JPPIPA 10(12) (2024)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Implementation of STEM Education in Schools: A Bibliometric Analysis (2003-2024)

Ghany Desti Laksita[1*], Widowati Pusporini[2], Era Mutiara[1], Zafrullah[1], Zamzami[1]

[1] Educational Research and Evaluation, Graduate School, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia
[2]Department of Educational Research and Evaluation, Graduate School, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia

Received: August 12, 2024
Revised: November 19, 2024
Accepted: December 26, 2024
Published: December 31, 2024

Corresponding Author:
Ghany Desti Laksita
ghanydesti.2023@student.uny.ac.id

DOI: 10.29303/jppipa.v10i12.8815

Abstract: STEM education offers significant benefits, including improving students' ability to solve problems, think critically and innovate. It not only prepares students to enter the workforce, but also facilitates their engagement in society at large. The main objective of this study is to provide a comprehensive bibliometric analysis of STEM education research from 2003 to 2024. It will identify the most prolific affiliations, sources, authors and documents as well as key research themes and trends in STEM education. This research is a bibliometric study with a PRISMA design that will help the authors to map the Scopus database. From the results of the above analysis, it can be concluded that the implementation of STEM education in schools shows a significantly increasing trend over the period 2003-2024, with a surge of publications starting in 2018 and peaking in 2020 and 2021 with 18 publications per year each. Asia was the most productive continent, with 47.52% of articles published by affiliates from this region, dominated by seven affiliates from countries such as Vietnam, Hong Kong, Turkey and Malaysia. Europe and Australia also showed high productivity with significant contributions from universities in countries such as Germany, Ireland, Greece and Australia.

Keywords: Bibliometric; STEM Education; Scopus database.

Introduction

21st century education requires students to have more complex skills than in previous eras (McGunagle & Zizka, 2020; Shurygin et al., 2024). In this context, effective learning should be able to develop critical thinking, problem solving, communication and collaboration skills. Education should not only aim to provide theoretical knowledge, but should also teach the practical application of that knowledge in everyday life (Morales-Doyle & Gutstein, 2019; Ziatdinov & Valles, 2022). This is important to prepare students for the increasingly complex and dynamic global challenges. Unfortunately, various problems still hinder the achievement of this ideal education. Among the main challenges faced is the gap between the educational needs of the 21st century and the reality on the ground resulting in uneven quality of education received by students. This is a barrier to preparing young people to participate in an increasingly knowledge-based global economy. STEM education is emerging as one of the solutions to address these issues.

STEM learning is an interdisciplinary approach that integrates science, technology, engineering, and mathematics in the learning process (Fadhilah et al., 2024; Saroro & Febrianto, 2024). STEM education aims to equip students with critical skills relevant to the 21st century, including problem solving, critical thinking, and the ability to work in teams (Azzahra & Rahyasih, 2024; Judijanto, 2024). By emphasizing the practical application of theoretical concepts, STEM education helps students understand the relevance of subject matter in a real-world context (Wati et al., 2024). STEM education not only encourages deep understanding in science and technology but also develops analytical and creative abilities. Thus, STEM is considered an educational approach that can answer the challenges of 21st century education by connecting theory with real practice.

How to Cite:
Laksita, G. D., Pusporini, W., Mutiara, E., Zafrullah, Z., & Zamzami, Z. (2024). Implementation of STEM Education in Schools: A Bibliometric Analysis (2003-2024). *Jurnal Penelitian Pendidikan IPA*, *10*(12), 944–959. https://doi.org/10.29303/jppipa.v10i12.8815

Any learning using any model or strategy certainly experiences obstacles because there is no perfect strategy (Kasneci et al., 2023). In the implementation of learning by using the STEM Model, of course, there are obstacles (Ha et al., 2020). The obstacles faced by teachers when implementing the STEM model, namely difficulties in terms of quantity or the number of students who are quite large with time services in the learning process that are not appropriate. Teachers have not been able to facilitate the needs of all students, especially those who experience learning problems.

STEM education offers significant benefits, including improving students' ability to solve problems, think critically and innovate. It not only prepares students to enter the workforce but also facilitates their engagement in the wider society. However, there is still a gap between expectations and reality in the implementation of STEM education. Although many studies have been conducted, the results are often inconsistent, suggesting divergent views on the effectiveness and best practices in STEM implementation.

Global trends show a significant increase in countries' efforts to implement STEM education (Li et al., 2020; Teo et al., 2021). Countries such as the USA, Singapore and Finland have invested considerable resources in STEM education to ensure their competitiveness on the global stage (Rezaei et al., 2022). In the USA, for example, initiatives such as "Educate to Innovate" have been launched to improve STEM achievement among students. In addition, countries in Asia, including China and South Korea, have introduced national STEM curricula to improve students' competencies in these fields.

Despite the many advantages, the implementation of STEM education faces various challenges (Sırakaya & Alsancak, 2022). One of the main challenges is the lack of resources, including adequate educational materials and laboratory facilities. In addition, the lack of training and professional development for STEM teachers is a significant obstacle to effective STEM curriculum implementation (Lo, 2021; Wan et al., 2021). Other challenges include resistance to change from traditional curricula and difficulties in assessing interdisciplinary STEM learning.

One of the current learning approaches that strongly supports the achievement of 21st century skills is STEM (Science, Technology, Engineering and Mathematics) based learning (Baran et al., 2019; Xu & Zhou, 2022). STEM consists of aspects of science, namely the use of knowledge and skills of the scientific process to understand and manipulate natural phenomena (Thahir et al., 2020). Technological aspects, namely using technology, namely knowing how new technologies can be developed and technology can be used to facilitate human work. Technical aspects, namely operating, designing or assembling with reference to science and technology. Mathematical aspects, namely analyzing, showing evidence, solving problems, interpreting solutions from data and calculation results. The application of STEM in learning models is needed to streamline the process and help students in understanding and capturing academic content, especially science learning, because science learning today does not only rely on memorization, but also requires students to always be involved and active in class, in addition to the broad scope of material and direct relevance to everyday life.

Research related to STEM bibliometric analysis has been conducted by various researchers (Ali & Tse, 2023; Bui et al., 2024; Cai et al., 2023; Lathifah et al., 2024; Ma & Hui, 2023; Sánchez & Martínez, 2021). While research conducted by Lathifah et al. (2024), showed the results of an increasing trend based on the analysis of 19 collections of STEM and ESD learning papers from 2010 to 2023. Bui et al. (2024) examined STEM and STEAM topics at the early childhood level from 1992-2022 with bibliometric analysis. Ali & Tse (2023) examined STEM related to the engineering design process (EDP) with a time span of 2011 to 2021. Ali & Tse (2023) identified key research trends and issues on EDP related to professional development, design thinking and computational thinking, STEM competencies, scientific inquiry, and the gender gap in k-12 STEM education. The difference between this research and these studies is that this bibliometric research not only uses VOSviewer but also uses the R Program in its analysis. In addition, this study covers a more general school level, from early childhood to high school.

The urgency of this research becomes even clearer when looking at the number of publications on STEM education that continues to increase each year, as seen in Figure 1. These data show a consistent increase from 2003 to 2023, reflecting the growing interest in STEM education worldwide. Nonetheless, the lack of agreement in the literature suggests the need for a more in-depth and systematic analysis. For this reason, this study uses a bibliometric approach and analysis tools such as Biblioshiny to analyze trends, key contributions, and research areas that still need to be explored.

Based on the previous description, a research question can be formulated in the form of "how is the bibliometric analysis of STEM education implementation in schools?" The bibliometric analysis question is important to understand the STEM education research landscape. It also helps in recognizing patterns of collaboration between researchers and institutions and reveals emerging and fading topics (Bornmann & Leydesdorff, 2014). The main objective of this study is to provide a comprehensive bibliometric analysis of STEM education research from 2003 to 2024. The research will identify the most prolific affiliations, sources, authors and documents as well as key research themes and trends in STEM education. As such, this research will not only provide insights into the development of STEM education but will also identify potential areas for further research and international collaboration, ultimately improving the quality of global education.

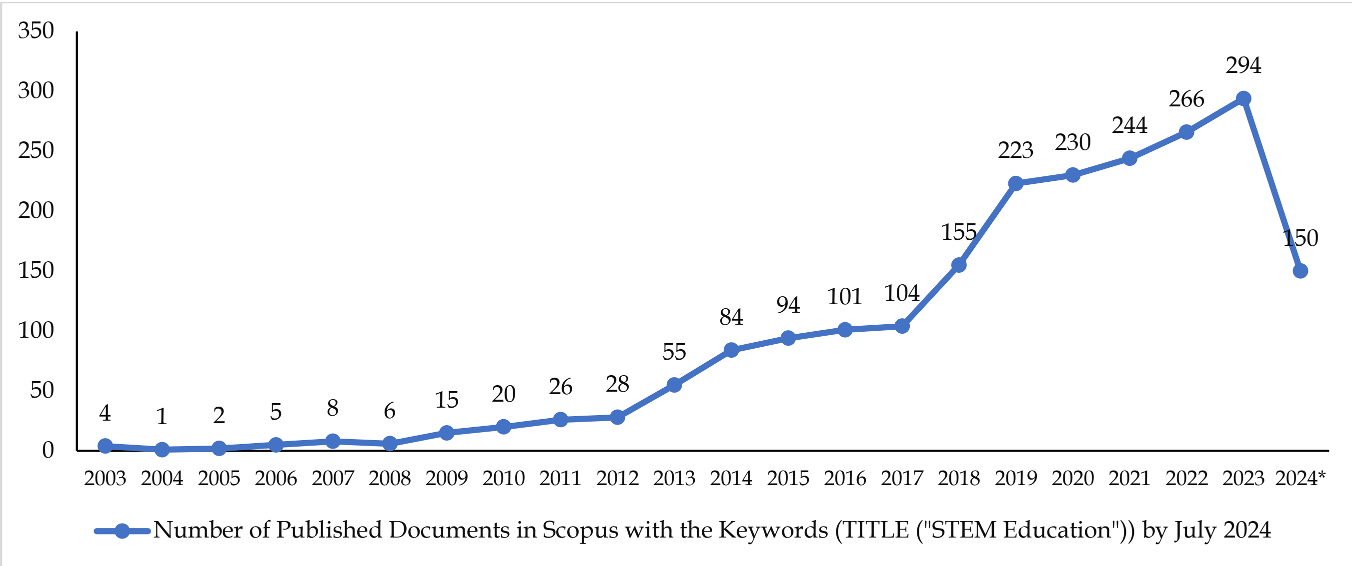

Figure 1. The Number of Publication Documents about STEM Education in Scopus (source: www.scopus.com) (*: The year still in progress)

Method

This research is a bibliometric study with a PRISMA design that will help the author to map the Scopus database. Bibliometric studies use quantitative methods to summarize the scientific output of a field by analyzing the intellectual, social, and conceptual relationships between various scientific elements, such as papers, authors, keywords, journals, institutions, and countries (Öztürk et al., 2024). Meanwhile, this study will interpret in detail the publication trends of each year, the most productive affiliations, the most productive sources, the most productive authors, the documents with the highest citations, the research focus, and the novelty of keywords analyzed by using R Program and VOSviewer on the focus of STEM implementation in schools.

According to Öztürk et al. (2024) there are four stages in bibliometric research. First, defining the aim of the research. Second, collecting data on the relevant literature. Third, analysis and visualization. Lastly, interpreting the findings and results. In the early stages of this research, researchers conducted a document search using predetermined keywords and conducted a search on the Scopus database. The search results are the samples studied and a total of 139 documents that are the focus of analysis and then the author uses the R Program in analyzing them. Furthermore, the researcher also used VOSviewer to perform keyword clustering and detect keywords that have high novelty, and offer more insight into the development of ideas and research focus. It is hoped that by using this strategy, this research can contribute to the development of science, especially in the field of educational research and evaluation.

The researcher used the main keyword, namely "Technology" and used all school keywords starting from schools for small children, home schooling, to high schools, this was done so that all schools were included in this analysis stage. So, the first search obtained 1188 documents. At the screening stage, the author limited it to "Social Sciences" and document types namely "Article" and "Conference Paper", so that 561 documents were eliminated leaving 627 documents.

In the Eligibility stage, the author then looked at all the documents manually and eliminated 28 documents, leaving 599 documents that survived until the included stage. Next, the author carried out an analysis using the Publish or Perish 8, R Program Biblioshiny and VOSviewer to map the results of publication trends in the field of technology use in schools. The author analyzes starting from main information, best authors, most influential sources, most productive countries, productive affiliates, documents with the highest citations, to novelty and keyword grouping. This analysis aims to provide in-depth insight into how technology is implemented at various school levels and identify emerging trends and patterns in the related literature.

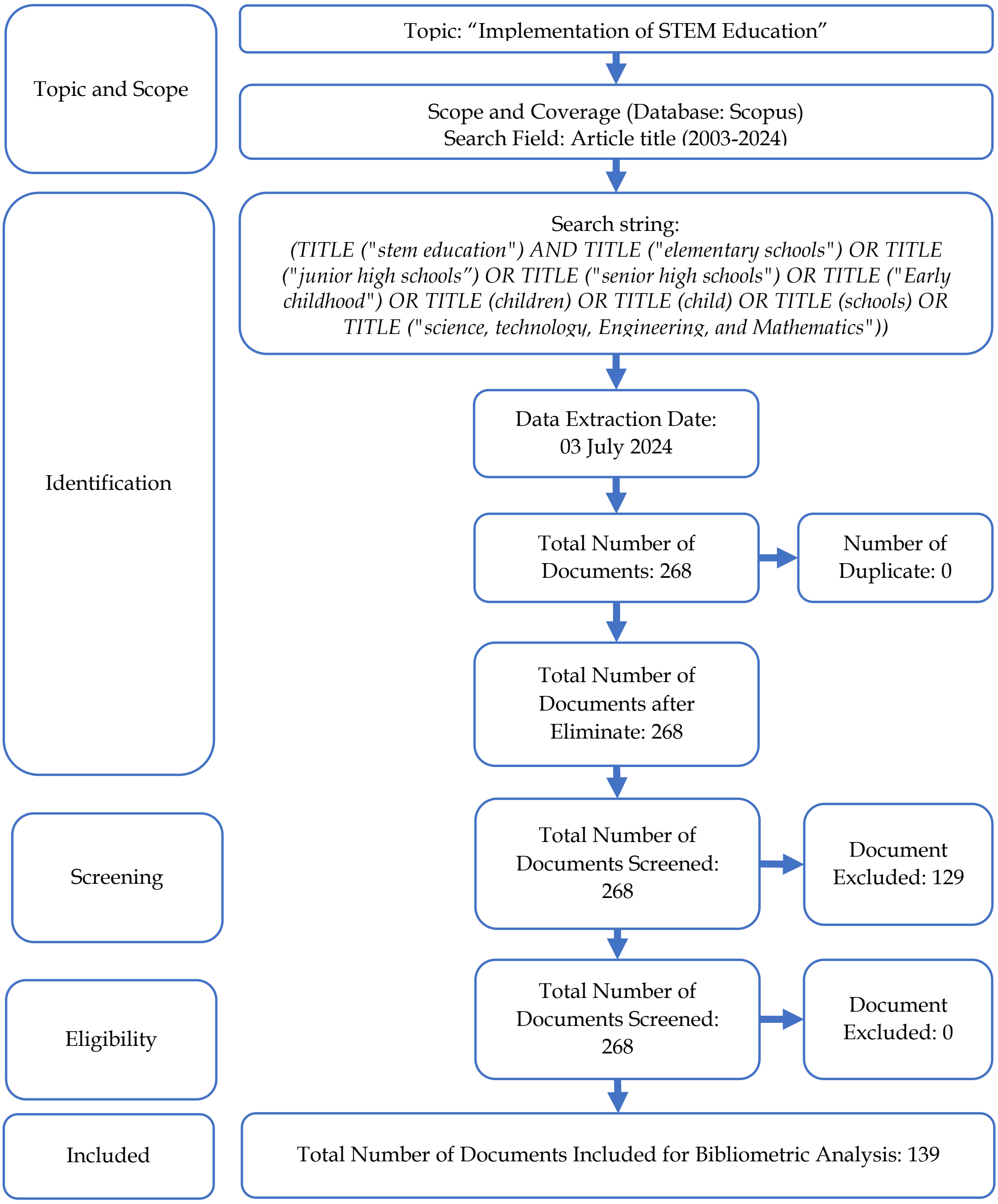

Figure 2. Research Methodology Diagram for Bibliometric Analysis on PRISMA Model. Flowchart by (Page et al., 2021)

Result and Discussion

The results and discussion of bibliometric analysis related to STEM education in schools are organized in 9 subchapters, namely main information, publication trends per year, citation trends per year, most productive countries, most productive affiliations, most productive authors, most productive journals, documents with the highest citations, and keyword novelty.

Main Information

The author analyzes Main Information in one of the menus in the R Program Biblioshiny which aims to obtain a general overview of the characteristics of the documents studied. This analysis includes information such as the publication and citation trends, number of publications per year, distribution of authors, and journal sources used, thus providing a basic understanding of trends and patterns in the use of technology in schools.

Figure 3. Main Information of General Statistics on the Results of Biblioshiny Analysis of Implementation of STEM Education in Schools with R Program

On the topic of implementing STEM education in schools over the period 2003 to 2024, the data shows that there were total of 139 published documents sourced from 100 journals and proceedings. The number of published documents experienced an annual growth of 8.91%, indicating increased interest and attention to this topic. The documents had an average age of 4.94 years, and each document received 14.59 citations on average, demonstrating the relevance and significant impact of this research in the field of STEM education.

The content of these documents includes 352 primary keywords (Keywords Plus) and 435 author-provided keywords (Author's Keywords). This large number of keywords reflects the diversity of topics and issues covered in the implementation of STEM education. With a total of 5640 references used, this shows that research in this field is supported by a broad and deep literature, indicating a strong research base.

In terms of author collaboration, 407 authors contributed to these documents, of which 19 were single authors. There were 19 single-author documents, while the average number of authors per document was 3.09, indicating that collaboration is an important element in STEM-related research. In addition, 13.67% of the documents involved international collaboration, indicating that the implementation of STEM education is a global issue that attracts attention from researchers in different countries. The types of documents published consisted of 107 articles and 32 conference papers, showing a balance between formal academic publications and presentation of research results in scientific forums.

Number of Publication Trends

Data on the number of publications from 2003 to 2024 shows a significant trend in the field of STEM education implementation. In the early period from 2003 to 2017, the number of publications was relatively low with a total of only 34 documents. This shows that in the early years, research and publications in this field were still in the developmental stage and may not have received wide attention. The increase that began to be seen from 2015 to 2017 with an average of around 6 to 8 publications per year signaled the beginning of increased interest in this topic. This result is in line with previous research conducted by Ha et al. (2020) that in 2017-2019 there was an increase in the number of publications related to STEM.

Starting in 2018, the number of publications related to STEM education experienced a significant spike, reaching 105 publications only in the period 2018 to 2024. The peak number of publications occurs in 2020 and 2021, with 18 publications per year each. This surge can be interpreted as a result of the growing awareness of the importance of STEM education in facing global challenges such as technological advancements, climate change, and the need to improve digital skills among students. The COVID-19 pandemic that began in late 2019 may also have prompted researchers and educators to focus more on STEM education, due to the urgent need to adapt to distance learning and innovations in teaching methods (Banila et al., 2021; Baucum & Capraro, 2021; Hamimah et al., 2022; Lestari et al., 2021; Putri et al., 2020; Rochim et al., 2021; Selco & Habbak, 2021; Sulistiyono et al., 2021). As a result, research in this area has become more relevant and urgent, resulting in more publications.

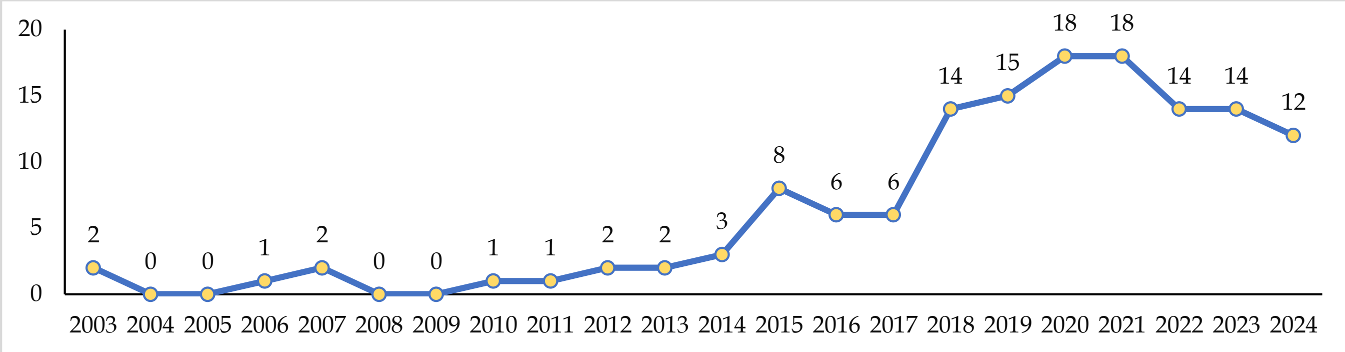

Figure 4. Publication Trends from 2003 to 2024 on Research of STEM Education in Schools

Citation Trends

Citation trend data from 2003 to 2024 shows a significant increase in research productivity related to the implementation of STEM education in schools. From 2003 to 2017, only 34 documents were published, indicating low attention to STEM education. Starting in 2018, there was a surge with 105 documents published until 2024, peaking in 2020 and 2021 with 18 documents each. The highest citations were recorded in 2018 with 336 citations, showing the huge impact of the research published in that year. This trend reflects the increasing recognition and appreciation of STEM research among academics and educational practitioners.

An increase in the number of cited documents also indicates the high quality of the research, with a peak in 2021 where 16 documents received citations. The highest h index was recorded in 2020 with a value of 5, indicating the significant influence of the research in that year. Older documents have a high citation age, while newer documents show potential to gain more citations in the future. Overall, this data highlights that STEM education research is a growing area, with increasingly significant contributions to knowledge and practice in this field.

Table 1. Citation Trends from 2003 to 2024 on Research of STEM Education in Schools

Year	Total of documents[a]	Total of citations[a]	Number documents of citations[a]	H-index[a]	Citable year[b]
2003	2(1.44%)	33(1.63%)	2(1.69%)	1	22
2004	-	-	-	-	-
2005	-	-	-	-	-
2006	1(0.72%)	19(0.94%)	1(0.85%)	1	19
2007	2(1.44%)	3(0.15%)	2(1.69%)	0	18
2008	-	-	-	-	-
2009	-	-	-	-	-
2010	1(0.72%)	6(0.30%)	1(0.85%)	0	15
2011	1(0.72%)	-	-	0	14
2012	2(1.44%)	44(2.17%)	2(1.69%)	1	13
2013	2(1.44%)	56(2.76%)	1(0.85%)	1	12
2014	3(2.16%)	211(10.40%)	3(2.54%)	2	11
2015	8(5.76%)	155(7.64%)	8(6.78%)	3	10
2016	6(4.32%)	112(5.52%)	6(5.08%)	2	9
2017	6(4.32%)	242(11.93%)	6(5.08%)	2	8
2018	14(10.07%)	336(16.57%)	14(11.86%)	4	7
2019	15(10.79%)	224(11.05%)	15(12.71%)	3	6
2020	18(12.95%)	301(14.84%)	15(12.71%)	5	5
2021	18(12.95%)	176(8.68%)	16(13.56%)	4	4
2022	14(10.07%)	76(3.75%)	12(10.17%)	3	3
2023	14(10.07%)	29(1.43%)	11(9.32%)	3	2
2024	12(8.63%)	5(0.25%)	3(2.54%)	1	1

a= Data Source by RIS files interpreted using Publish or Perish 8 & Microsoft Excel
b= Data Source by R Program, data accessed by July 13th, 2024

Table 2. The 15 Most Productive Affiliates Research Regarding the Implementation of STEM Education in Schools during 2003-2024

Rank	Affiliation	Start	City	Country	Continent	Number of Articles
1st	Charles Sturt University	2020	New South Wales	Australia	Australia	14 (10,07%)
2nd	Dong Thap University	2021	Dong Thap	Vietnam	Asia	9 (6,47%)
3rd	Ruhr Universität	2019	Bochum	Germany	Europe	8 (5,76%)
4th	The Education University of Hong Kong	2021	Ting Kok	Hong Kong	Asia	7 (5,04%)
5th	Mary Immaculate College	2021	County Limerick	Ireland	Europe	6 (4,32%)
6th	Middle East Technical University	2017	Ankara	Turkey	Asia	5 (3,60%)
7th	Thai Nguyen University of Education	2021	Thai Nguyen	Vietnam	Asia	5 (3,60%)
8th	Universiti Teknologi Mara	2022	Selangor	Malaysia	Asia	5 (3,60%)
9th	Universiti Tunku Abdul Rahman (Utar)	2021	Perak	Malaysia	Asia	5 (3,60%)
10th	University of Crete	2020	Crete	Greece	Europe	5 (3,60%)
11th	Beijing Normal University	2021	Beijing	China	Asia	4 (2,88%)
12th	Canakkale Onsekiz Mart University	2022	Canakkale	Turkey	Asia	4 (2,88%)
13th	Muş Alparslan University	2018	Muş	Turkey	Asia	4 (2,88%)
14th	Niigata University	2022	Niigata	Japan	Asia	4 (2,88%)
15th	Queensland University of Technology	2012	Brisbane	Australia	Australia	4 (2,88%)

Description: Data Analysis using R Program Biblioshiny, data analyzed on July 17, 2024

The data in Table 2 shows the 15 most productive affiliates in research on the implementation of STEM education in schools over the period 2003-2024.

The Most Productive Affiliation

From the country column, it can be seen that affiliates from Asia dominate the list with seven affiliates, showing the increasing attention to STEM education in the region (Nguyen et al., 2020). Countries such as Vietnam, Hong Kong, Turkey and Malaysia showed significant contributions in the number of articles published. Continentally, Asia leads the way with 47.52% of articles published by affiliates from this continent. Europe and Australia also showed high productivity with universities from countries such as Germany, Ireland, Greece and Australia contributing significantly. The number of articles shows that Charles Sturt University from Australia was the most productive with 14 articles, followed by Dong Thap University from Vietnam with 9 articles, and Ruhr Universität from Germany with 8 articles. This shows that although some affiliates have only just started their research in recent years, they are able to be very productive in the field of STEM education.

The Most Productive Country

The Table 3 below, shows the 15 most productive countries with the highest number of articles in the field of STEM education implementation in schools. The United States ranks first with a total of 86 articles since 2003, with an average of 3.91 articles per year and a total of 214 citations. Malaysia and Turkey have 38 articles each, although Malaysia started contributing in 2014 and Turkey in 2015. However, Turkey has higher total citations than Malaysia, although the average citations per article are almost the same. Australia, despite only starting to publish articles since 2012, shows high productivity with 36 articles and a total of 296 citations, resulting in a significant average citations per article.

European countries such as Spain and Hong Kong also showed significant performance, with Spain having a very high average citations per article, showing that despite the lower number of articles, the quality and impact of research in this country is very high. In Asia, countries such as China, Japan and Indonesia also showed prominent contributions. Overall, these data show that the productivity and impact of research in the implementation of STEM education in schools varies significantly between countries. While some countries have a higher number of articles, the impact of research as measured by total citations and average citations per article indicates the high quality and relevance of research in a particular country.

Overall, these data show that the productivity and impact of research in the area of implementing STEM education in schools varies greatly between countries. Although some countries have a higher number of articles, the impact of research measured by total citations and average citations per article shows the high quality and relevance of research in certain countries.

This highlights the importance of not only the quantity but also the quality of research in the field of STEM education.

Table 3. The Top 15 Productive Country with The Highest Number of Article in the Field of Implementation of STEM in schools

Rank	Country	Continent	SYP	NA	AAPY	TC	AAC
1st	USA	North America	2003	86	3.91	214	15.30
2nd	Malaysia	Asia	2014	38	1.73	47	7.80
3rd	Turkey	Europe	2015	38	1.73	130	7.60
4th	Australia	Australia	2012	36	1.64	296	26.90
5th	Spain	Europe	2014	20	0.91	164	82.00
6th	China	Asia	2019	18	0.81	38	7.60
7th	Hong Kong	Asia	2017	16	0.73	138	46.00
8th	Japan	Asia	2018	14	0.64	107	26.80
9th	Indonesia	Asia	2016	13	0.59	88	22.00
10th	Germany	Europe	2019	10	0.45	2	2.00
11th	Ireland	Europe	2021	9	0.41	7	3.50
12th	Canada	North America	2015	8	0.36	39	13.00
13th	Thailand	Asia	2016	8	0.36	85	28.30
14th	Greece	Europe	2011	7	0.32	116	58.00
15th	Kazakhstan	Asia	2023	7	0.32	0	00.00

Description: Data Source by R Program and Google Schoolar, data accessed on 3rd July, 2024, SYP: Start Year of Production, NA: Number of Articles, AAPPY: Average Article Production Per Year (2003-2024), TC: Total of Citation, AAC: Average of Article Citations

The Most Productive Authors

The data below, Table 4 lists 15 contributing authors in the field of education, specifically STEM, along with their institutional affiliation, country, h-index, total citations (TC), and number of publications (NP). This information provides insight into the authors' academic contributions and influence in the international research community.

Table 4. The Most Productive Authors in STEM Education in Schools 2003-2024

Rank	Author	Affiliation	Country	h_index	NP	TC	SYP
1st	Lyn D. English	Queensland University of Technology	Australia	2	3	232	2012
2nd	Michail Kalogiannakis	University of Thessaly	Yunani	2	2	116	2020
3rd	Ton De Jong	University of Twente (emeritus)	Netherland	2	2	58	2013
4th	Denis Gillet	Ecole Polytechnique Fédérale de Lausanne (EPFL)	Swiss	2	2	58	2013
5th	Lena Danaia	Charles Sturt University	Australia	2	3	44	2020
6th	Carmen Huser	Charles Sturt University	Australia	2	2	44	2020
7th	Amy Macdonald	Charles Sturt University	Australia	2	2	44	2020
8th	Shukla Sikder	Charles Sturt University	Australia	2	2	44	2020
9th	Les Dawes	Qld University of Technology	Australia	2	2	37	2012
10th	Peter Hudson	Penn State University	USA	2	2	37	2012
11th	Laurence Earl Whitman	University of Arkansas	USA	2	2	33	2003
12th	Tonya L Witherspoon,	Wichita State University	USA	2	2	33	2003
13th	Carlos C. F. Marotto	The University of British Columbia	Canada	2	2	32	2018
14th	Marina Milner-Bolotin	The University of British Columbia	Canada	2	2	32	2018
15th	Mustafa Sami Topçu	Yıldız Technical University	Turkey	2	2	32	2022

Description: Data Source by R Program and Google Schoolar, data accessed on 3rd July, 2024, NP: Number of Production, TC: Total of Citation, SYP: Start Year of Production

From the data, it can be seen that English (2017); Gillet et al. (2013) from Queensland University of Technology, Australia, is the author with the highest total citations (232), despite having the same h-index (2) as the other authors. This shows that although their number of publications (NP) is not very high, their published articles have a great impact in the academic community. Many authors are affiliated with leading universities in different countries, including Australia, the USA and Canada, demonstrating the geographical diversity in STEM research. Some authors, such as Lena Danaia, Carmen Huser, MacDonald et al. (2020), are all from Charles Sturt University in Australia, indicating a strong research group at the institution.

Overall, these data show that despite their uniform h-index (2), some authors managed to achieve high levels of influence with sizable citation totals. This may indicate that their work is highly recognized and referenced in the STEM education literature. In addition, the presence of authors from different countries and universities indicates significant international collaboration and contribution in this research. The involvement of researchers from Australian universities seems to be prominent, indicating the country's important role in advancing STEM education globally.

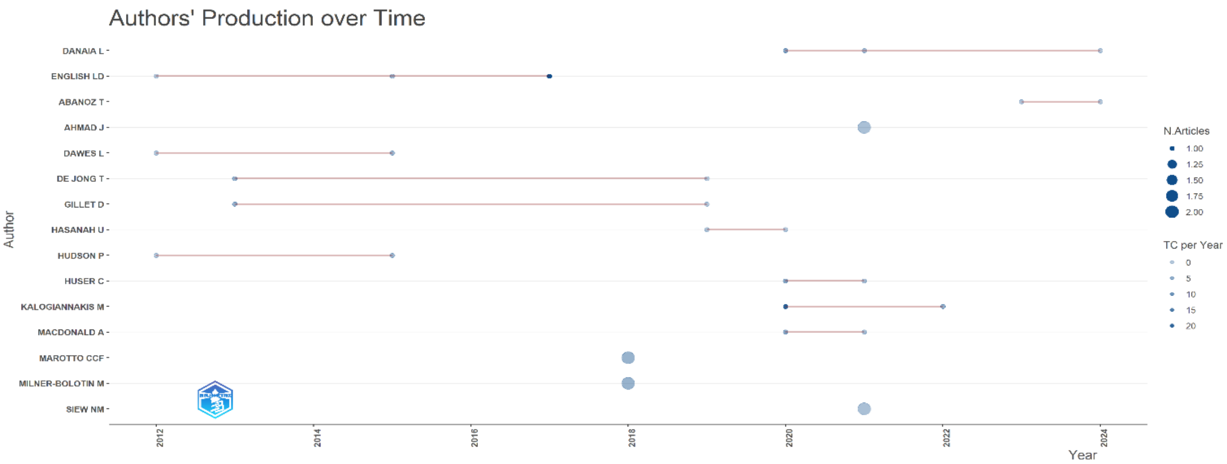

Figure 5. Author with Total Production Time in the Research of Implementation of STEM

The Figure 5 illustrates the production of publications by various authors over the period from 2012 to 2024. Each horizontal line represents an author's active publishing period in relation to the size of the circle indicating the number of articles published in that year, and the color and size of the circle indicates the total citation (TC) per year for each article. From the data, it can be seen that some authors such as "Dania L." and "Hudson P." have a long production time span, indicating consistent contributions in their research. In particular, "Hudson P." has the longest line indicating this author's activity from 2012 to 2020.

In addition, the data shows that some authors have shorter production periods but with significant contributions. For example, "Kalogianakis M." is seen to be active mainly in the period around 2018 and has a significant number of citations indicated by the larger circle size. "Marotto CCF" and "Siew NM" also show article production in certain years with a relatively high number of citations. This data indicates that although some authors may not be active every year, their contributions still have a major impact in the scientific community based on the number of citations received.

The Most Cited Documents

The data presented shows the 15 most-cited documents in the field of STEM education in schools. In the top spot is Lyn D. English's 2017 paper in the *International Journal of Science and Mathematics Education*, which discusses challenges and perspectives in STEM education, including integration, equity and extension to STEAM. This paper has the highest total citations, reflecting its significant impact with 195 citations and an average of 24.38 citations per year. This was followed by León et al. (2014) study in Learning and Individual Differences, which examined the effects of autonomy and motivation on math achievement in high school. The study highlighted the importance of student autonomy in improving academic performance, evidenced by a strong citation count of 164 and an average of 14.91 per year. Recent research also stands out, such as the 2020 paper by Dorouka et al. (2020) on the use of tablets and apps in early childhood education, which has gained 101 citations at an average of 20.20 per year. This shows a growing interest in the integration of technology in STEM education from an early age. Another noteworthy study is the 2018 study by Thibaut et al. (2018) which explored how teacher attitudes and school context influence teaching practices in integrated STEM education, contributing 99 citations at an average of 14.14 per year.

Table 5. The Top 15 Documents with the Highest Citations in the Field of STEM Education in Schools

Rank	Title	Authors	TC
1st	Advancing Elementary and Middle School STEM Education (2017)	Lyn D. English	195
2nd	Self-determination and STEM education: Effects of autonomy, ….	Jaime León , Juan L. Núñez, Jeffrey Liew	164
3rd	Tablets and apps for promoting robotics, mathematics, STEM education … (2020)	Pandora Dorouka, Stamatis Papadakis, ..	101
4th	The influence of teachers' attitudes and school context … STEM education (2018)	Lieve Thibaut, Heidi Knipprath, …	99
5th	Analysis of Students' Critical Thinking Skill of … STEM Education Project-Based Learning (2018)	Mutakinati L, Anwari I, Kumano Y	96
6th	Teacher Professional Development for Science, Technology, Engineering and Mathematics (STEM) Education: … (2019)	Ching Sing Chai	87
7th	Personalised learning spaces and federated online labs for STEM Education at School (2013)	Denis Gillet, Ton de Jong, Sofoklis…	56
8th	STEM Education in Early Childhood: A Review of Empirical Studies (2021)	Zhi Hong Wan, Yushan Jiang, Ying Zhan	51
9th	In the Guise of STEM Education Reform: … STEM-Focused High Schools (2015)	Lois Weis, Margaret Eisenhart, …	50
10th	The impact of an out-of-school STEM … and STEM careers (2019)	Evrim Baran, Sedef Canbazoglu Bilici…	46
11th	Students' Attitudes towards STEM Education: …. (2016)	Nadi Suprapto	45
12th	STEM Education in Secondary Schools: Teachers' Perspective …. (2020)	Thi Phuoc Lai Nguyen, Thi …	45
13th	Reimagining the Role of School Libraries in STEM Education: Creating … (2012)	Mega M. Subramaniam, June Ahn, …	42
14th	Racial capitalism and STEM education …. (2019)	Daniel Morales-Doyle, Eric "Rico" …	38
15th	Effective Early Childhood STEM Education: Findings ….	Amy MacDonald, Carmen Huser, …	35

Description: Data Source by R Program, data accessed on 3rd July, 2024
TC: Total of Citation

The list also highlights diverse topics such as project-based learning in STEM education Mutakinati et al. (2018) and teacher professional development through the TPACK framework (Chai, 2019; Suprapto, 2016). The presence of these studies indicates a broad interest in various aspects of STEM education, from classroom practice to professional development. Overall, citation metrics reveal that both basic and contemporary research is highly valued, with a clear trend towards the integration of traditional STEM and emerging educational technologies. The high number of citations for these documents demonstrates their continued relevance and influence in shaping the discourse of STEM education in schools (Subramaniam et al., 2012).

The Most Productive Source and Overall Source

The data Table 6 contains information on the top 15 sources of relevant journals and proceedings in the field of STEM education. The data includes the h-index, total of citations (TC), number of publications (NP), year of publication (PY_start), and the quartile rank to which the journal belongs. The journal with the highest h-index and TC (Total of Citation) is the Indonesian Journal of Science Education with an h-index of 5 and a total of 141 citations, placing it first on this list. Despite only starting to be published in 2018, this journal has managed to accumulate quite a lot of citations. This shows that this journal has a significant influence in its field. The journal is in the Q3 quartile, which signifies an intermediate position in quality and impact (Weis et al., 2015).

Proceedings such as "Proceedings - Frontiers in Education Conference, FIE" and "IEEE Global Engineering Education Conference, EDUCON" despite having a lower h-index (4 and 2), show a significant number of publications (6 and 4) and play an important role in disseminating the latest research in engineering and science education. However, they are not indexed in the journal quartile, which may reflect their focus on conference-based contributions rather than journal articles.

Journals such as "International Journal of Educational Research," "International Journal of Science Education," "Sustainability (Switzerland)," and "Thinking Skills and Creativity" are in the Q1 quartile, indicating that these journals are considered high-quality journals with greater impact in their fields. Although their h-index is not very high (2), their placement in Q1 indicates that they are important platforms for cutting-edge research.

Table 6. Top 15 of the Most Productive Source in the Field of STEM in Education in Schools

Rank	Source	H	TC	NP	SYP	Q
1	Jurnal Pendidikan IPA Indonesia	5	141	5	2018	Q3
2	Proceedings - Frontiers in Education Conference, FIE	4	45	6	2003	-
3	Education Sciences	3	44	4	2021	Q2
4	Journal of Baltic Science Education	3	23	4	2020	Q2
5	Journal of Turkish Science Education	3	71	3	2016	Q2
6	Eurasia Journal of Mathematics, Science and Technology Education	2	26	3	2014	Q2
7	Eurasian Journal of Educational Research	2	31	2	2015	Q3
8	IEEE Global Engineering Education Conference, EDUCON	2	70	4	2013	-
9	International Journal of Educational Research	2	29	2	2020	Q1
10	International Journal of Engineering Education	2	5	2	2017	Q2
11	International Journal of Science Education	2	35	2	2016	Q1
12	Lumat	2	32	2	2018	Q3
13	Pegem Egitim ve Ogretim Dergisi	2	28	2	2018	-
14	Sustainability (Switzerland)	2	57	2	2020	Q1
15	Thinking Skills and Creativity	2	24	2	2020	Q1

Description: Data Source by R Program, data accessed on 3rd July, 2024, H: H-index, TC: Total of Citation, NP: Number of Production, SYP: Start Year of Production, Q: Quartile

Some journals such as "Journal of Baltic Science Education" and "Journal of Turkish Science Education" show a strong regional focus yet also have an international impact, with h-indexes of 3 and 71 respectively and respectable citation totals. This reflects their contribution to supporting and promoting educational research in the Baltic region and Turkey, while remaining relevant on the global scene.

Journals with fewer publications but in the higher quartile (such as "International Journal of Educational Research" and "Thinking Skills and Creativity") show that despite the small number of publications, each publication has a significant impact. This contrasts with journals that have more publications but are in the lower quartile, which may have a focus more on quantity than quality.

Overall, this data provides a snapshot of the quality, relevance and impact of various journals and proceedings in the field of STEM education. Journals in the higher quartiles tend to have greater influence within the academic community, while conference proceedings play an important role in sharing the latest discoveries and innovations in education.

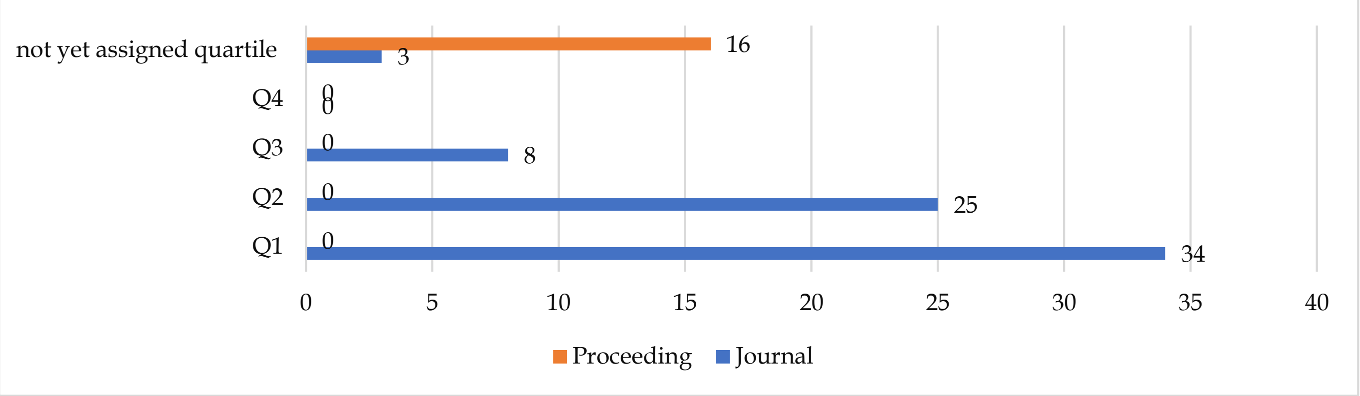

Figure 6. Comparation of reference typ

The diagram shows a comparison of the number of publications published in proceedings and journals considering quartile levels (Q1-Q4) as well as unindicated categories. Journal publications dominate at all quartile levels, with the highest number in Q1 reaching around 35 publications. In Q2, there were around 25 journal publications, while in Q3 and Q4 there were around 10 and less than 5 publications, respectively. In contrast, no proceedings publications were detected in any quartile (Q1-Q4).

In the "not yet assigned quartile" category, journals have about 5 publications while proceedings have about 10 publications. This shows that although proceedings have publications that have not been classified in a particular quartile, the number is still lower than journal publications in that category. Overall, journal publications show higher quality with dominance in Q1 and Q2, as well as more publications in all quartiles compared to proceedings.

Document with the Highest Citation

The majority of documents, 73 documents or 52.52%, only received between 1 and 10 citations. This suggests that most publications have a relatively low impact in terms of the number of citations. In addition, there were 24 documents that received no citations at all, which also accounted for 17.27% of the total documents. This number indicates that almost one in five documents did not manage to attract attention or references from other studies.

On the other hand, 24 documents received between 21 to 54 citations, which also accounts for 17.27% of the total documents. This indicates that there is a group of documents that have a moderate impact, attracting quite significant attention from the scientific community. A total of 11 documents received between 11 to 20 citations, accounting for 7.91% of the total documents, indicating that a small proportion of documents have a rather low impact but are still better than documents that only have 1 to 10 citations.

Table 7. Citation Level of Document about STEM Education in Schools. Analyze using R Program

Number of citations	Number of documents	Percentage %
>100	3	2.16
55 to 100	4	2.88
21 to 54	24	17.27
11 to 20	11	7.91
1 to 10	73	52.52
0	24	17.27

Data analyzed on 26 July 2024 with excel

The documents that had the highest impact, with more than 100 citations, amounted to only 3 documents or 2.16% of the total. In addition, there were 4 documents that received between 55 and 100 citations, accounting for 2.88% of the total. Although these percentages are small, these documents show very significant influence in their field, suggesting that there are some very influential publications.

Overall, this data indicates that the distribution of citations to publications tends to be uneven, with most documents receiving few citations and only a small number of documents receiving a high number of citations. This reflects the typical distribution in scientific publications, where only a small number of works become highly influential while the majority receive more limited recognition.

Focus Research

In addition to the analysis using the R Program, researchers also analyzed keywords to identify groups and novelties using VOSviewer. Group and novelty analysis of keywords aims to group related topics and find the latest trends. This helps researchers understand the relationship between various concepts and see the developments and innovations that emerge in this field

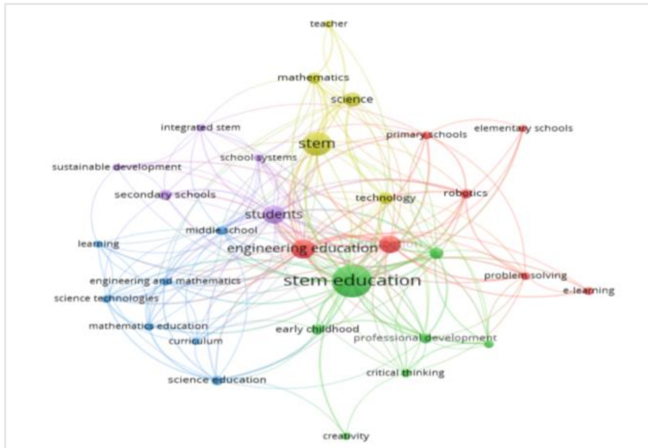

Figure 7. Keywords Clustering in the Field of Implementation of STEM Education in Schools

The figure above shows a visualization of keywords that frequently appear in STEM education related literature, generated using VOSviewer. In this visualization, the related keywords are grouped into five clusters marked with different colors. Based on the image, there are five main clusters with different colors: red, green, blue, yellow, and purple.

Table 8. Fifth Grouping Keywords in the Field of Implementation of STEM Education in Schools

Rank	Color	Cluster Title	Keywords
1st	Red (7 items/22.58%)	Technology and Education in Elementary Schools	E-learning, Education, Elementary Schools, Engineering Education, Primary Schools, Problem Solving, Robotics
2nd	Green (7 items/22.58%)	Creativity and Professional Development in Education	Creativity, Critical Thinking, Early Childhood, Professional Aspects, Professional Development, Project-Based Learning, STEM Education
3rd	Blue (7 items/22.58%)	Science and Mathematics Education in Secondary Schools	Curriculum, Engineering and Mathematics, Learning, Mathematics Education, Middle School, Science Education, Science Technologies
4th	Yellow (5 items/16.13%)	Education and Technology for Teachers	Mathematics, Science, STEM, Teacher, Technology
5th	Purple (5 items/16.13%)	Sustainable Development in Secondary Education	Integrated STEM, School System, Secondary Schools, Students, Sustainable Development

Description: Data Source by VOSviewer, data accessed on 3rd July, 2024

The first cluster is the red cluster with the name "Technology and Education in Primary Schools". This cluster illustrates the importance of technology integration in primary education. With keywords such as e-learning, primary school, technical education and robotics, this cluster shows how technology can be used to improve learning at the primary level. The use of e-learning enables wider and more flexible access to educational materials, while robotics and engineering education can foster early problem-solving skills. The main focus of this cluster is to prepare primary school students with the basic skills needed in the digital and technological age.

The second cluster is a green cluster named "Creativity and Professional Development in Education". This cluster highlights the importance of creativity and professional development in the education system. By including keywords such as creativity, critical thinking, professional development, and project-based learning, this cluster emphasizes how education should encourage innovation and critical thinking. Professional development for teachers is also an important aspect, allowing them to continuously update their skills and implement more effective teaching methods. This is important not only for early childhood education but also for the entire continuous learning process.

The third cluster is a blue cluster with the name "Science and Mathematics Education in Secondary Schools". This cluster focuses on the importance of science and mathematics education at the secondary school level. With keywords such as curriculum, mathematics education, science education and science technology, this cluster emphasizes that these subjects are important foundations for further education and careers in related fields. Science and mathematics education helps to develop the analytical and critical thinking skills required in various technological and scientific fields. This points to the importance of paying special attention to teaching and developing strong curricula in these subjects.

The fourth cluster is a yellow cluster with the name "Education and Technology for Teachers". This cluster highlights the role of teachers in integrating technology in teaching, particularly in math and science education. Keywords such as mathematics, science, technology and teachers emphasize the importance of supporting teachers with the necessary tools and training to use technology effectively in teaching. Technology can be a powerful tool to enhance learning and make complex concepts more accessible to students. This cluster reflects the need to strengthen teachers' capacity to apply educational technology to achieve better learning outcomes.

The fifth cluster is a purple cluster named "Sustainable Development in Secondary Education". This cluster focuses on integrating sustainability concepts in education at the secondary school level. With keywords such as sustainable development, school system, and students, this cluster emphasizes the importance of teaching students about relevant environmental and social issues. Education for sustainable development focuses not only on theoretical understanding but also on its practical application in everyday life. It helps mold students into responsible individuals who are aware of the environmental impact of their actions, and encourages critical thinking about global issues.

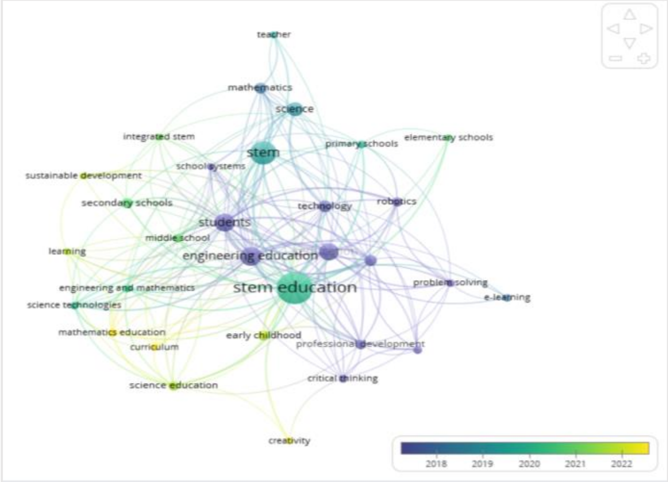

Figure 8. Keyword Novelty on Overlay Visualization Menu Analysis with VOSviewer

Yellow keywords indicate that they are just starting to be used and have great potential to become further research topics in the field of STEM education. One of the recommended keywords is 'creativity'. In the context of STEM education, creativity plays an important role in developing students' critical thinking and problem-solving skills. Creative approaches allow students to explore STEM concepts more deeply and innovatively, and encourage them to create unique solutions to real problems. Therefore, further research on how to integrate creativity into the STEM curriculum can provide valuable insights on how to improve student engagement and learning effectiveness.

Another keyword, 'mathematics education', is also highly relevant to STEM education as mathematics is one of the main foundations of science, technology and engineering. Further research on teaching mathematics in STEM contexts can help strengthen interdisciplinary linkages and enhance students' understanding of the practical applications of mathematics in everyday life and future careers. Meanwhile, the keyword 'curriculum' indicates the importance of developing and customizing curricula that support STEM learning. A well-designed curriculum can help align educational objectives with the needs of industry and society, ensuring that students acquire relevant skills and are prepared for future challenges. Therefore, research on effective and innovative curriculum development is essential to support the successful implementation of STEM education in schools.

Conclusion

Based on the results of the above analysis, the implementation of STEM education in schools shows a significant upward trend over the period 2003-2024, with a surge in publications beginning in 2018 and peaking in 2020 and 2021. Asia was the most productive continent, with the largest percentage of articles published by affiliates from countries such as Vietnam, Hong Kong, Turkey and Malaysia. Europe and Australia also showed high productivity with significant contributions from universities in countries such as Germany, Ireland, Greece and Australia. Lyn D. English from Queensland University of Technology, Australia, recorded the highest number of citations. There are five clusters with 'creativity', 'mathematics education', and 'curriculum' as recommended keywords for conducting further research in the field of STEM in Education.

Acknowledgments
The author would like to thank the Universitas Negeri Yogyakarta for providing analysis facilities for this research.

Author Contributions
Article writing was done by G.D.L. Data collection and data analysis were done by E.M, and Z.Z. Direction, guidance, review of ideas, concepts, methodology, analysis were done by W.P.

Funding
This research was funded by the researcher independently.

Conflicts of Interest
The authors declare no conflict of interest.

References

Ali, M., & Tse, A. W. C. (2023). Research Trends and Issues of Engineering Design Process for STEM Education in K-12: A Bibliometric Analysis. *International Journal of Education in Mathematics, Science and Technology*, *11*(3), 695–727. Retrieved from https://eric.ed.gov/?id=EJ1386699

Azzahra, S. F., & Rahyasih, Y. (2024). Strategi Peningkatan Mutu Sumber Daya Manusia melalui Program Literasi Digital di Sekolah. *Pendekar: Jurnal Pendidikan Berkarakter*, *7*(2), 64–70. https://doi.org/10.31764/pendekar.v7i2.24032

Banila, L., Hana, L., & Ridwan, S. (2021). Penerapan Blended Learning dengan Pendekatan STEM untuk Meningkatkan Kemampuan Literasi Sains Siswa pada Pembelajaran Biologi di Masa Pandemi COVID-19. *Jurnal of Biology Learning*, *3*(1), 27. https://doi.org/10.32585/jbl.v3i1.1348

Baran, E., Bilici, S. C., Mesutoglu, C., & Ocak, C. (2019). The impact of an out-of-school STEM education program on students' attitudes toward STEM and STEM careers. *School Science and Mathematics*, *119*(4). https://doi.org/10.1111/ssm.12330

Baucum, M. N., & Capraro, R. M. (2021). A system for equity: enhancing STEM education during a pandemic. *Journal of Research in Innovative Teaching & Learning*, *14*(3), 365–377. https://doi.org/10.1108/JRIT-12-2020-0087

Bornmann, L., & Leydesdorff, L. (2014). Scientometrics in a changing research landscape. *EMBO Reports*, *15*(12), 1228–1232–1232. https://doi.org/10.15252/embr.201439608

Bui, T.-L., Nguyen, T.-H., Nguyen, M.-T., Tran, T.-T., Nguyen, T.-L., Tran, V.-N., Phuong, U., Vu, C.-T., & Hoang, A.-D. (2024). Research on STEM in Early Childhood Education from 1992 to 2022: A Bibliometric Analysis from the Web of Science Database. *European Journal of Educational Research*, *13*(3), 1057–1075. https://doi.org/10.12973/eu-jer.13.3.1057

Cai, Z., Zhu, J., & Tian, S. (2023). Research Progress of STEM Education Based on Visual Bibliometric Analysis. *Sage Open*, *13*(3). https://doi.org/10.1177/21582440231200157

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. *Asia-Pacific Education Researcher*, *28*(1). https://doi.org/10.1007/s40299-018-0400-7

Dorouka, P., Papadakis, S., & Kalogiannakis, M. (2020). Tablets and apps for promoting robotics, mathematics, STEM education and literacy in early childhood education. *International Journal of Mobile Learning and Organisation*, *14*(2). https://doi.org/10.1504/IJMLO.2020.106179

English, L. D. (2017). Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education*, *15*. https://doi.org/10.1007/s10763-017-9802-x

Fadhilah, P. N., Wardatussaidah, I., & Wardhani, P. A. (2024). Analisis Pendekatan Steam Dalam Pembelajaran IPA di Sekolah Dasar Kelas V. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, *9*(2), 3280–3294. https://doi.org/10.23969/jp.v9i2.13780

Gillet, D., Jong, T., Sotirou, S., & Salzmann, C. (2013). Personalised learning spaces and federated online labs for STEM education at school. *IEEE Global*

Engineering Education Conference, EDUCON. https://doi.org/10.1109/EduCon.2013.6530194

Ha, C. T., Thao, T. T. P., Trung, N. T., Dinh, N., & Trung, T. (2020). A bibliometric review of research on STEM education in ASEAN: Science mapping the literature in Scopus database, 2000 to 2019. *Eurasia Journal of Mathematics, Science and Technology Education*, *16*(10), 1889. https://doi.org/10.29333/ejmste/8500

Hamimah, H., Zainil, M., Anita, Y., Helsa, Y., & Kenedi, A. K. (2022). Pelatihan pengembangan bahan ajar berbasis STEM sebagai solusi pembelajaran di masa pandemi COVID-19 bagi guru sekolah dasar. *Dedication: Jurnal Pengabdian Masyarakat*, *6*(1), 33–42. https://doi.org/10.31537/dedication.v6i1.655

Judijanto, L. (2024). Analisis Pengaruh Tingkat Literasi Digital Guru dan Siswa terhadap Kualitas Pembelajaran di Era Digital di Indonesia. *Sanskara Pendidikan Dan Pengajaran*, *2*(02), 50–60. https://doi.org/10.58812/spp.v2i02.391

Kasneci, E., Sessler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F., Gasser, U., Groh, G., Günnemann, S., Hüllermeier, E., Krusche, S., Kutyniok, G., Michaeli, T., Nerdel, C., Pfeffer, J., Poquet, O., Sailer, M., Schmidt, A., Seidel, T., & Kasneci, G. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences*, *103*, 102274. https://doi.org/10.1016/j.lindif.2023.102274

Lathifah, S. S., Widodo, A., Kaniawati, I., & Sriyati, S. (2024). Research Progress, Trends, and Updates on STEM Learning-ESD: A Bibliometric Analysis. *Jurnal Penelitian Pendidikan IPA*, *10*(5), 214–222. https://doi.org/10.29303/jppipa.v10i5.6513

León, J., Núñez, J. L., & Liew, J. (2014). Self-determination and STEM education: Effects of autonomy, motivation, and self-regulated learning on high school math achievement. *Learning and Individual Differences*, *43*. https://doi.org/10.1016/j.lindif.2015.08.017

Lestari, H., Rahmawati, I., Siskandar, R., & Dafenta, H. (2021). Implementation of blended learning with a stem approach to improve student scientific literacy skills during the covid-19 pandemic. *Jurnal Penelitian Pendidikan IPA*, *7*(2), 224. https://doi.org/10.29303/jppipa.v7i2.654

Li, Y., Wang, K., Xiao, Y., & Froyd, J. E. (2020). Research and trends in STEM education: a systematic review of journal publications. *International Journal of STEM Education*, *7*(1), 11. https://doi.org/10.1186/s40594-020-00207-6

Lo, C. K. (2021). Design principles for effective teacher professional development in integrated STEM education. *Educational Technology & Society*, *24*(4), 136–152. Retrieved from https://www.jstor.org/stable/48629251

Ma, K., & Hui, B.-H. (2023). A Bibliometric Analysis of Literature on Attitudes in STEM Education in 2008-2022. *Journal of Baltic Science Education*, *22*(6), 1038–1049. Retrieved from https://www.ceeol.com/search/article-detail?id=1202911

MacDonald, A., Huser, C., Sikder, S., & Danaia, L. (2020). Effective early childhood STEM education: Findings from the little scientists evaluation. *Early Childhood Education Journal*, *48*(3). https://doi.org/10.1007/s10643-019-01004-9

McGunagle, D., & Zizka, L. (2020). Employability skills for 21st-century STEM students: the employers' perspective. *Higher Education, Skills and Work-Based Learning*, *10*(3), 591–606. https://doi.org/10.1108/HESWBL-10-2019-0148

Morales-Doyle, D., & Gutstein, E. (2019). Rico. *Race Ethnicity and Education*, *22*(4). https://doi.org/10.1080/13613324.2019.1592840

Mutakinati, L., Anwari, I., & Yoshisuke, K. (2018). Analysis of students' critical thinking skill of middle school through STEM education project-based learning. *Jurnal Pendidikan IPA Indonesia*, *7*(1). https://doi.org/10.15294/jpii.v7i1.10495

Nguyen, T. P. L., Nguyen, T. H., & Tran, T. K. (2020). STEM education in secondary schools: Teachers' perspective towards sustainable development. *Sustainability (Switzerland)*, *12*(21). https://doi.org/10.3390/su12218865

Öztürk, O., Kocaman, R., & Kanbach, D. K. (2024). How to design bibliometric research: an overview and a framework proposal. *Review of Managerial Science*. https://doi.org/10.1007/s11846-024-00738-0

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., & Moher, D. (2021). Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. *Journal of Clinical Epidemiology*, *134*, 103–112. https://doi.org/10.1016/j.jclinepi.2021.02.003

Putri, C. D., Pursitasari, I. D., & Rubini, B. (2020). Problem based learning terintegrasi STEM di era pandemi covid-19 untuk meningkatkan keterampilan berpikir kritis siswa. *JIPI (Jurnal IPA Dan Pembelajaran IPA)*, *4*(2), 193–204. https://doi.org/10.24815/jipi.v4i2.17859

Rezaei, M., Emamjomeh, S. M. R., Ahmadi, G. A., Assareh, A., & Niknam, Z. (2022). A Comparative Study of Integrated STEM Curriculum in Finland, Singapore and the United States to Provide Recommendations for Iranian Curriculum Planners. *Iranian Journal of Comparative Education*, *5*(1), 1765–1788.

https://doi.org/10.22034/ijce.2022.251947.1227
Rochim, R. A., Prabowo, P., & Budiyanto, M. (2021). Analisis kebutuhan perangkat pembelajaran model pjbl terintegrasi stem berbasis e-learning di masa pandemi covid-19. *Jurnal Basicedu*, *5*(6), 5370–5378. https://doi.org/10.31004/basicedu.v5i6.1655
Sánchez, D. L. V, & Martínez, A. G. (2021). Educación Stem, Un Campo De Investigación Emergente: Análisis Bibliométrico Entre 2010–2020. *Investigações Em Ensino de Ciências*, *26*(3), 195. https://doi.org/10.22600/1518-8795.ienci2021v26n3p195
Saroro, E. K. S. E. K., & Febrianto, P. T. (2024). Pembuatan Miniatur Dispenser Sebagai Salah Satu Pembelajaran STEAM di Sekolah Dasar Kelas V. *Jurnal Ilmiah Kajian Multidisipliner*, *8*(4). https://shorturl.asia/GHSB4
Selco, J. I., & Habbak, M. (2021). STEM students' perceptions on emergency online learning during the covid-19 pandemic: Challenges and successes. *Education Sciences*, *11*(12), 799. https://doi.org/10.3390/educsci11120799
Shurygin, V., Anisimova, T., Orazbekova, R., & Pronkin, N. (2024). Modern approaches to teaching future teachers of mathematics: the use of mobile applications and their impact on students' motivation and academic success in the context of STEM education. *Interactive Learning Environments*, *32*(6), 2884–2898. https://doi.org/10.1080/10494820.2022.2162548
Sırakaya, M., & Alsancak, S. D. (2022). Augmented reality in STEM education: a systematic review. *Interactive Learning Environments*, *30*(8), 1556–1569. https://doi.org/10.1080/10494820.2020.1722713
Subramaniam, M. M., Ahn, J., Fleischmann, K. R., & Druin, A. (2012). Reimagining the role of school libraries in STEM education: Creating hybrid spaces for exploration. *Library Quarterly*, *82*(2). https://doi.org/10.1086/664578
Sulistiyono, E., Pangestu, W. T., & Wana, P. R. (2021). Efektivitas Pembelajaran STEM (Science, Technology, Engineering And Mathematic) Untuk Meningkatkan Hasil Belajar Siswa di Masa Pandemi Covid-19. *Jurnal Educatio FKIP UNMA*, *7*(3), 791–795. Retrieved from https://ejournal.unma.ac.id/index.php/educatio/article/view/1207
Suprapto, N. (2016). Students' attitudes towards STEM education: Voices from Indonesian junior high schools. *Journal of Turkish Science Education*, *13*(Specialissue). https://doi.org/10.12973/tused.10172a
Teo, T. W., Tan, A.-L., & Teng, P. (2021). *STEM education from Asia: Trends and perspectives*. https://doi.org/10.4324/9781003099888
Thahir, A., Anwar, C., Saregar, A., Choiriah, L., Susanti, F., & Pricilia, A. (2020). The Effectiveness of STEM learning: scientific attitudes and students' conceptual understanding. *Journal of Physics: Conference Series*, *1467*(1), 12008. https://doi.org/10.1088/1742-6596/1467/1/012008
Thibaut, L., Knipprath, H., Dehaene, W., & Depaepe, F. (2018). The influence of teachers' attitudes and school context on instructional practices in integrated STEM education. *Teaching and Teacher Education*, *71*. https://doi.org/10.1016/j.tate.2017.12.014
Wan, Z. H., Jiang, Y., & Zhan, Y. (2021). STEM education in early childhood: A review of empirical studies. *Early Education and Development*, *32*(7), 940–962. https://doi.org/10.1080/10409289.2020.1814986
Wati, P., Nusantara, T., & Utama, C. (2024). Efektivitas PjBL-STEM Terhadap Keterampilan Berpikir Kritis dan Motivasi Belajar Siswa Sekolah Dasar. *Cetta: Jurnal Ilmu Pendidikan*, *7*(2), 126–143. https://doi.org/10.37329/cetta.v7i2.3264
Weis, L., Eisenhart, M., Cipollone, K., Stich, A. E., Nikischer, A. B., Hanson, J., Ohle Leibrandt, S., Allen, C. D., & Dominguez, R. (2015). In the guise of STEM education reform: Opportunity structures and outcomes in inclusive STEM-focused high schools. *American Educational Research Journal*, *52*(6). https://doi.org/10.3102/0002831215604045
Xu, S.-R., & Zhou, S.-N. (2022). The Effect of Students' Attitude towards Science, Technology, Engineering, and Mathematics on 21st Century Learning Skills: A Structural Equation Model. *Journal of Baltic Science Education*, *21*(4), 706–719. https://doi.org/10.33225/jbse/22.21.706
Ziatdinov, R., & Valles, J. R. (2022). Synthesis of modeling, visualization, and programming in GeoGebra as an effective approach for teaching and learning STEM topics. *Mathematics*, *10*(3), 398. https://doi.org/10.3390/math10030398