STEM in physics learning: Benefits, challenges, and future research opportunities

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Abstract
Data-driven approaches have emerged for several reasons, including the continuous evolution of the education sector. Across various educational fields and levels, STEM integration in learning has been implemented. Therefore, this journal presents data on the role of STEM in Physics Education. The research discussion on the use of STEM in Physics learning can also serve as a coherent background and literature review for readers who wish to conduct further research. The literature review is conducted by considering the bibliometric perspective of publications related to STEM integration in Physics learning. This study supports the journal's importance by highlighting the need for reputable journal publications. The analysis aims to provide a comprehensive bibliography and review of STEM's use in Physics learning, utilizing the "Bibliophagy" function within the "bibliometric" package of R-studio. A total of 880 papers, published between 2014 and 2025, were reviewed. This study provides perspectives, namely a general overview, annual publication numbers, prominent authors, institutions with the highest citations per document, and countries with the highest productivity. This analysis generates journals, highly cited authors, reference networks, and groups with significant contributions to the literature. This journal can be used to improve the understanding of readers or future researchers regarding global research, identify research gaps, and support further research in this field.

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1. Introduction

STEM education is both an educational ideology and a curriculum grounded in an instructional approach that integrates four disciplines: science, technology, engineering, and mathematics, all of which are related to real-world problems (Czerniak & Johnson, 2014). Science, Technology, Engineering, and Mathematics (STEM) education is an essential need in terms of recruitment, retention, and reform in practical education (Gehrke & Kezar, 2017). The STEM concept was first introduced by National Science Foundation Education Director Judith Ramaley in 2001 (Yıldırım & Altun, 2015) STEM learning serves to create a learning environment and provide students with integrated learning that focuses on improving the skills needed in the job market. This is necessary so that students can learn the fragmented pieces of knowledge. STEM approach equips students with skills of productivity, strengthens questioning, provides critical and creative thinking, identifies problems encountered in daily life and produces valid solutions, encourages students to take social responsibility and work collaboratively in order to adapt the skills of 21st century (Kırıcı & Bakırcı, 2021).

STEM education is vital for students to develop 21st century skills such as problem solving, innovation, creativity, communication and collaboration (Sarı et al., 2020). STEM education has been recognized as an effective approach to increasing student motivation and interest in learning STEM disciplines (Mustafa et al., 2016). In integrative STEM education, the quality of learning and student interest have the potential to increase with project-based activities. With project-based education integrated with the fields of mathematics, engineering, technology and science, their enthusiasm in learning will increase. At this stage, methods based on problem solving, exploration, and research are very closely related to the integration of STEM education (Sahin & Adiguzel, 2014). The goal of implementing quality STEM education is to produce quality science graduates, scientists,

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mathematicians, and technology experts. In addition, this method aims to prepare children for post-secondary education, facilitating problem solving in the real world (Akgunduz, 2016). Innovations in science education are necessary within a new sociocultural environment that enables the acquisition of a robust understanding of science, technology, engineering, and mathematics (STEM), which can be applied in everyday situations by students to contribute to their personal development and active integration into society as science and technology-literate citizens (Lupión-Cobos, et al., 2022).

The use of STEM in Physics learning is still in its growth period, and its full potential can be developed more broadly. One of the challenges in realizing change in STEM is the emergence of complexity due to the many intersecting fields that have their own epistemologies, cultures, and practices (Kezar, A et al., 2017). This journal provides well-articulated and in-depth data for STEM academics and practitioners in Physics learning. Specifically, this journal seeks to explain and provide further understanding of integrated STEM methods and their impact on Physics learning models, transform the relationship of each STEM element in the Physics learning process, and improve Physics learning outcomes. Furthermore, the journal is expected to reveal substantial practical and theoretical implications regarding STEM in Physics learning. This journal examines data algorithms from Scopus through an extensive literature review with bibliometric analysis. This literature review covers 1.118 journals and conference proceedings in the study period 2014–2025.

This review aims to illuminate the evolution of data algorithms within the academic landscape, specifically focusing on their role and application as documented in the Scopus database. To achieve this, a science mapping analysis will be conducted to visualize and highlight the developmental trends. Furthermore, the review will delve into the most pertinent applications of STEM principles, particularly within the physics learning process, by conducting an extensive review of literature that utilizes data algorithms. The intention is to identify and explore the prevalent models emerging from the gathered data. Finally, this review seeks to pinpoint the most promising avenues for future research regarding the implementation of STEM in physics education.

This journal's literature review is designed to address several key research questions. Firstly, it aims to determine the current trends in publications concerning the application of STEM within physics education. Secondly, it seeks to identify the most prominent themes that emerge in the utilization of STEM within the physics learning process. Thirdly, the review will identify the most influential authors contributing to the body of knowledge on the use of STEM in physics education. Finally, it will provide a comprehensive overview of the current state of scientific research regarding the application of STEM principles in the physics learning process.

2. Method

This journal's research method analyzes academic research journals on STEM applied in Physics learning. A bibliometric data search was conducted using the keywords "STEM" and "Physics Education" on the Scopus database on January 30, 2025. All journals with keywords related to this journal title will be detected, ensuring completeness in the document data. Scopus, a bibliographic database developed by Elsevier starting in 2002 and released in November 2004, has since incorporated many articles published before its launch (Thelwall & Sud, P., 2022). Scopus covers 240 disciplines and has over 76 million journals to provide researchers, instructors, librarians, and students with the facts and data needed for further research (beta.elsevier.com, 2023). The structure of a scientific field can be identified from its research activities (Ronda-Pupo, 2017). To understand the research structure on the diversity of themes, bibliometric analysis is used (Castriotta et al., 2019). Bibliometric analysis makes it possible to identify current trends and future research paths (Li et al., 2017). Bibliometric methods or "analysis" are now firmly established as scientific specialties and are an integral part of research evaluation methodology especially within the scientific and applied fields, the methods are used increasingly when studying various aspects of science and also in the way institutions and universities are ranked worldwide (Ellegaard & Wallin., 2015).

2.1. Bibliometric analysis

Bibliometric methods are among the most commonly used techniques for analyzing basic research output. These methods are increasingly valued as tools for measuring scientific quality, productivity, and evolution (Rodriguez-Bolivar et al., 2018). In recent years, bibliometric analysis has gained tremendous popularity in business research, which can be attributed to the advancements, availability, and accessibility of bibliometric software such as Gephi, Leximancer, VOSviewer, and scientific databases like Scopus and Web of Science, as well as the cross-disciplinary pollination of bibliometric methodologies from information science to business research (Donthu, et al., 2021). Keyword selection is crucial in bibliometric analysis as it directly impacts findings and results. Bibliometric analysis is completed using the "Biblioshiny" function within the "bibliometrix" package (Aria et al., 2017). This section contributes to the data literacy system by providing an accurate bibliometric analysis of publications on the application of STEM in Physics learning. The evolution of the STEM definition, which this research addresses, in Physics learning, covering publications, citations, and impact through the analysis of the following bibliometric indicators: published documents, received citations, journal impact factor (IF), H-index, most cited publications, most cited authors, and data on the geographical distribution of publications. The bibliometric performance analysis of this study is divided into two parts. First, the overall production and impact of published documents are examined in this section to provide a broad overview of research output. Second, this section investigates more detailed performance aspects, specifically analyzing the production and impact of individual authors, the journals in which they publish, and the various research fields represented in the dataset.

Table 1 shows some relevant characteristics of the dataset. The table presents 1,118 publications that are most cited globally and are revealed as the most influential publications in STEM research in Physics learning.

Table 1. Data Characteristics

No	Main Information	Results
1.	Documents	1.118
2.	Sources (Journals, Books, etc)	407
3.	Keywords Plus (ID)	3.587
4.	Author's Keywords (DE)	2.194
5.	Timespan	2014:2025
6.	Average citations per doc	8.558
7.	Authors	3.337
8.	Authors of single-authored docs	125

3. Results and Discussion

STEM has captured the imagination and brought challenges and opportunities for academics and practitioners, including in Physics education. The general results of a quantitative count summary, the number of publications per year showing the chronological distribution of publications, the most cited articles by other authors, the most prominent authors, journals with the highest citations per article, institutions with the highest citations per document, and countries with the highest productivity are presented in the bibliometric analysis results. Furthermore, this analysis provides networks of references, journals, and co-cited first authors, as well as their respective clusters. The aim of this research is to gain a comprehensive perspective on the development of research on the use of STEM in Physics education and has a scope covering all available documents, languages, and countries. The results of the Annual Scientific Production are shown in Figure 1.

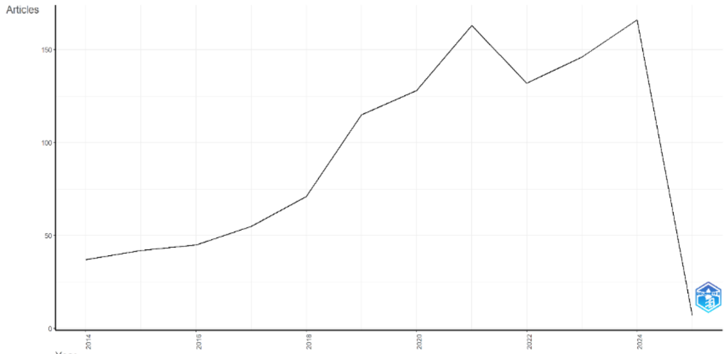

Figure 1. Annual Scientific Production

Table 2. Annual Scientific Production

No	Main Information	Articles
1	Year	37
2	2014	42
3	2015	45
4	2016	55
5	2017	71
6	2018	115
7	2019	128
8	2020	163
9	2021	132
10	2022	146
11	2023	166
12	2024	7

Figure 1 and Table 2 display the distribution of publications on the use of STEM in Physics learning during the period of 2014 – January 2025. The number of publications and the average citations per year can illustrate research output (Gautam, 2017). A relevant measure in the number of publications is the annual growth rate of publications. The influence of published work on research is a reflection of the annual average citations in the use of STEM in Physics learning and can provide key insights into the impact of its application. The growth in the number of articles published starting from 2014 shows an increase in research publications that can be observed when using STEM in Physics learning. Although the research results show a decrease in 2025 due to the presence of data from January, which does not yet have an annual growth rate for 2025 in the following months, Table 2 reveals that 2021 and 2024 were high-impact years.

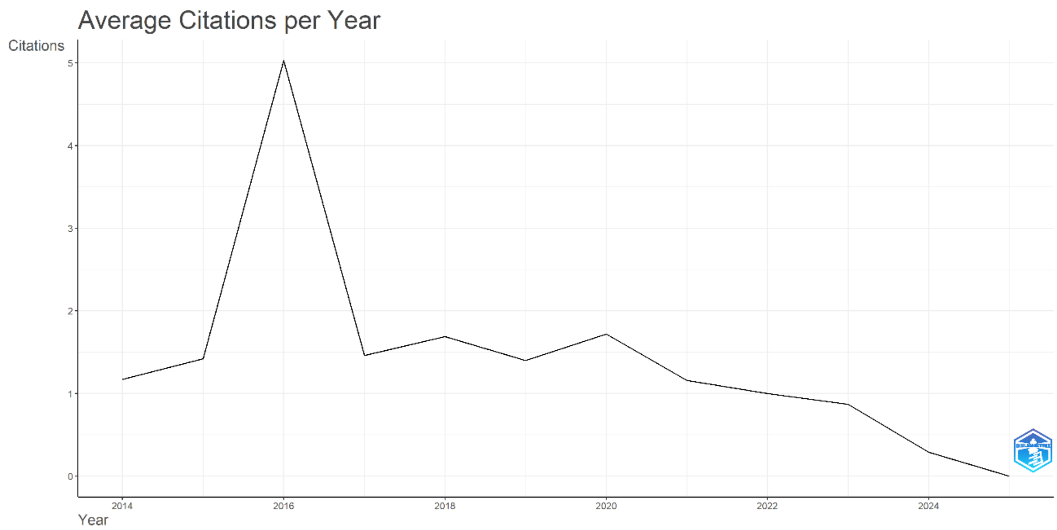

Figure 2. Average Citations Per Year

Table 2 illustrates the detailed average annual citation time of published journals. The measure used to indicate the influence of published journals is the average citations per year. It can be observed that there was an increase in citations from 2014, peaking in 2016. Following 2016, there was a significant decrease in citations each year until 2025. There are three citation peaks in 2016, 2018, and 2020. Publications from earlier years are generally the most cited due to the time lag between publication and reference. It takes between 3 and 7 years for a publication to reach its highest number of citations (Wang, 2013).

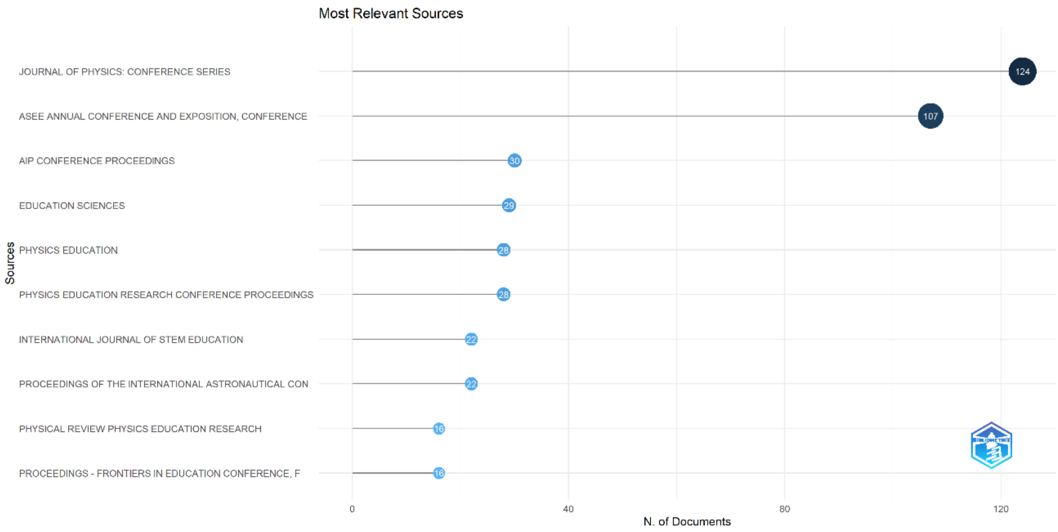

Figure 3. Most Relevant Sources

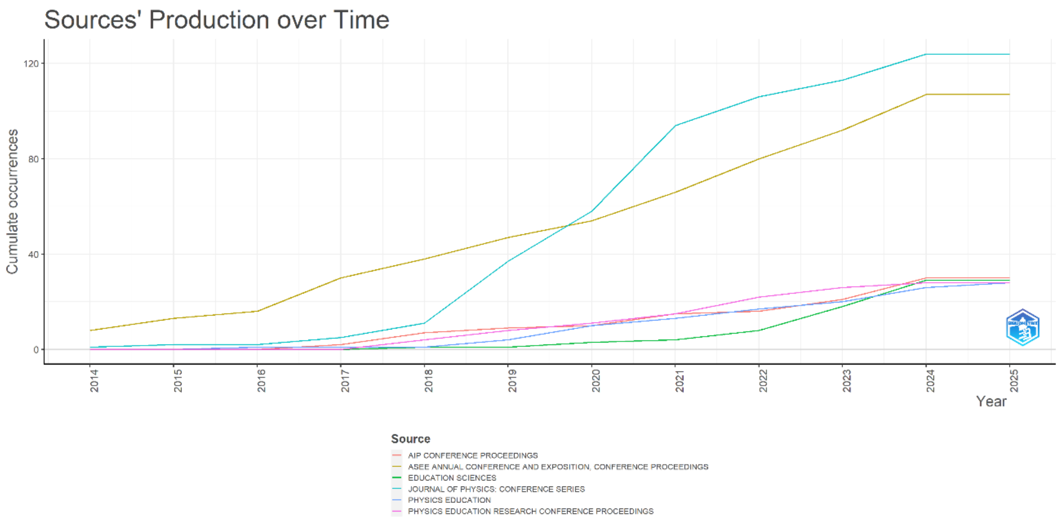

Figure 4. Sources' Production over Time

Figure 3 presents relevant sources listing the 10 significant sources that concentrate on publishing scientific articles about the use of STEM in Physics learning. Figure 4 illustrates the distribution of these 10 sources, which are the dominant and most relevant journals. Notably, the Journal of Physics Conference Series ranks first with 124 journals, followed by the ASEE Annual Conference and Exposition Conference with 107 journals. Figure 4 shows the contribution of each of the top 11 sources during the 2014–2025 period. It indicates the top ten sources with the highest number of published articles and how they have evolved in publishing more articles over time. The graph shows that after 2018, there was a surge in the number of papers published, particularly by the Journal of Physics Conference Series, and the ASEE Annual Conference and Exposition Conference, which consistently published articles each year. Most of the leading publication outlets are conferences or open-access journals.

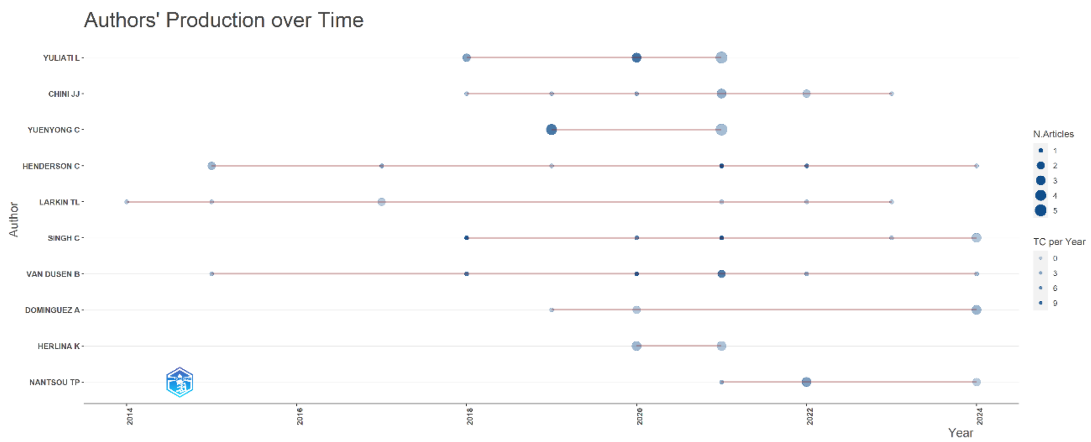

Figure 5. Authors' Production over Time

Table 3. Most Relevant Authors

No	Author	Articles
1	Yuliati L	10
2	Chini Jj	9
3	Yuenyong C	9
4	Larkin Tl	7
5	Henderson C	7
6	Singh C	7
7	Van Dusen B	7
8	Dominguez A	6
9	Herlina K	6
10	Nantsou TP	6

Figure 5 illustrates the development in article production from 10 different authors over time, and Table 3 lists the names of relevant authors with the highest number of publications who have made significant contributions in this field. It is also important to know which authors are the most productive and most cited; author productivity over time can typically be evaluated based on the number of citations their writings receive each year. According to Figure 5, Larkin TL, Henderson C, and Van Dusen B are authors with the longest contribution periods, but Table 3 shows that the most productive author is Yuliati L. In Figure 5, the color intensity is proportional to the annual time mentioned, and the bubble size is proportional to the annual number of publications.

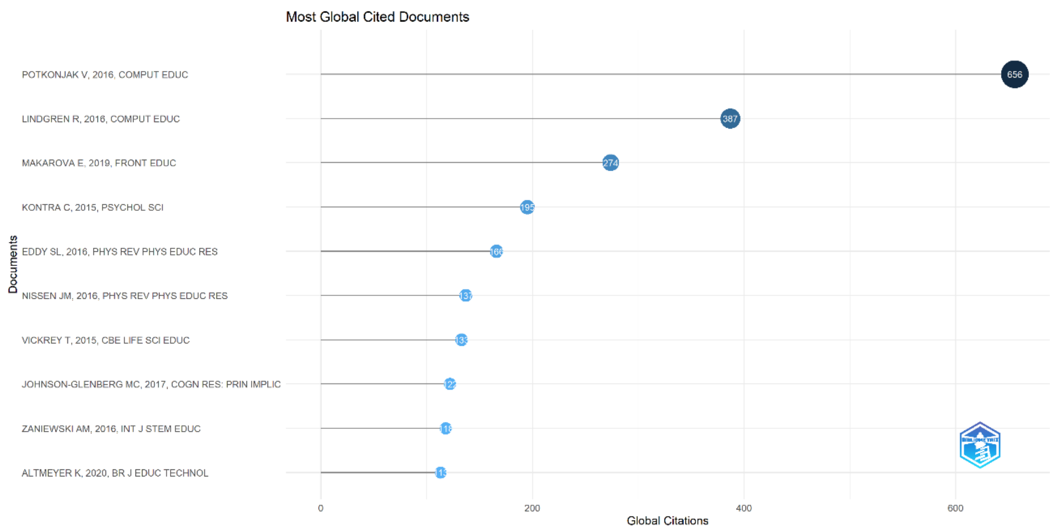

Figure 6. Most Global Cited Documents

Figure 6 highlights the diversity of journals that host leading authors, including the themes found within those journals. Additionally, the figure shows the most cited papers during the period of 2014–2025. Citations and references allow us to build intellectual connections (Appio et al., 2014). Citation analysis can be used to measure the impact of an article, which depends on the number of citations from other works. Global citations refer to how many times other works cite an article in the database, including works in other research fields and disciplines. The most cited author based on the data shown in the figure is Potkonjak V. As the reference with the highest citation power, the field of computer science is increasingly solidifying its position and continues to grow in terms of quantity and quality. The topics that are mostly observed and cited by researchers are those related to the use of technology in STEAM learning.

3.1. Research trends Topics

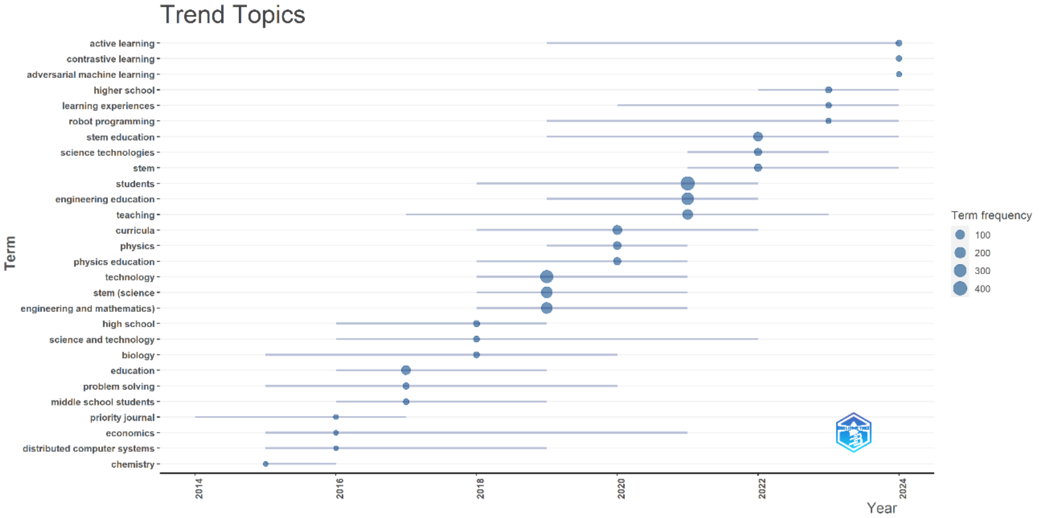

Figure 7. Trend Topics

Table 4. Most Frequent Words

No	Words	Occurrences
1.	students	412
2.	technology	323
3.	engineering education	275
4.	stem (science, technology, engineering and mathematics)	213
5.	teaching	153
6.	curricula	115
7.	education	103
8.	stem education	103
9.	physics	61
10.	students	412

Figure 7 and Table 4 show the Trend Topics of the top author keywords. The figure illustrates the subject categories and most relevant research areas. To explore common themes in the use of STEM in Physics learning, a keyword analysis was conducted. The map shows the variation of the most frequently occurring keywords. Among the most frequently occurring keywords related to the research theme of the use of STEM in Physics learning, and its main concepts, can be identified, as shown in the diagram above. This fact clearly supports the idea that there are different approaches, developments, and applications with respect to meaning in this research field. In total, the keyword "Student" appeared 412 times in the dataset, and is the most frequently occurring keyword in the journals. Trend Topics indicate that research on the use of STEM in Physics learning has so far largely focused on students, engineering education, teaching, learning, and curriculum. These keyword pairs suggest that researchers have shown great interest in the use of STEM in Physics learning, also indicating that other themes have received less attention.

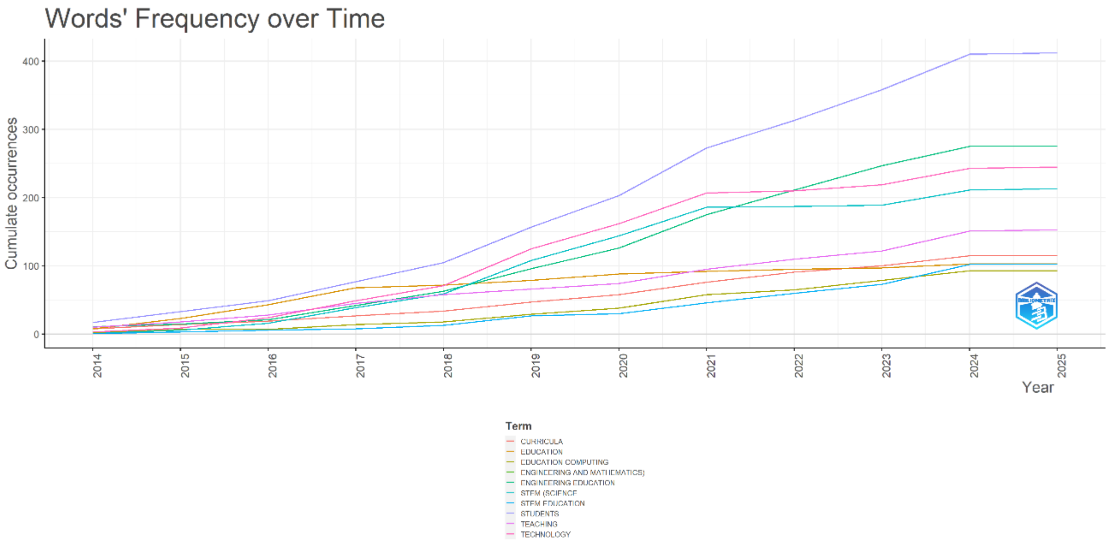

Figure 8. Words' Frequency over Time

Figure 8 illustrates the ten most common words in research associated with the keywords "STEM," "education," and "physics." Based on the content analysis of articles published in each period, a second analysis was conducted focusing on the conceptual evolution of the main themes. Therefore, 10 thematic areas were identified: students, engineering education, STEM (science, technology, engineering, and mathematics), teaching, education, curricula, education computing, STEM education, E-learning, and physics. These thematic areas consolidate the main themes and research fields related to STEM in Physics learning. The thematic area of "students" is present in all evaluated periods and the number of themes increases in each period, indicating that research themes are more interested in the "students" thematic area and various matters related to that theme.

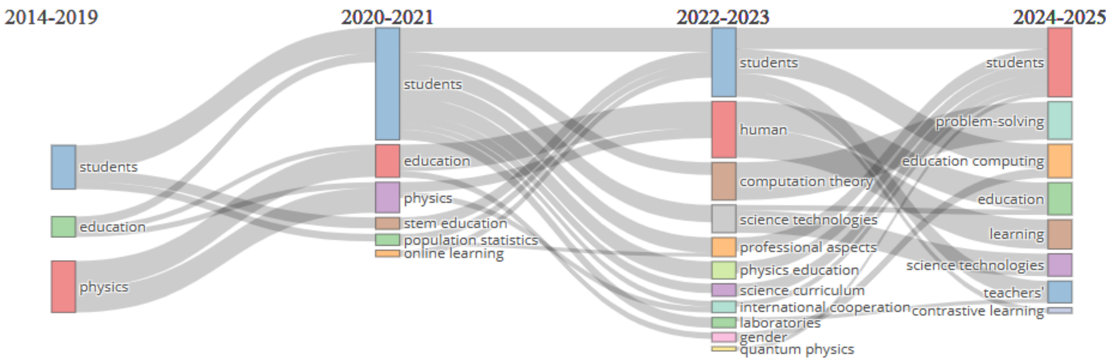

Figure 9. Thematic Evolution

Figure 9 details the distribution of reviewed articles based on application domain, published during the 2014–2025 period. Three research themes related to STEM in Physics learning and their main concepts can be identified during 2014-2019. In this context, due to their contribution to the growth of STEM research in Physics learning, these three themes are considered highly important. This period marks the starting point of scientific research, and the number of publications produced has grown rapidly, while not yet encompassing other research themes. In the second period (2020-2021), 6 research themes related to STEM in Physics learning were identified, as shown in the strategic diagram in the Figure. In this regard, due to their contribution to the growth of STEM in Physics learning, 11 research themes are considered important in the third period (2022-2023). Additionally, 11 research themes are considered central due to their contribution to the growth of the use of STEM in Physics education. During 2024-2025, in the fourth period (2024-2025), 80 research themes were identified related to STEM in Physics learning. There are 8 research themes in this context considered critical due to their contribution to the growth of STEM in Physics learning.

3.1.1. Social Structure

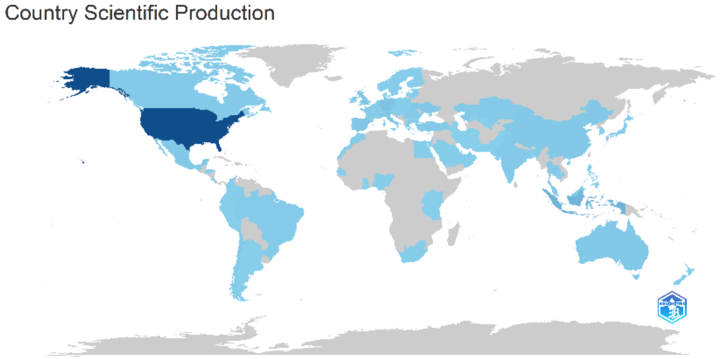

Figure 10. Countries' Scientific Production

Table 5. Countries' Scientific Production

No	Region	Frequency
1.	USA	960
2.	Indonesia	193
3.	Germany	76
4.	Spain	59
5.	Italy	56
6.	UK	55
7.	Malaysia	45
8.	Portugal	45
9.	Australia	44
10.	Mexico	39

The geographical distribution of publications and research regions, which helps in evaluating the geographical development in this field. Figure 10 and Table 5 list the most productive countries regarding STEM publications in Physics education during 2014–2025. The development of STEM has attracted much attention from researchers from at least 73 countries. Table 3 lists the top publishing countries in STEM publications in Physics education, with the top three countries being the United States, Indonesia, and the United Kingdom. The USA appears to be the most productive country with 960 publications, followed by Indonesia and Germany with 193 and 76 publications, respectively. The top publishing countries in Asia are Indonesia and Malaysia. There is a need for the importance of developing more empirical studies in the use of STEM in Physics learning and its integration with various other cutting-edge concepts. Additionally, although blockchain technology is being applied in developing countries (e.g., Indonesia and Malaysia), these countries, like other developing countries, are expected to make more efforts to develop research on the use of STEM in Physics learning.

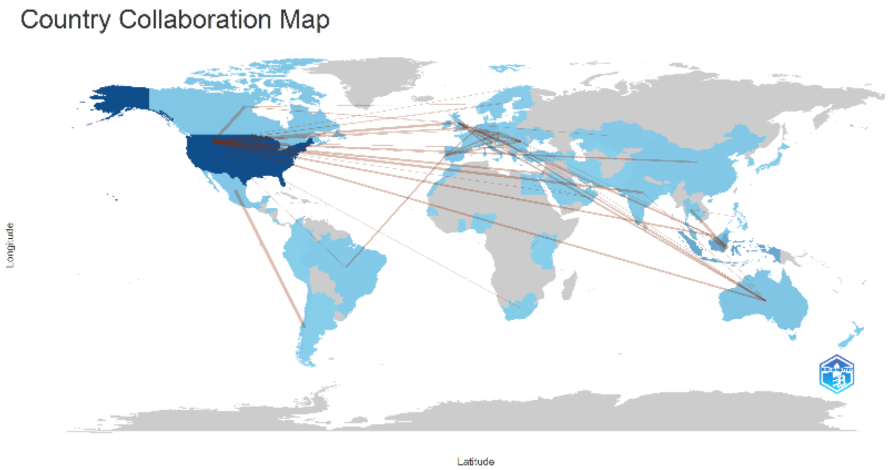

Figure 11. Countries' Collaboration World Map

Table 6. Countries' Collaboration World Map

No	Collaboration	Frequency
1.	Indonesia-Malaysia	16
2.	Mexico-Chile	7
3.	USA-Canada	7
4.	Indonesia-Thailand	6
5.	USA-India	5
6.	USA-UK	5
7.	Romania-Czech	4
8.	UK-Australia	4
9.	USA-Israel	4
10.	Australia-Austria	4

Figure 11 and Table 6 illustrate the main affiliated institutions that conduct and present the most relevant institutional data related to the results of research on the use of STEM in Physics learning. Cooperation among educational institutions is the most formal way of intellectual association in scientific research (Cisneros et al., 2018). The affiliation analysis conducted by the authors indicates that the most relevant institutional data correlated with research on the use of STEM in Physics learning. Global collaboration networks enable developing countries to participate in the knowledge creation process traditionally led by developed countries (Palacios-Callender & Roberts, 2018). The advancement and maturation of ideas are driven by the meeting of two viewpoints. This can also enhance the quality of published journals by many authors, as it minimizes errors and contributes to the convergence of different disciplines (Tahamtan et al., 2016). The strength of the relationship between two countries is an indication of the extent of cooperation (collaboration). The assessment shows that Indonesia and Malaysia have relatively higher levels of international research collaboration compared to other countries. Collaboration among academics is necessary to develop a field, thus requiring more cross-country collaboration. In conducting research and publishing more, most countries collaborate with other countries; for example, the USA has diverse collaboration levels and the highest number of publications.

4. Conclusion

Research on the use of STEM in physics learning presents the first bibliometric study and its main concepts, identifying key themes, and related research fields. More than 1,118 original research articles have been analyzed and processed using the "Biblioshiny" function in the "bibliometrix" package from R-studio. This study provides several contributions to the field. First, it analyzes annual publication and citation counts by examining publication patterns. STEM journal publications on Physics learning have been increasing annually, but experienced a significant decrease in 2025 due to the 11 months in 2025 where publication development is yet unknown. The highest citation count occurred in 2016. Second, we identify the most influential studies and authors by mapping citations and co-authorship networks. This study identifies the most prominent authors by analyzing. The author with the highest number of publications is Yuliati L. The author with the highest average citations per document is Potkonjak V. The journals with the highest citations per article are the Journal of Physics Conference Series and the ASEE Annual Conference and Exposition Conference. This may indicate that these journals not only receive more articles but also represent the most prominent authors. This study also analyzes the impact of the most influential countries, with the United States ranking first in terms of publication quantity. Third, it maps the intellectual structure by identifying the most prominent themes and helping researchers avoid stagnation and move the field in a more advanced direction. The themes students, engineering education, STEM (science, technology, engineering, and mathematics), teaching, education, curricula, education computing, STEM education, E-learning, and physics are the main research fields related to the use of STEM in Physics learning. Given the large volume of publications and citations received in this field, it is expected that there will be a growing interest and serve as a support for other fields such as research focusing on students, engineering education, teaching, curriculum, education computing, and E-learning. The most active journals in the field of STEM use in Physics learning have gained prestige in the scientific community, which encourages the continuous research, development, and implementation of Intelligence and its main themes. Fourth, based on the results of this bibliometric analysis, this study provides a visual overview of the development and structure of the main definitions and concepts of STEM use in Physics learning over the past 10 years (2014–2025). These thematic areas help visualize how Intelligence and its main components range from data creation to its exploitation, both at individual and collective levels, and at strategic levels. In this regard, research themes in these thematic areas are considered important due to their contribution to the growth of STEM use in Physics learning.

Like other studies, this research has some limitations. We only looked at articles published from 2014 to January 2025, so we don't have information about earlier research. Also, we chose specific keywords based on what other researchers have used. It's possible that there are other important keywords that we didn't include.

Author Contributions

Siti Awaliyah Saripah: Conceptualization, Methodology, Data curation, Writing - Visualization, Investigation, Editing. Siti Awaliyah Saripah and Firmanul Catur Wibowo: Software, Original draft preparation. Firmanul Catur Wibowo, I Made Astra, Esmar Budi: Supervision, Validation, Reviewing. All the authors have read and approved the final manuscript.

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The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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