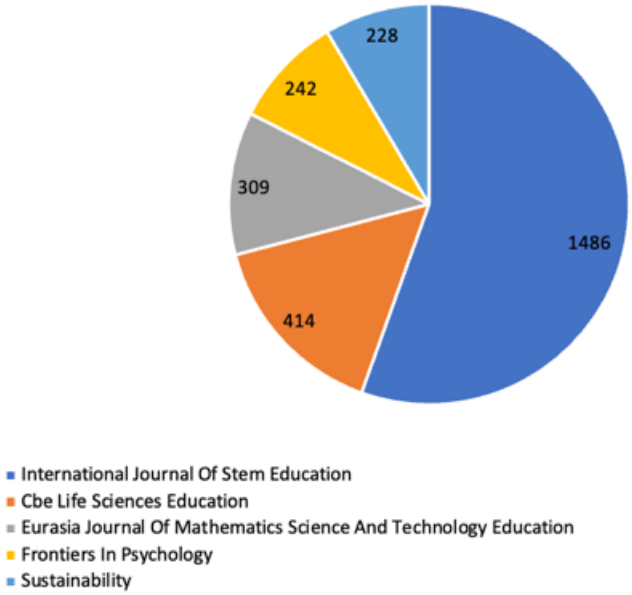
countries. There are 88 countries shown on the visualisation map, which are divided into 5 clusters. The United States has the most significant number of publication citations in STEM PD research. In addition, the characteristics of publications on STEM PD were analysed based on the map of international research cooperation. Cluster 1 is shown in red, indicating linkages between 14 countries, indicating that the cluster has dominant collaborative interactions. The US is located in cluster 2, shown in red, connected to 11 countries. Although located in cluster 2, the US is connected to productive countries such as Australia and Turkey. Furthermore, cluster 3 is shown in blue, consisting of 7 countries, cluster 4 is yellow with 6 countries, and cluster 5 is purple with 2 countries.

Characteristics of STEM-PD Publications by Journal Source

One of the fundamental tenets of citation analysis is that it can disclose the influence of a specific article based on the citations it receives from other articles (Abdullah et al., 2023; Rossetto et al., 2018). The sources with the highest number of publication citations in the citation analysis by source are shown in Figure 6. The International Journal of STEM Education is ranked as the first source based on the number of publications examining STEM-PD, with 1486 citations. The next in rank is CBE Life Sciences Education, Eurasia Journal of Mathematics Science and Technology Education, Frontiers in Psychology, and Sustainability.

Figure 6

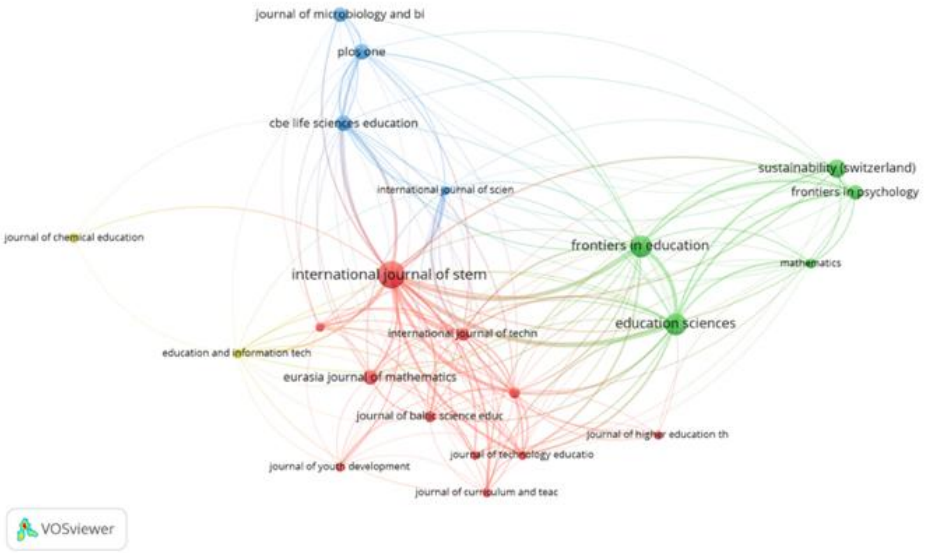
Journals with the most significant number of cited articles



The International Journal of STEM Education is the most cited publication for STEM professional development. It is also the journal with the greatest interconnection, with 18 other journal sources connected to it. When a journal is listed in quartile 1, it is superior to journals ranked in other quartiles in quality (Vijayan & V R, 2021).

Figure 7

Network visualization map of source-based citation analysis



The network visualisation map in the source-based citation analysis is shown in Figure 7. 22 sources are divided into 4 clusters. International Journal of STEM Education is the journal with the most dominant interconnection, which is connected to 21 other journal sources. The journal is a Q1-ranked journal, which means that in terms of quality, it has advantages over others (Vijayan & V R, 2021).

The results of the above characteristics generally indicate the contribution of authors and institutions that provide a reputable picture in scientific publications on STEM PD. Authors and experts in STEM PD publications appear to be highly productive, and their publications also have many citations. The citations are mostly from highly reputable authors and journals, suggesting that the publications are highly influential and relevant to the field (Rossetto et al., 2018; Wang et al., 2019). It was also found that many countries with developed education systems have publications on STEM PD, indicating that considerable attention is paid to STEM teaching in these countries.

The Development of STEM PD Research

The development of research on STEM PD can be seen from the development of the number of publications on STEM PD and the development of STEM PD methods carried out in the last decade. STEM-PD publications can be seen in 764 databases from Scopus spread over 2013-2023. In general, the critical information from these databases is depicted in Figure 8.

Figure 8

Important data from the database

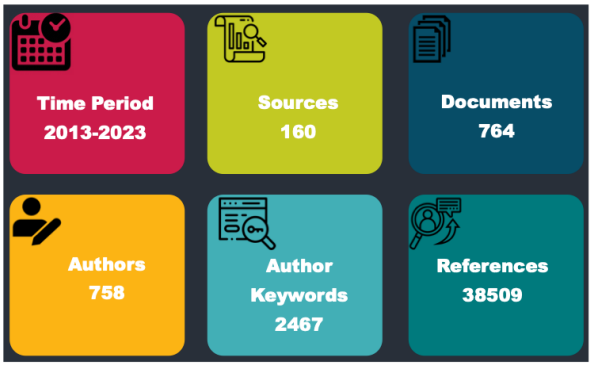
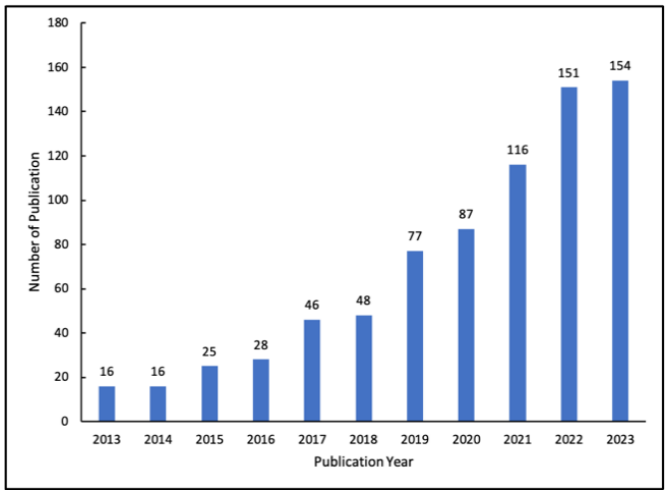


Figure 8 demonstrates research publications on STEM-PD consisting of 764 documents published in 160 international journals, with 758 authors. The development of research publications on STEM-PD from 2013-2023, as shown in Figure 3, has increased yearly. The highest increase is from 2021 to 2022, an increase of 35 articles.

Figure 9

Trend distribution of STEM-PD publications



The increase in the number of articles on STEM-PD is because, in recent years, STEM learning has become essential in several countries and the centre of policymakers' attention (Assefa, 2013; Aydin-Gunbatar et al., 2020; Byars-Winston, 2014; Ha et al., 2020). The development of STEM learning needs to be balanced with the development of students' abilities and knowledge. The development of teachers' abilities must accompany the development of learners' abilities, so teachers need to develop their professionalism in implementing STEM learning (Bouwma-Gearhart, 2012; Chai, 2019; Hancock, 2016; Pham et al., 2023).

Training teachers through professional development to build teachers' STEM education curriculum and improve teachers' perceptions and understanding of STEM education is paramount (Han et al., 2022; Kelley et al., 2020). The data show that professional development and confidence in implementing STEM learning are significant for teachers to implement integrated STEM learning successfully (Han et al., 2022; Nadelson, 2017). According to research, various studies on STEM PD have been carried out in multiple fields, such as in the fields of science (Saat et al., 2021), chemistry

(Adebusuyi et al., 2022; Oztay et al., 2022), mathematics (Johari et al., 2022b), English education (Aguirre-Muñoz & Pando, 2021), and other teachers have participated in STEM PD implementation studies.

Recent publications on implementing STEM PD for teachers have used various strategies to implement such programmes. Research on STEM PD show several techniques used in implementing STEM PD, such as partnership methods (Saat et al., 2021), community-based (Weinberg et al., 2021), use of technology (Ng & Park, 2021; Wahono et al., 2022), computational thinking (Colclasure et al., 2022; Jocius et al., 2021), engineering practice (Christian et al., 2021) and various other approaches. The objectives of implementing STEM PD also vary, including improving teachers' teaching skills in STEM learning (Wahono et al., 2022), self-ability (DeChenne, 2015), and other competencies.

Research on STEM PD shows a significant surge in the number of publications. This reflects the increasing attention being paid to this field. STEM PD has flourished with the adoption of innovative and interdisciplinary approaches (Christian et al., 2021; Wahono et al., 2022; Weinberg et al., 2021). These approaches include using digital technologies, project-based learning, inter-teacher collaboration and emphasising 21st-century skills. The growth in publications and the variety of methods used show significant progress in improving the quality of education and skills in STEM fields.

Trends in STEM PD Research Topics

An author keyword analysis is essential to the analysis in bibliometric research as it identifies leading research topics (Abdullah et al., 2023). In addition, the emergence of author-defined keywords indicates the existence of spatial proximity between the various issues analysed (Donthu et al., 2021).

Most Used Keywords in Studies

In the dataset of 764 publications, a total of 5870 keywords were used. The analysis was conducted with keywords repeated 10 times in the study. A total of 103 keywords met this criterion and formed 5 distinct clusters. The list of top keywords based on the keyword analysis is shown in Table 1. "Professional development" was the most popular keyword with 135 occurrences.

Table 1

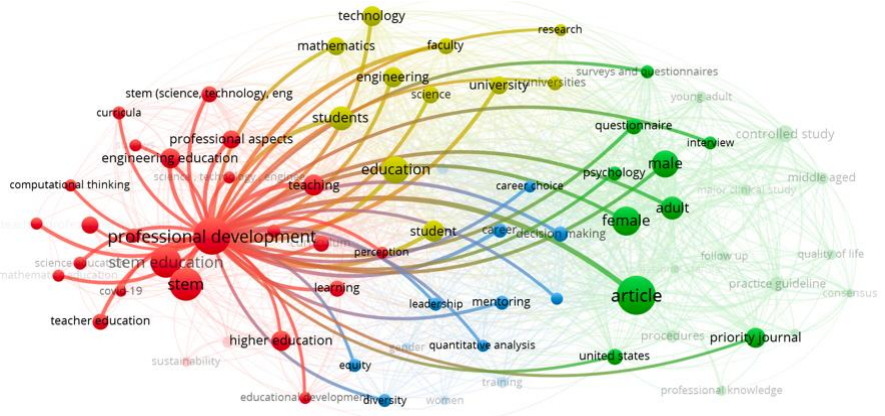
List of top keywords based on occurrences analysis

No	Keyword	Occurrences	Total Link Strength
1	Professional development	135	425
2	STEM	107	209
3	STEM Education	95	141
4	Education	68	535
5	Students	53	427
6	Teaching	40	307
7	Higher Education	37	109
8	Engineering	35	333
9	Technology	35	286
10	Engineering Education	35	164

The keyword network visualisation map is shown in Figure 10. The map categorizes these keywords into 4 clusters. Cluster 1 is represented by the colour red, Cluster 2 by the colour green, Cluster 3 by the colour blue, and Cluster 4 by the colour yellow. The magnitude of each keyword node shows its frequency in the database, while the line linking them indicates their relationship.

Figure 10

Keyword network visualization map based on co-occurrence analysis



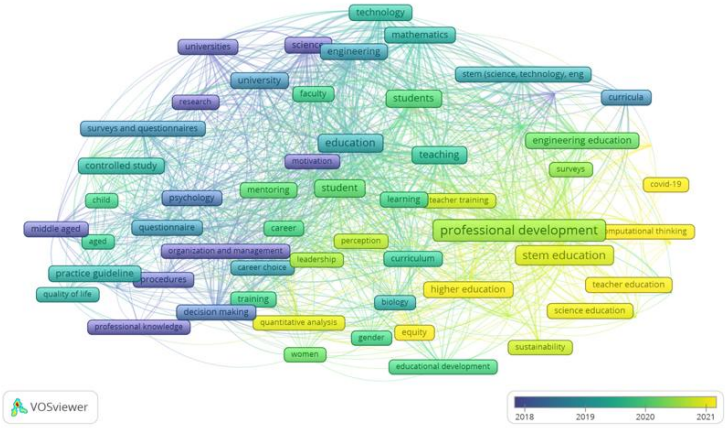
"Professional development" appears the most, with 135 occurrences, and is related to 26 other keywords. Other keywords are STEM, STEM education, teacher education, teacher professional development, teaching, educational development, and curricula. These keywords indicate that professional development requires teachers to be able to implement more effective STEM learning strategies and have the perception that STEM is an integrative learning that requires resources and support from various aspects of the school environment, learners, and curriculum (Du et al., 2019; Farrow et al., 2022; Han et al., 2022; Lin et al., 2021).

Primary keywords that appear on Keyword Trends in Studies

The following analysis shows the trend of keywords in the STEM-PD field that emerged in the 2012-2022 timeframe, as shown in Figure 11.

Figure 11

Keyword trends



The colour indicates the average number of publications per year (Donthu et al., 2021). The bluish indicates those keywords used in the early years, while the yellow indicates keywords appearing in the most recent publications. Classifying keywords can be considered as themes or subthemes of an article (Abdullah et al., 2023; Gunawan et al., 2022).

The keywords "teacher education", "science education", "computational thinking", "higher education", "stem education", and "teacher training" are some of the new research areas in Teacher

Professional Development (TPD) in STEM education. These themes can be assumed to continue to be popular and essential in implementing STEM-PD. This information can help researchers and academics choose suitable themes for their research and ensure they are still helpful and not outdated. Trends in STEM PD research topics can be observed by analysing frequently occurring keywords and the relationships between these keywords. By examining the frequency and relationships between keywords, we can identify the most popular research areas and how these topics interact with each other (Donthu et al., 2021; Ha et al., 2020). This analysis helps identify emerging trends and research directions in STEM education.

Bibliometric analysis is used to characterise STEM PD research in this literature review. This is one of the methods used in this investigation to detect significant developments. This method's analysis aids in mapping the scientific literature that has come before (Nobanee et al., 2021). The description of recent publications on STEM professional development provides opportunities for innovation and the development of more effective programmes for instructors in various fields. Consequently, the description can be used to develop STEM PD by employing strategies and approaches consistent with the requirements of teachers, curriculum, stakeholders, and other relevant parties. In addition, implementing the STEM PD programme is required to develop the professional competence of teachers in current learning trends. This can be used for future research expansion.

Conclusion

This research presents a complete bibliometric analysis of the STEM PD research theme conducted using VOSviewer and Microsoft Excel. The database in this study used Scopus, which surveyed publication results from 2013 to 2023. The analysis in this study focused on three main points: the characteristics of STEM PD publications, the development of STEM PD research, and trends in STEM PD research topics. The three points illustrate the increase in publications on STEM PD, which shows the increasing interest and importance of this topic among practitioners and researchers; the main issues that are often associated are related to teacher competence, teacher training, educational development, and curriculum; there are collaboration and research networks between authors and institutions from various countries, which shows that STEM PD is a global issue that can involve many parties; the source of journals and authors that have a high reputation shows that the quality of publications is very important in the field of STEM PD; and the implementation of STEM PD is carried out using diverse and comprehensive methodologies aimed at improving teacher competence in STEM teaching practices. The results of this study indicate that the study of STEM PD is a dynamic field and will continue to evolve as it makes tangible contributions to the improvement of STEM teaching that will provide practical recommendations for stakeholders, researchers, academics, and trainers to guide further research.

Limitations and Recommendations

Two factors limit this study. This study relies on a limited number of keywords and is potentially constrained by using a singular database (Scopus) to collect articles. Second, despite using formal software in this study (VOSviewer software and Microsoft Excel), the author conducted subjective research, which may have led to errors. Future studies should employ a larger sample size by expanding the keywords and utilizing multiple databases. In addition, it is possible to conduct bibliometric analysis using various software (such as BibExcel and HistCite). Given the growing number of studies discussing teacher professional development in STEM education, additional research is suggested to provide a more thorough explanation.

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