Mapping the global landscape of STEM education: a bibliometric analysis using Scopus database

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ABSTRACT

Global innovation, economic growth, and societal advancement require excellence in science, technology, engineering, and mathematics (STEM) education. This study performed a bibliometric examination of articles related to STEM in education. A bibliographic dataset indexed in the Scopus database from 1980 to 2023 was analyzed using Excel and VOSviewer software. A total of 2,595 publications were taken for analysis. Bibliometric analysis results indicate that there has been a consistent growth in publications related to STEM education, and the highest number of publications was in 2022. The top three contributors are authors from North America, Oceania, Europe, and Asia. The United States was the most active contributor to STEM publications and had connections with Australia and Turkey. The most prolific journal is the International Journal of STEM Education, which has garnered 2,588 citations. Keywords such as “STEM,” “STEM education,” “STEM,” and “Education computing” were frequently used in these articles. Consequently, by shedding light on specific gaps in the existing literature, a comprehensive analysis of STEM education could aid scholars and practitioners in advancing their current understanding of this field.

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1. INTRODUCTION

Pursuing excellence in science, technology, engineering, and mathematics (STEM) education is a cornerstone in the global quest for innovation, economic growth, and societal advancement. STEM education has gained increasing prominence on national and international educational agendas as nations recognize its pivotal role in fostering critical thinking, problem-solving skills, and technological innovation [1]–[3]. This recognition has sparked research efforts to understand, improve, and advance STEM education practices worldwide.

In the contemporary digital information and connectivity setting, the application of bibliometric analysis has emerged as a formidable instrument for meticulously examining the dynamic landscape of research in STEM education. This sophisticated analytical approach serves as a potent means to unravel intricate patterns, discern prevailing trends, and extract invaluable insights, hence fostering a more profound comprehension of the global STEM educational research community. By harnessing data from diverse scholarly publications, bibliometric analysis plays a pivotal role in explaining the complex dimensions of research pursuits within the STEM educational area. In essence, its systematic examination offers a nuanced perspective, contributing significantly to the scholarly discourse and advancing collective understanding of STEM education research.

Amidst the recent proliferation of STEM education research, an imperative exists to systematically consolidate the dispersed knowledge and insights prevalent across an extensive body of scholarly literature. While extant reviews and studies have delved into various facets of STEM education, a noticeable gap persists in the absence of a comprehensive bibliometric analysis aimed at synthesizing global trends, discerning influential voices, and meticulously mapping the intellectual landscape of STEM education research. The demand for such an analytical endeavor becomes apparent as it represents an unexplored avenue in the scholarly landscape, holding the potential to provide a cohesive overview of STEM education research.

Demonstrating the significance of this scholarly undertaking, recent studies have underscored the imperative for more expansive research into pivotal facets of STEM education. These critical dimensions encompass the exploration of effective pedagogical strategies [4], the seamless integration of technology [5], and a discerning analysis of the repercussions of gender disparities [6]. Such categorical calls for research not only highlight the dynamic nature and contemporary relevance of the field but also highlight the necessity for a comprehensive review. In responding to these scholarly requirements, this paper aims to contribute substantively by offering an in-depth examination that aligns with the evolving discourse surrounding these crucial aspects of STEM education.

It is worth mentioning, however, that this study contributes to a more systematic and updated review of the literature on STEM education in contrast to most previous literature reviews that focused on individual aspects of STEM education. This bibliometric analysis aims to bridge this gap by offering a holistic, data-driven view of STEM education research, thus facilitating informed decisions, fostering international collaboration, and advancing the field in a concerted, evidence-based manner. The following research questions drive the bibliometric process:

i) What is the trend of research on STEM in education published to date?
ii) Which countries and authors contribute significantly to the study of STEM in education?
iii) What are the most influential publications on STEM in education?
iv) What are the main keywords of scientific research on STEM in education?

In the forthcoming sections of this paper, a detailed examination of the methodologies utilized for both data collection and analysis will be conducted. Following this, the research findings will be systematically presented, paving the way for a comprehensive discussion on the implications derived from the bibliometric analysis. This aims to elucidate the significance of the findings for the global STEM education research community and, concurrently, to inform educational policymakers worldwide.

2. LITERATURE REVIEW

Cultivating a robust STEM foundation is crucial for the progress and prosperity of nations, especially in both developing [6] and developed countries [7]. For developing countries like India, STEM education provides individuals with the competencies and expertise necessary to address complex issues, foster creativity, and contribute significantly to economic advancement [6]. In doing so, it positions countries to nurture talented nations capable of seizing opportunities and meeting the evolving demands of the future [8].

However, according to a report [9], no developing country surpasses India in the number of STEM degrees awarded. Consequently, there is a continual surplus of job opportunities for qualified professionals. This situation raises concerns as businesses are facing challenges, and progress in various sectors, particularly in developing countries such as Malaysia, Vietnam, and Cambodia, is slowing down. The scarcity of several STEM degrees in these developing nations indirectly underscores the lesser popularity of STEM education, indicating the need for further studies, as emphasized by Yamada [10].

Meanwhile, in developed nations such as the United States, STEM education has unequivocally risen as a prominent trend. This is substantiated by the United States being recognized as a trailblazer in formulating clear and systematic STEM education policies and strategies, thereby setting an exemplary standard for other countries, including Germany [7], [11]. Moreover, in Germany, the ever-progressing demands of the industrial sector have prompted the adoption of a STEM education strategy. This approach underscores employment-oriented educational objectives and the practical aspects of teaching [12].

Beyond the United States and Germany, other developed countries, including the United Kingdom, Australia, and China, are also advocating STEM education. However, it can be summarized that each country has a different goal and focus in the implementation of STEM education. The United Kingdom has strategically prioritized STEM education, emphasizing the cultivation of a versatile workforce equipped with proficient STEM skills through the establishment of the National STEM Strategy Group [13]. In Australia, the primary emphasis in STEM education is on cultivating students' interest in STEM subjects and inspiring them to pursue further studies or careers in STEM-related fields [14]. Meanwhile, in China, the primary focus is on integrating various disciplines within K-12 STEM education. The country is actively exploring the development of localized STEM education tailored to meet its unique needs [15].

Despite evidence indicating that several developed countries, including the United States, the United Kingdom, Germany, Australia, and China, have taken significant strides to promote STEM education, a research gap persists, particularly in the comparative analysis of STEM education implementation strategies and their effectiveness. While documented efforts exist at the individual country level, there is limited cross-country research systematically evaluating the outcomes and impacts of diverse STEM education policies and approaches. Additionally, there is a lack of studies examining how successful STEM education models can be transferred between developed countries, taking into account diverse socio-economic, cultural, and educational contexts [14], [15]. Hence, further research is needed to address this gap.

Additionally, Siregar *et al*. [16] recommends the promotion of research pertaining to trends in STEM education to discern the global development patterns in this field. Such research not only provides insights for governments, policymakers, and researchers to identify countries requiring heightened attention in STEM education but also furnishes crucial information for determining subsequent actions. The results of such research can illuminate the necessary steps for raising awareness about STEM education and degrees among future generations.

Moreover, delving into STEM education trends through research facilitates the identification of research gaps within a country, as noted by Irwanto *et al*. [17]. This, in turn, allows subsequent researchers to concentrate on areas crucial for enhancing awareness of the importance of STEM education and degrees in that specific country. This effort serves to mitigate redundant or repetitive research in STEM education, thereby averting a meager impact, especially in developing countries, where the persistent surplus of job offers for qualified employees continues to exact a significant toll.

Table 1 reveals that a multitude of studies have delved into the realm of STEM education through bibliometric analysis [18]–[27]. However, upon a thorough scrutiny of the existing literature, it becomes evident that discernible research gaps are waiting to be addressed. This observation not only underscores the need for further investigation but also points towards promising avenues for additional investigation in the dynamic field of STEM education.

3. METHOD

In the current bibliometric study, the researchers examined the publications from the Scopus science database. They extensively compared these publications to a previous biblio-metric study utilizing Scopus, including scientific journals, books, and conference proceedings [28], [29]. The study used various data fields available in Scopus, such as source title, abstract, author keywords, year of publication, research area, affiliation, and document type [30], [31]. Scopus is one of the largest curated databases and provides data access through its search, discover, and analyze options. According to the recently updated Scopus content coverage guide [31]–[33], the database currently contains over 1.7 billion cited references, making it a valuable resource for obtaining a comprehensive overview of global scientific research output.

A bibliometric analysis was conducted using the Scopus database up until August 2023. The search query used was TITLE ("STEM" OR "stem" And Education) to find relevant publications in the English language. Since titles are the first thing readers see, we searched only within titles to ensure that the identified publications are specifically related to STEM in education. This approach also helps to avoid a high rate of irrelevant publications. Our search strategy is illustrated in Figure 1. A total of 2,595 publications were obtained from the search.

In this study on bibliometrics in the field of STEM education, we conducted a performance analysis to examine various aspects of research. Firstly, we investigated the publication trends (RQ1) and identified the countries that made significant contributions (RQ2). Additionally, we explored the sources they originated from (RQ3) and their associated keywords (RQ4).

To analyze the data, the study utilized Microsoft Excel to calculate the frequency and percentage of each publication. Also generated graphs to visualize the findings. The study employed VOSviewer (version 1.6.19), a freely available software tool, to enhance our investigation. VOSviewer helped us extract citation information, bibliographical details, and keywords from the research papers. Furthermore, VOSviewer was used to map the intellectual structure of STEM in education by conducting keyword co-occurrence analysis and bibliographic coupling analysis of the documents. This analysis helped us identify the relationships and connections between different keywords and documents, providing a deeper understanding of the research landscape in STEM education.

Table 1. Summary of previous studies related to bibliometric analysis on STEM education

Author	Objective	Bibliometric attributes examined	TDE	Data source & coverage	Research gaps	Contribution
[18]	To assess the bibliographic content of case studies on STEM education	Number of publications, citation count, co-citation analysis, author productivity, institution productivity, top keyword productivity, co-occurrence analysis	750	Scopus 2006 - 2022	Limited to the articles of Scopus database.	This research has identified significant countries, authors, and publications that have a lasting impact on research trends to highlight the main research directions.
[19]	To review STEM education literature for PSTs (pre-service teachers) and provide recommendations for future research and practices.	Keyword analysis, research institution, co-occurrence analysis, number of publications, author background	31	ProQuest Education, 14 STEM journals, and 17 Indonesian-accredited journals 2007–2021	Limited to articles in ProQuest Education and STEM journals.	A review of the movement, intervention, development, and conceptualization of STEM education for PSTs in Indonesia to derive a conceptual STEM framework provides recommendations for implementing and developing STEM learning for PSTs.
[20]	To assess the role of integrated STEM education in improving the quality of education.	Number of publications, citation analysis, keywords analysis, keywords co-occurrence analysis, most prolific authors and sources.	150	Scopus 1993 - 2020	Limited to the articles in the Scopus database.	This study has given an overview of the past, present, and future trends in the research area of STEM and quality of education.
[21]	To analyze the development of research trends on technology-based educational supervision.	Keyword analysis, citation analysis, trend analysis	461	Google Scholar 2000-2022	Limited to the articles of Google Scholar.	This study illustrates that academic supervision can be developed by referring to the terms STEM, quality, and performance.
[22]	To better understand the research progress in STEM education worldwide.	Number of publications, citation analysis, author analysis, keyword analysis, main source analysis	1,910	Web of Science (Core Collection) 2006 - 2021	Limited to the articles of Web of Science databases and also limited to the articles in the English language.	The research hotspots in the future identified are STEM achievements, different approaches to discipline integration, educational equality, and teacher education.
[23]	To ascertain the existing situation of STEAM education research.	Publishing source, year-wise publication, keyword analysis.	100	Scopus 2012 - 2022	Limited to Scopus database.	It provides the visualization of global and Southeast Asia clusters that can be used as a starting point for future STEAM research.
[24]	To objectively examine the STEM education literature on technical teachers' pedagogical beliefs.	Number of publications, number of citations, authors' productivity, impact analysis, keyword analysis, authorship co-occurrences, top 20 countries	144	Web of Science (Core Collection) and Scopus 1990 - 2021	Limited to the articles of Web of Science (core collection) and Scopus databases, and also limited to articles in the English language.	Highlights the current research trends in this domain by identifying the most impactful documents, topics, contributing authors, journals, and countries.
[25]	To evaluate the scientific results of publications in the field of STEM education in middle school.	The number of citations, top 10 most productive countries, top 15 most active journals, bibliographic coupling, top 10 most productive authors, co-authorship, top 10 most cited papers, keyword analysis.	272	Scopus 2000–2020	Limited to the articles in Scopus and also limited to the articles in the English language.	This study looked into STEM education in middle schools, as one of the most important factors influencing the decision on scientific research selection is the middle school science classes.
[26]	To evaluate the scientific results of STEM education in the Association of Southeast Asian Nations (ASEAN) region.	Publication output and growth trend, country-wise analysis, institution-wise analysis, source publishing analysis, keyword analysis, co-occurrence analysis, author-wise analysis	175	Scopus 000 - 2019	Limited to the articles in the Scopus database and also limited to articles in the English language.	Overview of the development of research in STEM education in terms of the collaboration of STEM education researchers in the ASEAN region and provides the main research directions for STEM education and their development during this period.
[27]	To describe the domain of STEM and STEM education or the topology of the field.	Co-word analysis, co-occurrence analysis	7265	Web of Science and ERIC 1901–2010	Limited to the articles of Web of Science and ERIC databases.	This study identified a missing discourse on "engineering education" at the elementary and secondary education levels. The underlying structure of the STEM field shows the presence of policy, financial resources, mentoring, and teacher education in urban and rural settings.

Note: TDE=Total documents examined.

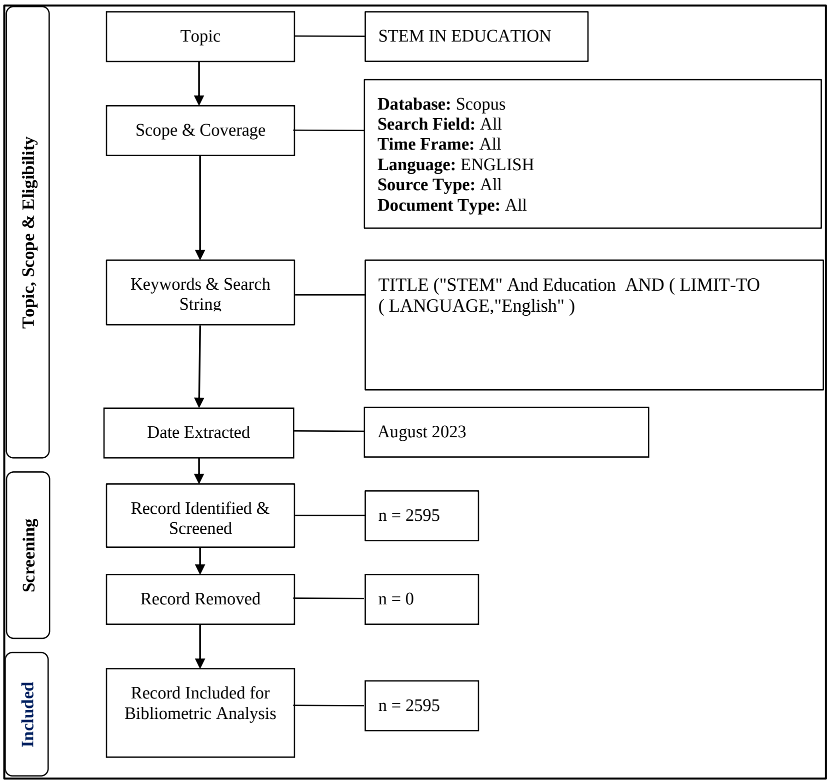

Figure 1. Flow diagram of the search strategy

4. RESULTS AND DISCUSSION

4.1. Annual growth of publication

Table 2 presents a comprehensive overview of annual publications related to STEM from 1980 to 2023. The first known study on STEM was conducted by Dare in 1980. The table shows the number of STEM research publications collected each year. Notably, 2022 recorded the highest number of publications, with 412 documents constituting 15.88% of the total. This data indicates a significant surge in STEM-related publications.

Table 2. Number of STEM research publications by year

Year	Number of documents	Percentage (%)	Cumulative percentage (%)
1980	1	0.04%	0.04%
1995	1	0.04%	0.08%
1999	1	0.04%	0.12%
2001	2	0.08%	0.16%
2003	4	0.15%	0.24%
2004	2	0.08%	0.39%
2005	3	0.12%	0.47%
2006	7	0.27%	0.59%
2007	10	0.39%	0.86%
2008	10	0.39%	1.25%
2009	20	0.77%	1.64%
2010	27	1.04%	2.41%
2011	44	1.70%	3.45%
2012	46	1.77%	5.15%
2013	74	2.85%	6.92%
2014	111	4.28%	9.77%
2015	136	5.24%	14.05%
2016	142	5.47%	19.29%
2017	140	5.39%	24.76%
2018	216	8.32%	30.15%
2019	294	11.33%	38.47%
2020	336	12.95%	49.80%
2021	347	13.37%	62.75%
2022	412	15.88%	76.12%
2023	208	8.02%	92.00%
Total	2595	100	

Furthermore, Figure 2 illustrates the growth trend of STEM activities since 2014. The figure displays a noticeable increase in the output of STEM-related content starting from 2014. Analyzing the annual growth of documents and categorizing the source types shed light on the specific studies currently being conducted within the STEM field. Overall, Table 2 and Figure 2 provide valuable insights into the evolution and trends of STEM research, emphasizing the rise in publications in recent years and the diversity of research within the STEM domain.

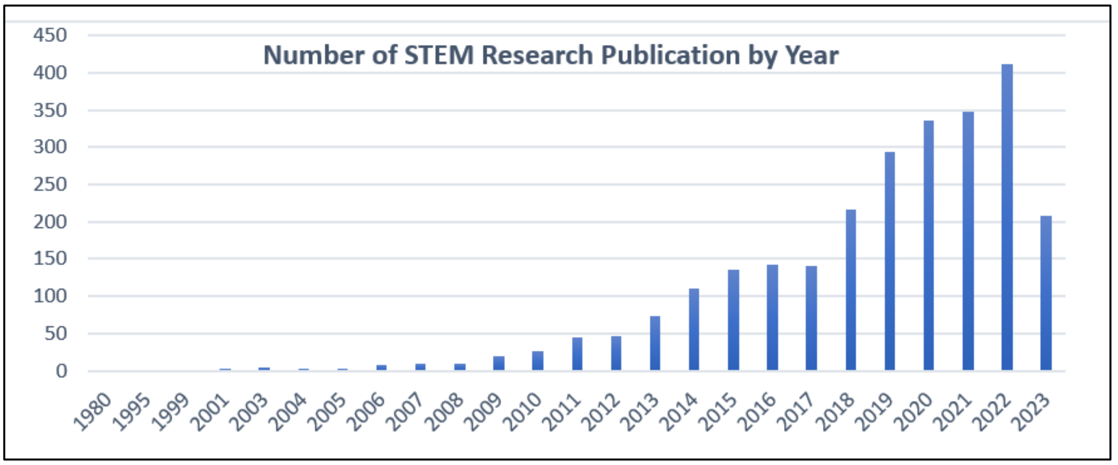

Figure 2. Total publications by year

4.2. Document type

This study also aimed to identify the publication venues of STEM documents by analyzing document source types. The results presented in Table 3 indicate that journals were the most frequently used source, accounting for 42.04% (1,091) of the total publications, followed by conference proceedings with 33.18% (861). After conferences, the next common sources were book chapters at 12.52% (325), editorials at 3.24% (84), reviews at 2.89% (75), and books at 2.12% (55). Other publications, such as notes, errata, short surveys, letters, and conference reviews, contributed to less than 1.5% of the documents. Table 4 reveals that a significant majority, 98% (2,553), of the STEM publications were written in English, indicating that English is the preferred language for most academic research in this field.

Table 3. Document type

Document type	Total publications (TP)	Percentage (%)
Article	1,091	42.04
Conference paper	861	33.18
Book chapter	325	12.52
Review	84	3.24
Book	75	2.12
Note	34	1.31
Erratum	28	1.08
Conference review	21	0.81
Letter	10	0.39
Short survey	10	0.39
Retracted	1	0.4
Total		100.00

Table 4. Languages

Source type	Total publications	Percentage (%)
English	2,553	98.38%
Spanish	25	0.96%
Russian	7	0.27%
Turkish	7	0.27%
Chinese	3	0.12%
Total	2,595	100.00

4.3. Publications by countries

Table 5 indicates the top 20 countries where most STEM publications originated. The United States (41.16%) had the leading position, followed by Australia (5.43%), Turkey (3.89%), China (3.85), Indonesia (3.85), Thailand (3.78), United Kingdom (3.58), Malaysia (3.55), Canada (3.28) and Spain (3.28). Four continents were represented among the top three contributors - North America, Oceania, Europe, and Asia. National affiliations of the remaining authors represented fewer than 10% of the total.

Additionally, the co-authorship analysis explores the formal partnerships between countries with affiliations. This examination has led to a better understanding of the relationships between countries and has provided valuable insights into the research field. Furthermore, it serves as a basis for justifying and inspiring new research endeavors in regions that are less represented.

Figure 3 displays an overlay visualization created using VOSviewer, illustrating collaborations over two years beginning in 2014. Notably, the United States (represented by the purple node) was the most active contributor to STEM publications in the early stages and had connections with Australia and Turkey. During the subsequent green phase (2014 to 2023), the United States emerged as the most prominent collaborator. It is evident that collaborations among authors from different affiliated countries are diverse and span various continents.

Table 5. Contributions from the top 20 countries

Country	Continent	TP	%
United States	North America	1,068	41.16%
Australia	Oceania	141	5.43%
Turkey	Europe	101	3.89%
China	Asia	100	3.85%
Indonesia	Asia	100	3.85%
Thailand	Asia	98	3.78%
United Kingdom	Europe	93	3.58%
Malaysia	Asia	92	3.55%
Canada	North America	85	3.28%
Spain	Europe	85	3.28%
Greece	Europe	55	2.12%
Hong Kong	Asia	55	2.12%
Germany	Europe	52	2.00%
Taiwan	Asia	52	2.00%
Russian Federation	Europe	41	1.58%
Viet Nam	Asia	38	1.46%
Japan	Asia	32	1.23%
United Arab Emirates	Asia	30	1.16%
Italy	Europe	27	1.04%
Netherlands	Europe	26	1.00%

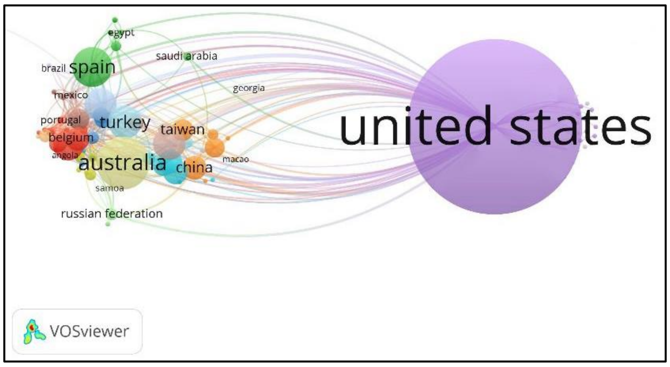

Figure 3. Overlay visualization of the most active contributor to STEM

4.4. Source titles and documents for publications

Table 6 lists 10 journals that have published at least 20 papers in the STEM field, focusing specifically on articles (totaling 2,595). Notably, the most prolific journal in this context is the International Journal of STEM Education, which has garnered 2,588 citations. Following closely, we find the Eurasia Journal of Mathematics Science and Technology Education, the Journal of Physics Conference Series, Education Sciences, and the Proceedings Frontiers in Education Conference (FIE). These top five sources, each having published 29 articles, have received 506, 452, 328, and a significant number of citations, respectively. Together, these five journals account for 10.98% of all STEM articles and are considered the most active publications in STEM research.

Table 6. Most active source titles

Source title	TP	TC	%
ASEE Annual Conference and Exposition Conference Proceedings	137	282	5.28%
Journal Of Physics Conference Series	118	452	4.55%
International Journal of Stem Education	53	2588	2.04%
Education Sciences	46	328	1.77%
Proceedings Frontiers in Education Conference Fie	39	310	1.50%
AIP Conference Proceedings	36	74	1.39%
Sustainability Switzerland	36	293	1.39%
Eurasia Journal of Mathematics Science and Technology Education	29	506	1.12%
Proceedings of the International Astronautical Congress Inc.	26	10	1.00%
IEEE Global Engineering Education Conference Educon	25	215	0.96%

Note: TP=total number of publications; TC=total citations

Overlays in Figure 4 and Table 7 lists the top 20 most cited publications in the STEM field. With 651 citations, the most cited article, Honey *et al.* [34] (STEM integration in K-12 Education: status, prospects, and an agenda for research) is published by the National Academy Press. A conceptual framework for integrated STEM education, published by Kelley and Knowles in Springer, is the second most cited source in STEM research, with 646 citations.

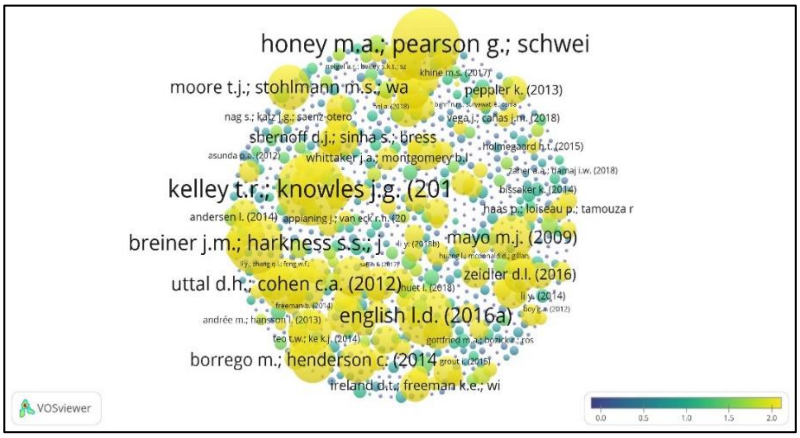

Figure 4. Network visualization map of top 20 highly cited articles

Table 7. Top 20 highly cited articles

Author(s)	Title	TC	C/Y
[34]	STEM integration in K-12 education: status, prospects, and an agenda for research	651	72.33
[35]	A conceptual framework for integrated STEM education	646	92.29
[36]	What is STEM? A discussion about conceptions of STEM in education and partnerships	440	40
[37]	STEM education K-12: Perspectives on integration	420	60
[38]	Spatial thinking and STEM education. When, why, and how?	332	30.18
[39]	Teachers' perception of STEM integration and Education: A systematic literature review	292	73
[40]	Increasing the use of evidence-based teaching in STEM higher education: A comparison of eight change strategies	260	28.89
[41]	Effect of COVID-19 on the performance of Grade 12 students: Implications for STEM education	254	84.67
[42]	Counter spaces for women of color in STEM higher education: Marginal and central spaces for persistence and success	254	50.8
[43]	Implementation and integration of engineering in K-12 STEM education	250	27.78
[44]	STEM education	220	27.5
[45]	Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching	190	23.75
[46]	Innovations in STEM education: The Go-Lab Federation of Online Labs	182	20.22
[47]	Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education	176	29.33
[48]	What are we talking about when we talk about STEM education? A review of the literature	169	42.25
[49]	Advancing elementary and middle school STEM education	165	27.5
[50]	Talking about leaving revisited: Persistence, relocation, and loss in undergraduate STEM education	163	40.75
[51]	STEM education: A deficit framework for the twenty-first century? A sociocultural sociocentric respons	157	22.43
[52]	Synthesizing results from empirical research on computer-based scaffolding in STEM education: A meta-analysis	154	25.67
[53]	A place for art and design education in the STEM conversation	151	13.73

Notes: C/Y=average citations per year.

4.5. Top keywords

Overlays in Figure 5 and Table 8 show which STEM keywords are most popular and can be used to describe hot research areas. Keywords and co-occurrence (or co-word) analysis suggest popular themes in the STEM literature (RQ4). The study finds that STEM education dominates the discourse in this field.

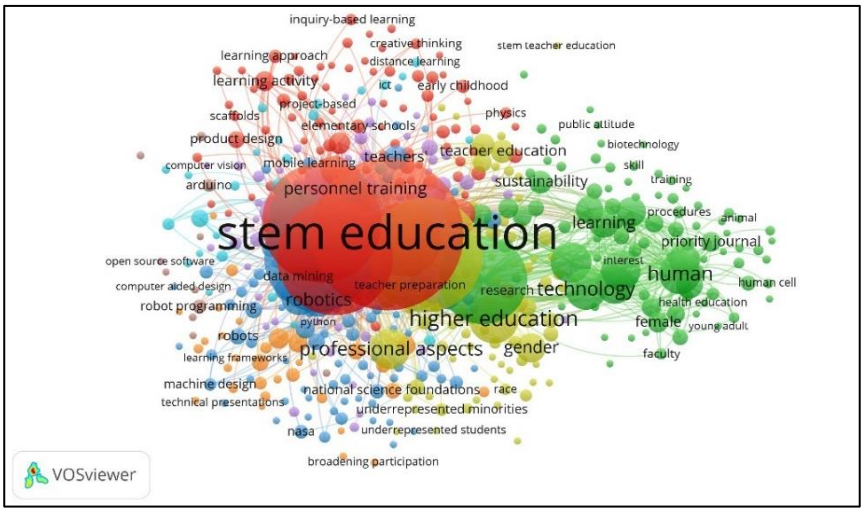

Figure 5. Overlay visualization of the author's keywords

Table 8. Top author's keywords

Author keywords	TP	Percentage (%)
STEM education	790	30.44%
STEM (science, technology, engineering, and mathematics)	536	20.66%
Students	507	19.54%
STEM	486	18.73%
Engineering education	451	17.38%
Education	323	12.45%
Teaching	239	9.21%
Curricula	161	6.20%
Education computing	146	5.63%
E-learning	141	5.43%
Higher education	126	4.86%
Science education	95	3.66%
Human	92	3.55%
Technology	90	3.47%
Engineering	89	3.43%
Professional aspects	87	3.35%
Science, technology, engineering and mathematics	87	3.35%
Science	84	3.24%
Mathematics	82	3.16%
Science, technology, engineering, and mathematics	75	2.89%

5. CONCLUSION

Based on an analysis of 2,595 publications found in the Scopus database, this study provided an overview of the current trends in STEM research. Over the past decade, publications have grown consistently; this upward trajectory is expected to persist. The study identified several countries, such as the United States, Australia, and Turkey, and authors with many publications and strong international collaborations. Consequently, these entities present opportunities for researchers from other countries to expand their research networks and collaborations. The most highly cited journals in this field are the International Journal of STEM Education, Eurasia Journal of Mathematics Science and Technology Education, and the Journal of Physics Conference Series. The limitation of this study is that the analysis is based solely on publications available in the Scopus database, which might not cover all STEM research publications. Future studies should consider including other databases and sources to ensure a more comprehensive overview of publication trends on STEM. Additionally, it will be good to consider incorporating data from multiple databases, including non-English language sources, to provide a more comprehensive view of STEM research trends.

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