

 **Review Article**

Research on STEM Education: A Bibliometric Review of Literature Over the Past 20 Years

Tiurma Juniar P. Nababan ¹ ¹Department of Chemistry Education, Universitas Negeri Jakarta, Jakarta, Indonesia**Abstract**

In recent years, Science, Technology, Engineering, and Mathematics (STEM) education has emerged as a major focus in countries worldwide. This study employs bibliometric analysis to assess the scientific output on STEM education indexed in the Scopus database between 2004 and 2024. Bibliometric software was used to visualize the data. This software provides a range of analytical functions, enabling the examination of various bibliometric indicators, such as publication counts, citation frequencies, authorship networks, and keyword co-occurrence networks. A total of 3,769 publications were retrieved for analysis. The findings highlight a significant surge in scientific output over the past four years, accounting for 71% of the total publications. International Journal of STEM Education emerging as the leading journal. The USA leads with 4,086 publications, followed by China and Turkey with 671 and 327, respectively. The most productive authors are affiliated with the top 10 universities and research institutions. Three keywords that frequently appear are technology, student, and education. The research spans both foundational and interdisciplinary topics, addressing STEM education across various levels, including primary and secondary schools, undergraduate studies, and computational education. The findings from such analysis can also inform the development of educational and research policies, supporting strategic decisions in advancing STEM education and research initiatives.

Keywords: Bibliometrics, Education, STEM Education, Students, Technology Correspondence
Tiurma Juniar P. Nababan
tiurma.nababankim23@gmail.com**Received**

January 28, 2025

Accepted

February 21, 2025

Published

March 7, 2025

Citation: Nababan, T. J. P. (2025). Research on STEM education: A bibliometric review of literature over the past 20 years. *Journal of Technology-Assisted Learning*, 1(1), 44–66.

© 2025 The Author(s).
Published by Scientia Publica
Media



This is an open access article distributed under the terms of the Creative Commons Attribution-NonCommercial License.

1. INTRODUCTION

Information and communication technology has advanced swiftly worldwide in the 21st century. In education, both teachers and students are encouraged to build skills that meet the needs of this modern era. As outlined by the P21 framework (Partnership for 21st Century Learning, 2015), 21st-century learning focuses on enhancing cognitive abilities, emphasizing that students should develop skills, knowledge, and competencies in technology, media, information, as well as learning and innovation skills (21st Century Student Outcomes, n.d.).

In recent years, STEM education—emphasizing Science, Technology, Engineering, and Mathematics—has gained prominence as a critical strategy for improving global educational quality (Chasokela, 2025; Ghufrooni, 2024; Manokore & Sibanda, 2024; Nwune et al., 2024; Samara & Kotsis, 2025; Selvan & Kalaiyaran, 2024; Simamora, 2024). This approach not only prepares students to tackle global challenges but also nurtures the critical and creative thinking skills essential for thriving in the digital era (Ciucu-Durnoi et al., 2024). As research in STEM education continues to grow, developing a comprehensive understanding of its trends, patterns, and contributions is crucial for advancing education in alignment with Industry 5.0. This innovative concept envisions industries that are more “sustainable, human-centered, and resilient,” representing the next phase of industrialization and building on the principles of Industry 4.0 (Madsen et al., 2023; Di Nardo & Yu, 2021).

In contemporary education, combining technology with STEM fields (Science, Technology, Engineering, and Mathematics) is becoming essential. Technology is transforming not only our access to

information but also the ways we teach and learn. Rapid advancements in digital tools—such as educational software, programming platforms, and online resources—are creating more opportunities for interactive and engaging learning experiences (Hebebci & Usta, 2022a).

Bibliometric studies provide a means to examine bibliographic data from published works on STEM education, shedding light on the relationships and interactions among research articles. For instance, Hernandez-Torran and Ibrayeva (2020) carried out a bibliometric study with a focus on creativity in education, exploring topics such as curriculum design, assessment strategies, teaching approaches, and learning environments. Likewise, Castillo-Vergara et al. (2018) analyzed creativity as a critical skill for improving organizational performance and as a basis for various research frameworks. While these studies address creativity within the contexts of education and business, bibliometric analyses dedicated specifically to STEM education remain relatively scarce.

The bibliometric method is an effective tool for analyzing academic literature and mapping developments and dynamics in STEM education research. Using quantitative bibliometric analysis, this method allows researchers to explore publication counts, author collaborations, and the most-discussed topics. This journal aims to present an up-to-date bibliometric analysis covering various aspects of STEM education, including key themes, curriculum development, and pedagogical innovations (Setiani Hasanah et al., 2022).

Applying the bibliometric method aims to offer a deeper understanding of STEM education trends, helping to identify research opportunities and best practices for educators and researchers. This journal, therefore, aspires to become a valuable resource for all stakeholders in advancing more effective and relevant STEM education in the future (Hebebci & Usta, 2022).

This study employs a bibliometric analysis to explore and map the profiles and emerging trends within STEM education (Chen et al., 2023). Its objective is to provide researchers, educational institutions, educators, and librarians with valuable insights into the future trajectory of STEM education research, enabling them to refine their research priorities and drive progress in the field. Furthermore, policymakers can utilize these findings to make informed decisions that promote and enhance STEM education research. By gaining a comprehensive understanding of existing studies, stakeholders can remain updated on recent advancements and contribute actively to the field's development. The key research questions are presented below:

1. What are the significant findings and progress made in STEM education research?
2. What are the main insights and latest developments within the STEM education literature?
3. How can the most-cited articles in STEM education research be summarized?
4. What are the emerging trends and visual representations of keywords in STEM education literature?
5. What patterns and visual mappings of keywords can be observed in STEM education research?
6. What is the knowledge structure within the STEM education literature?

2. DATA AND METHODS

The bibliometric research method in the STEM education field (Science, Technology, Engineering, and Mathematics) involves conducting various bibliometric analyses. Research trends reflect the collective activities of scholars focusing on specific scientific subjects. Within STEM education, these trends highlight critical elements that demonstrate the field's growth and increasing attention. Bibliometric mapping serves as a valuable tool for researchers to identify potential future directions for their studies. Scopus, recognized for its rigorous content selection and periodic reviews by an independent Advisory Board, ensures the availability of high-quality data (Baas et al., 2020). Bibliometric studies depend on bibliographic databases to gather information about scientific publications, including titles, authors, abstracts, keywords, and references. As one of the largest curated citation and abstract databases, Scopus is an excellent resource for such research, offering extensive coverage of scientific journals, conference proceedings, and books on both regional and global scales (Pranckutè, 2021).

2.1. Process and Method of Article Selection

Bibliographic data was extracted from Scopus (www.scopus.com) on September 19, 2024, initially identifying 8,369 documents related to STEM education using the search query “TITLE (STEM education).” Following the approach outlined by Page et al. (2021a), the selection process focused on documents published between 2004 and 2024, prioritizing articles as the primary type of scientific publication. Articles were chosen because they typically present original research findings, which are well-suited for analysis and comparison using bibliometric methods. The selection was further refined to include only English-language articles. Duplicate records were removed, and the remaining articles were evaluated for relevance to the topic. Ultimately, 3,769 articles were selected for inclusion in this bibliometric study. The selection process is illustrated in Figure 1.

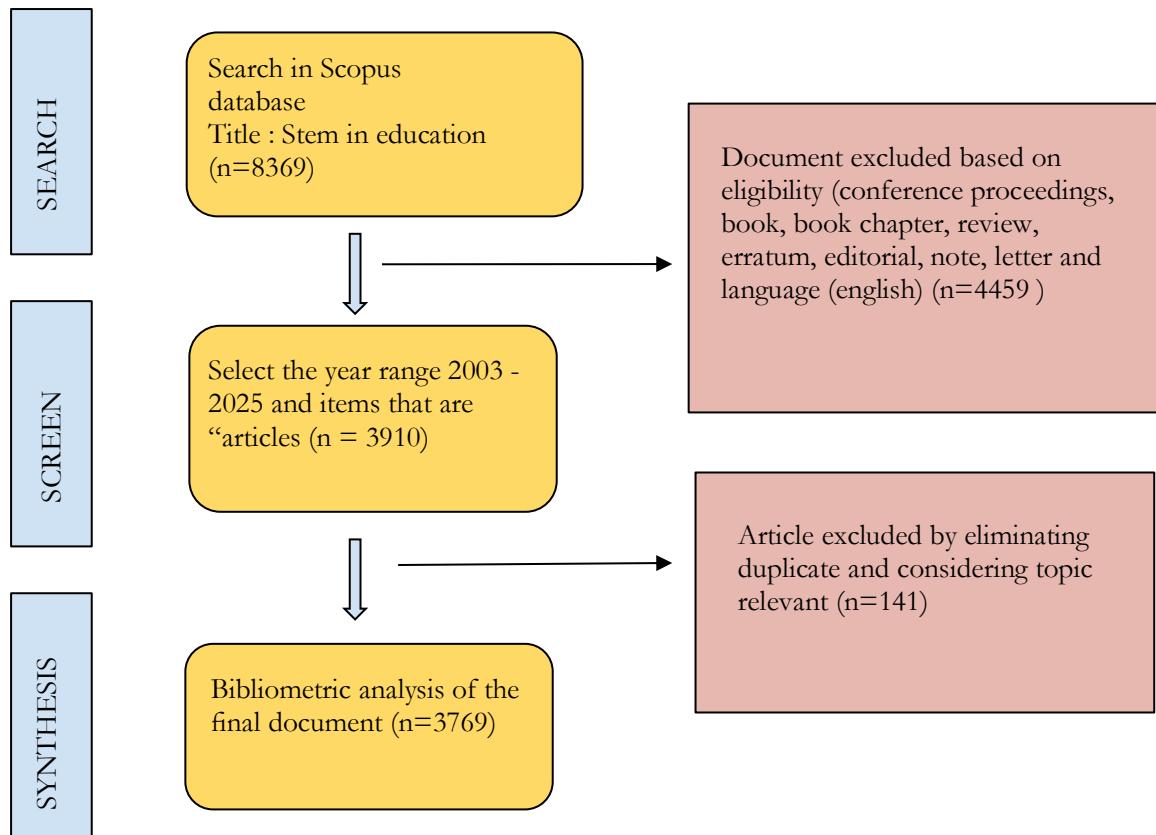


Figure 1. Process and Method of Article Selection

2.2 Analysis of Data

The selected documents were extracted in BibTeX (.bib) format, containing details such as author names, affiliations, titles, countries, journal names, and keywords. These files were descriptively analyzed in alignment with the research questions. The article selection process adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. PRISMA provides a structured framework to improve the quality of systematic reviews and meta-analyses by prioritizing transparency, rigor, and accuracy—critical for evidence-based decision-making, particularly in disciplines like health (Page et al., 2021b). Bibliometric software was used to visualize the data. This software provides a range of analytical functions, enabling the examination of various bibliometric indicators, such as publication counts, citation frequencies, authorship networks, and keyword co-occurrence networks. Furthermore, the software ensures standardized and consistent metric measurements, enhancing the reliability and comparability of the data analysis with other STEM education literature.

A quantitative descriptive analysis was conducted to identify key information in STEM education research, including source titles, leading countries, and affiliations. The study also analyzed author pair citations through authorship analysis. Additionally, co-occurrence knowledge mapping was employed to visualize development pathways, trends, keywords, and themes within the field. The most commonly used

keywords highlighted the prominence of specific themes in the domain. To evaluate the frequency and significance of term usage on the co-occurrence knowledge map, keyword co-occurrence mapping was applied. A stronger correlation between two keywords indicated their more frequent co-occurrence within the same publication.

3. FINDINGS AND DISCUSSION

3.1 Key Information

Table 1 presents key data from the bibliometric study on articles related to STEM education (Science, Technology, Engineering, and Mathematics), analyzing trends over time to track shifts in research interests and focuses. The study examines several important aspects, including publication trends, research topics, and collaboration within the field. Sourced from the Scopus database over a defined period, the data highlights various points such as the total number of published articles to identify growth patterns, key research areas like teaching methods, educational technology, and policy, as well as emerging topics in STEM education. It also identifies underexplored areas and challenges in STEM education, which could guide future research priorities. Through the collection and analysis of this data, bibliometric research provides a comprehensive overview of the STEM education landscape, helping researchers and policymakers understand the field's current direction and future needs.

Table 1. Key Data Information in Bibliometric Study

No	Description	Results
MAIN INFORMATION ABOUT DATA		
1	Timespan	2004:2024
2	Sources (Journals, Books, etc)	1013
3	Documents	3731
4	Annual Growth Rate %	37.13
5	Document Average Age	3.62
6	Average citations per doc	16.4
7	References	0
DOCUMENT CONTENTS		
9	Keywords Plus (ID)	4229
10	Author's Keywords (DE)	7870
AUTHORS		
11	Authors	10128
12	Authors of single-authored docs	484
AUTHORS COLLABORATION		
14	Single-authored docs	524
15	Co-Authors per Doc	3.48
16	International co-authorships %	15.06
DOCUMENT TYPES		
17	Article	3731

3.1.1 Trends in Publication

Figure 2 displays the findings of a bibliometric analysis on the annual scientific output in the field of STEM education from 2004 to 2024, revealing a notable upward trend. This time frame marks a crucial stage in the development of STEM education, shaped by global policies, technological progress, and an increasing recognition of the importance of incorporating STEM into the educational framework.

Between 2004 and 2010, the field experienced an early phase of growth, with publication numbers still relatively low but steadily increasing. STEM-related publications started to appear as the concept of STEM education was introduced in several developed nations, including the United States and the United Kingdom. During this period, research mainly concentrated on creating STEM-based curricula and teaching models to support the implementation of the concept.

According to Price's Law, a small proportion of individuals in a population or system are responsible for the majority of the results or performance, a concept often referred to as the power distribution principle. In linear regression analysis, R^2 (coefficient of determination) measures how well the model accounts for the total variation in the data. A value of R^2 closer to 1 indicates a more accurate model for predicting outcomes. Essentially, R^2 reflects how well the regression line fits the observed data or the percentage of the total variance in the dependent variable that is explained by the independent variable. With an R^2 value of 0.8239, close to 1, this model shows strong predictive ability and effectively explains data variation.

Publication trends in bibliometric studies on STEM education (Science, Technology, Engineering, and Mathematics) show a significant upward trend in recent years. (Prahani et al., 2024) Between 2017 and 2024, the number of articles published annually has increased considerably, with approximately 400 to 600 publications each year. This rise reflects the growing interest in STEM research and curriculum development.

Figure 3 illustrates the average annual citation count for STEM education research. The data shows that the influence of STEM education topics has fluctuated over time. Certain years exhibit higher citation rates, indicating increased recognition and impact, while other years have lower citation numbers. In particular, the years 2007, 2011, 2014, 2016, and 2018 are notable for their higher impact, suggesting that publications from these years contributed more significantly to the advancement of STEM education.

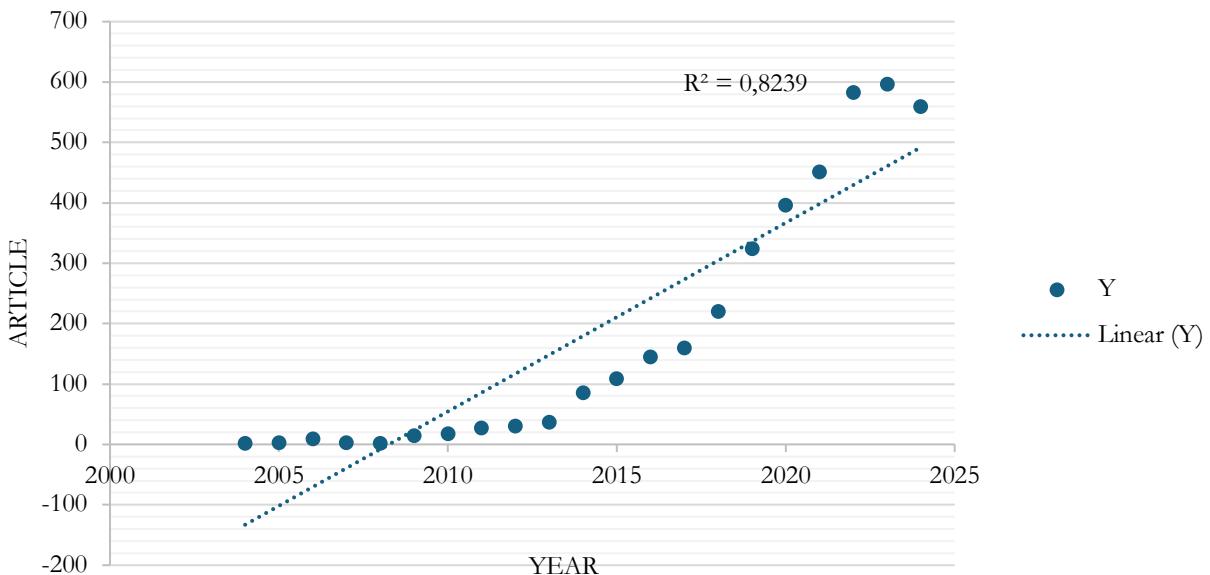


Figure 2. Annual Scientific Production

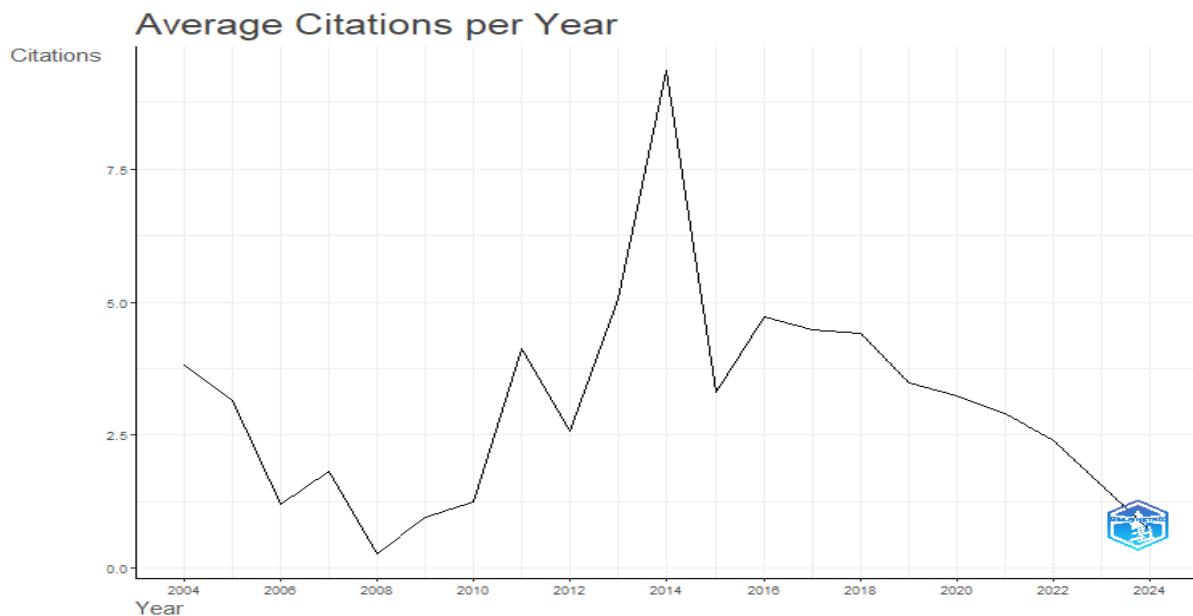


Figure 3. Average Number of Citations per Year in STEM Education Literature (2004-2024)

3.1.2 Thematic Development

A Sankey diagram is used to connect various elements related to research in this field, such as topics, authors, institutions, or publications. Here is a further explanation of how the Sankey diagram functions in bibliometric analysis within the theme of STEM education (Bonilla-Chaves & Palos-Sánchez, 2023a). Based on Figure 4, keywords that frequently appear in STEM education articles are highlighted, with lines or arrows indicating the relationships between these keywords. For example, terms like “creativity,” “innovation,” “STEM curriculum,” or “project-based learning” may be connected with more or fewer studies depending on how often these terms are used in the publications analyzed.

The Sankey diagram can also show the flow of publications from authors or institutions focusing on STEM education themes. This flow provides an overview of individual or research group contributions to the existing literature. Visualizing relationships between emerging themes, such as connections between STEM education and subtopics like technology learning, problem-based approaches, or 21st-century skills, can offer insights into trends and emerging topics in STEM education research.

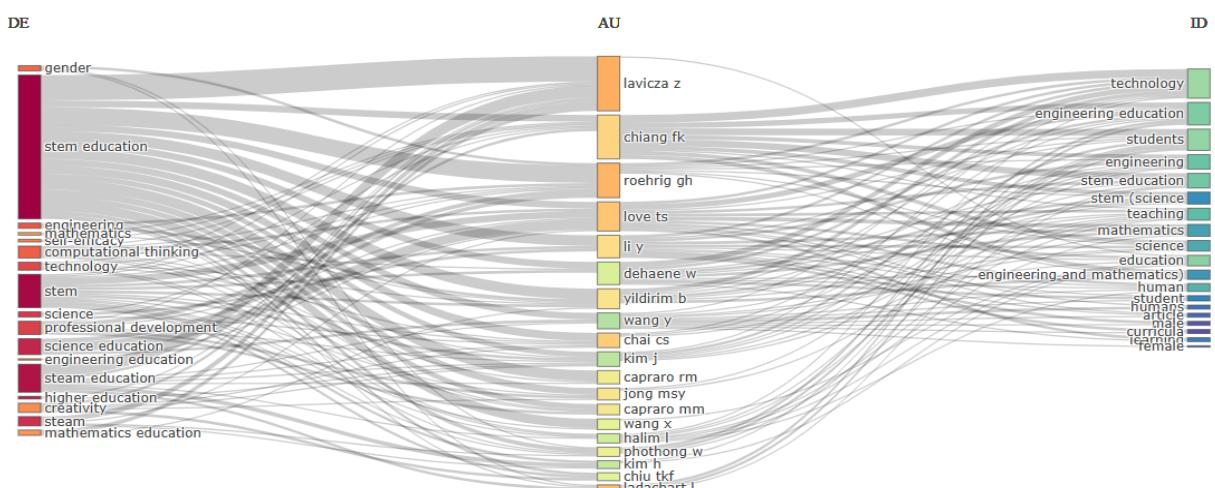


Figure 4. Thematic Evolution of STEM Education Research Illustrated by a Sankey Diagram

3.2 Researcher Profiles and Source Titles

3.2.1 Top Authors

The most productive authors offer valuable insights into the development of research on STEM education, including their productivity, collaboration patterns, and research impact. Table 2 highlights the top ten authors in the field. Notably, Chai CS has an h-index of 10, indicating that at least 10 of their works have been cited 10 or more times. Meanwhile, Roehrig GH stands out with the highest g-index of 18, signifying the significant impact of their most-cited articles. Additionally, Henderson C has accumulated the highest total number of citations across their publications, reflecting the broad recognition of their contributions within the academic community.

Table 2. Top Authors and Their Influence on STEM Education Research

Author	h_index	g_index	m_index	TC	NP	PY_start
Chai CS	10	14	1,67	404	14	2019
Jong MSY	9	11	1,50	246	11	2019
Roehrig GH	9	18	0,69	610	18	2012
Halim L	8	10	0,80	343	10	2015
Love TS	8	11	1,14	133	16	2018
Henderson C	7	7	0,50	1302	7	2011
Lin KY	7	7	0,78	214	7	2016
Osman K	7	7	0,64	300	7	2014
Capraro MM	6	10	0,55	389	10	2014
Capraro RM	6	10	0,6	253	10	2015

Authors' Production over Time

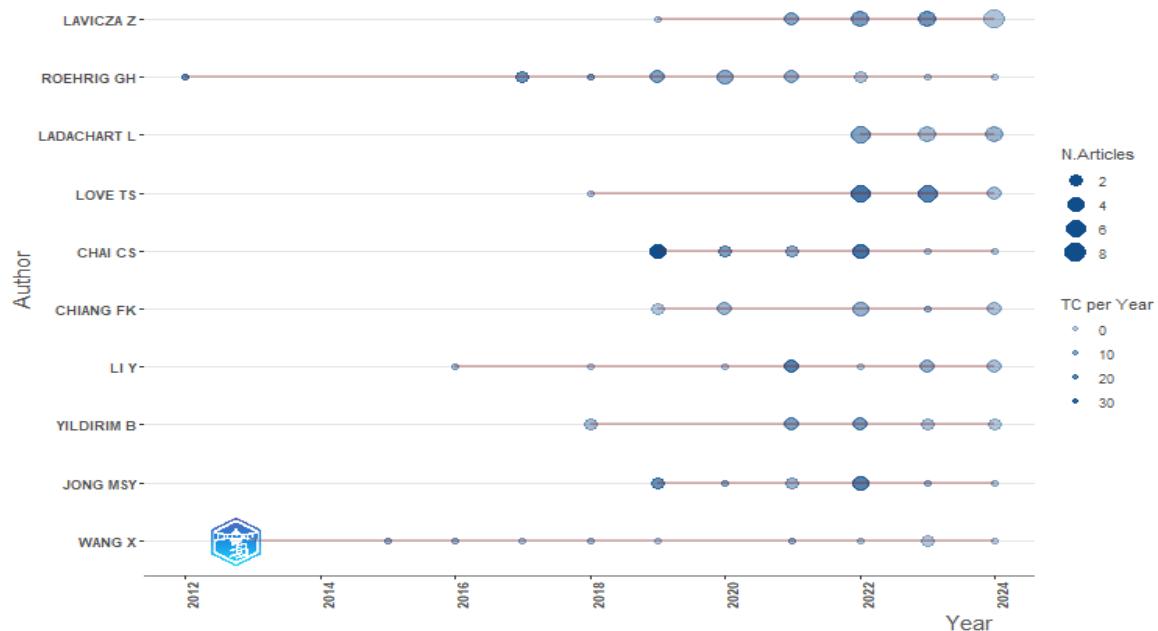


Figure 5. Top Authors' Production Over Time

Figure 5 illustrates the scientific output of leading authors from 2012 to 2024. Roehrig GH emerges as a key contributor to research on STEM education, with a consistent publication record. His first article, "Is Adding the E Enough? Investigating the Impact of K-12 Engineering Standards on STEM Integration

Implementation," has garnered significant attention, achieving an impressive annual citation rate of 17.62. Similarly, Lavicza Z is highlighted as the most prolific author, publishing 22 articles between 2017 and 2024, accompanied by a notable citation count during this period.

Lotka's Law, introduced by Lotka in 1926, describes the distribution of publications per author in a given field of study. It can be used to analyze publication patterns within this area, helping to identify prominent authors, assess research quality, and highlight emerging trends. As such, Lotka's Law is a valuable tool in bibliometric analysis, offering insights into publication dynamics in STEM education and supporting researchers in developing more effective research strategies and educational policies.

Figure 6 reveals that a small number of authors produce the majority of documents, while the number of documents decreases significantly as the number of authors per document increases. In other words, fewer authors are responsible for a large volume of publications, while the majority contribute to fewer works. According to the data, 8,589 authors have contributed just one work on STEM education, while only one author has written 22 articles. Given the novelty of the topic, it can be inferred that most authors are relatively new to the field.

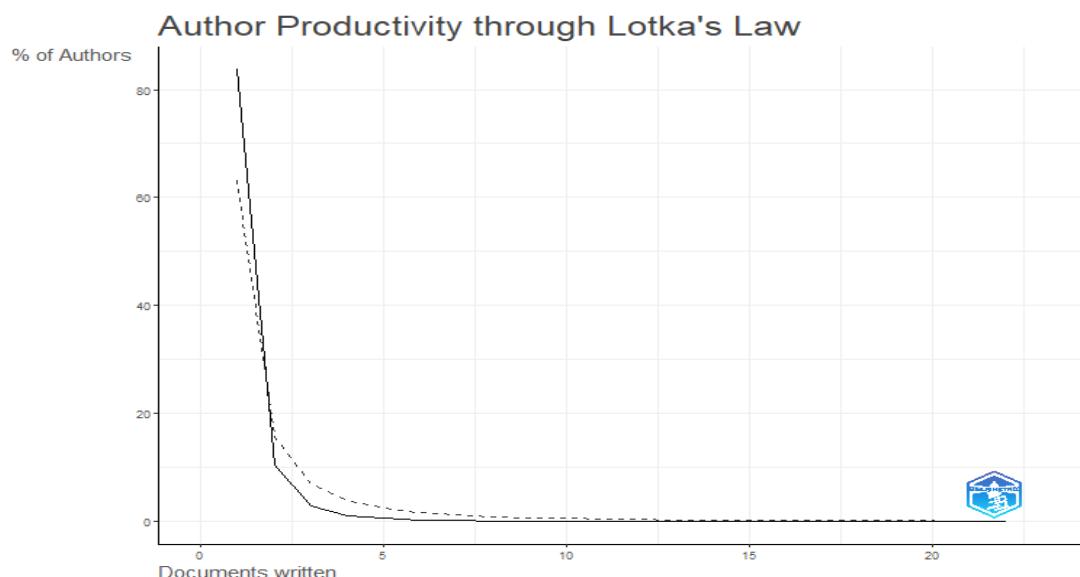


Figure 6. Author Output According to Lotka's Law

3.2.2 Sources

Table 3 highlights the ten most influential sources in the field, with the International Journal of STEM Education emerging as the leading journal. Since its establishment in 2014, it has published 49 articles on STEM education, achieving an h-index of 28 and accumulating 2,771 citations. The Eurasia Journal of Mathematics, Science, and Technology Education and the Journal of Science Education and Technology also stand out, each with an h-index of 22, reflecting their impactful and widely recognized academic contributions. Notably, the Journal of Science Education and Technology, the oldest among these journals, holds the second-highest citation count, total 2,503.

Bradford's Law is applied alongside top data sources to examine the distribution of publications within a scientific field. This law suggests that when publications on a specific topic are distributed across multiple journals, they exhibit a distinct pattern. In Figure 7, the shaded area represents the core zone, or primary sources, which include the most relevant and influential studies on the topic. These core sources should be prioritized when producing publications on STEM education. The journals in this zone are as follows: Education Sciences, International Journal of STEM Education, Frontiers in Education, Sustainability (Switzerland), Eurasia Journal of Mathematics, Science, and Technology Education, Journal of Science Education and Technology, International Journal of Technology and Design Education, International Journal of Science and Mathematics Education, Education and Information Technologies, International Journal of Science Education, Frontiers in Psychology, Journal of Baltic Science Education,

Journal of Chemical Education, Research in Science and Technological Education, Cultural Studies of Science Education, Journal for STEM Education Research, Journal of Research in Science Teaching, School Science and Mathematics, Research in Science Education, and CBE Life Sciences Education. These journals play a critical role in advancing research and providing innovative perspectives on STEM education.

Table 3. Key Sources and Their Local Influence

Source	h_index	g_index	m_index	TC	NP	PY_start
International Journal of STEM Education	28	49	2,55	2771	98	2014
Eurasia Journal of Mathematics, Science and Technology Education	22	39	2,00	1660	71	2014
Journal of Science Education and Technology	22	49	1,10	2503	67	2005
International Journal of Technology and Design Education	20	39	1,67	1609	66	2013
Education Sciences	18	31	2,25	1263	153	2017
International Journal of Science and Mathematics Education	18	30	2,00	968	49	2016
International Journal of Science Education	18	34	1,38	1180	43	2012
Journal of Research in Science Teaching	18	31	1,29	2061	31	2011
Cultural Studies of Science Education	16	26	1,23	689	32	2012
Sustainability (Switzerland)	15	23	2,14	799	73	2018

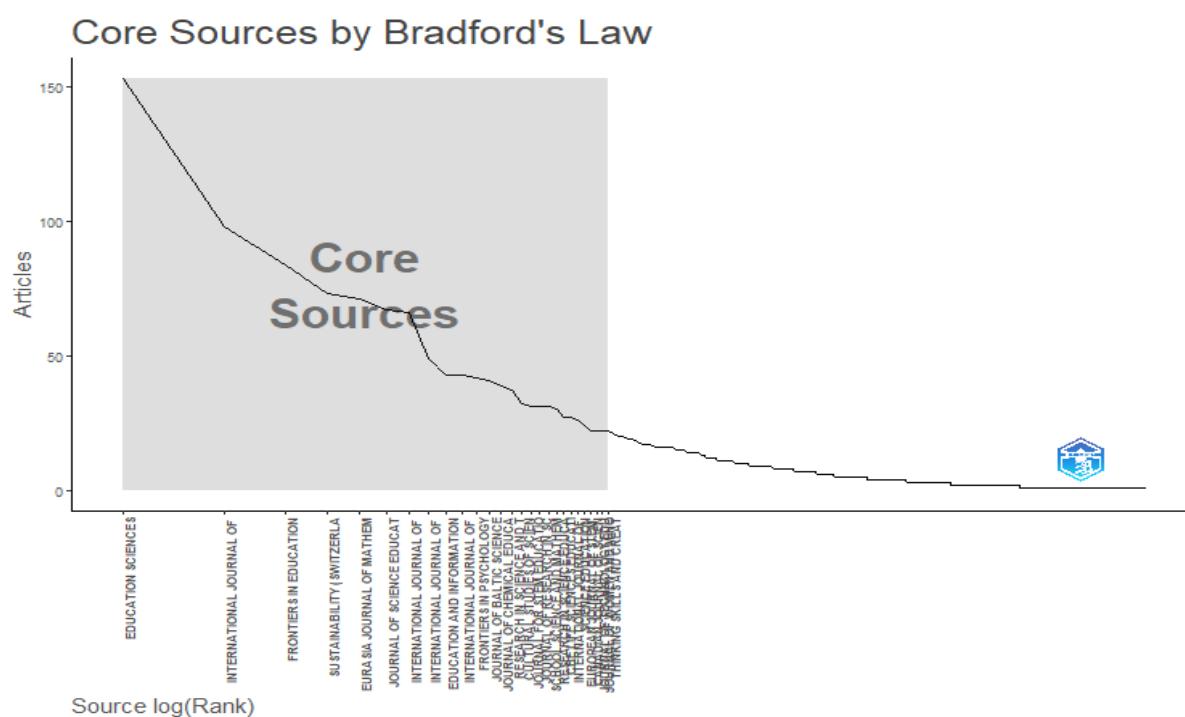


Figure 7. Core Sources According to Bradford's Law

Figure 8 illustrates a steady increase in publications, with consistent growth in contributions over time. The International Journal of STEM Education and the Eurasia Journal of Mathematics, Science and Technology Education started publishing articles earlier in the observed period, beginning in 2014 with 1 and 4 articles, respectively. Over time, the increasing volume of publications from these journals highlights their emergence as prominent platforms for research in science education and creativity.. These journals have progressively gained influence and excellence, offering valuable insights into the field's evolution, factors driving its growth, and potential challenges or opportunities ahead. This trend is especially beneficial for researchers, educators, and policymakers to stay responsive to current needs and trends. Additionally, the data reveals that Education Science experienced rapid growth in STEM education publications beginning in 2022, eventually surpassing other sources to become the leading journal in 2024.

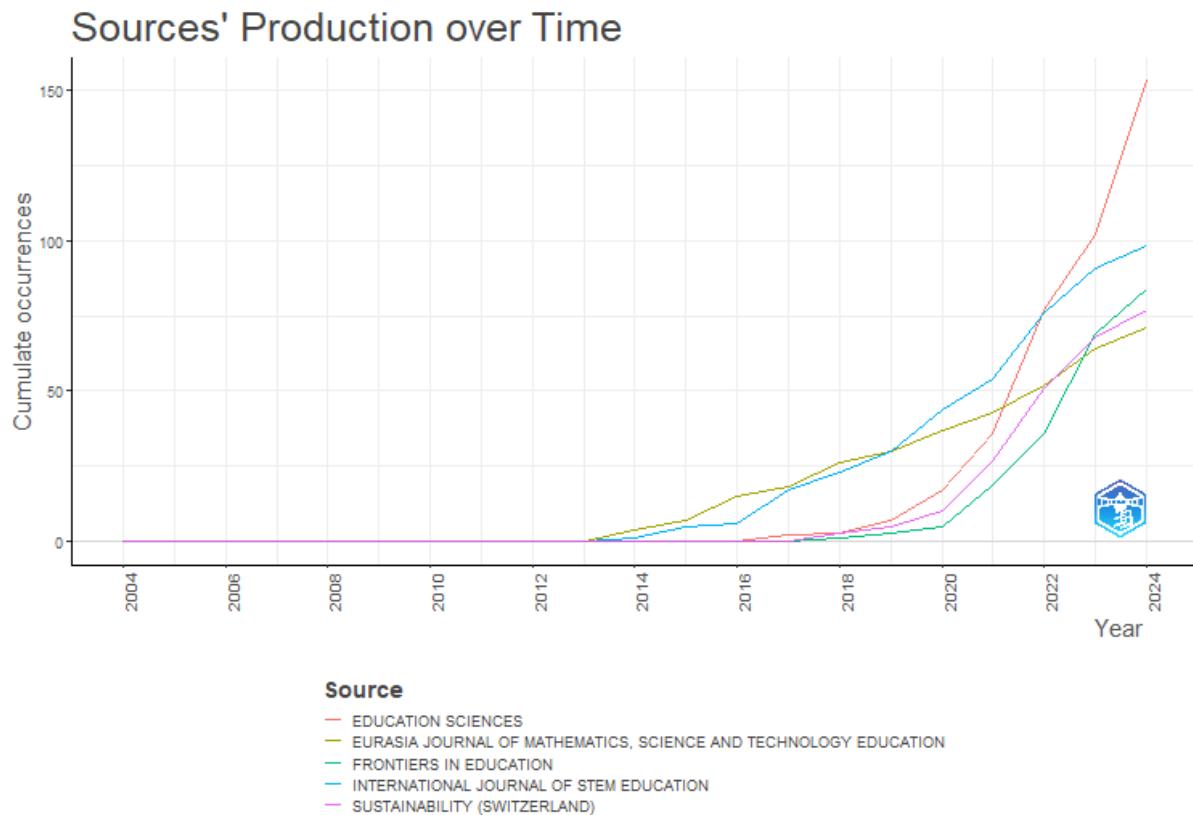


Figure 8. Growth of Publications in Core Sources

3.3 Most Impactful Literature

Table 4 highlights the most cited articles in STEM education, reflecting their significant impact on advancing research in this multifaceted field. Most of these influential works utilize quantitative methodologies. The top-ranked article, authored by Freeman S. in 2014 and published in the *Proceedings of the National Academy of Sciences of the United States of America*, introduced the idea that active learning enhances student performance in science, technology, and mathematics (Freeman et al., 2014). Another key work, Weintrop D.'s 2016 study in the *Journal of Science Education and Technology*, defined computational thinking in mathematics and science education, exploring its application to problem-solving, system design, and understanding human behavior. (Kong & Abelson, n.d.).

Ranked fourth and fifth, the works of Henderson C. (2011) in the *Journal of Research in Science Teaching* and Potkonjak V. (2016) in *Computers & Education* both conducted systematic reviews of the literature on the use of augmented reality (AR) technology to enhance STEM learning. Their research synthesized 28 studies published between 2010 and 2017. Through qualitative content analysis, they identified common features of AR applications in STEM education, examined the teaching strategies and

techniques employed, and analyzed the evaluation methods used in the interventions. The review concluded that the majority of AR applications in STEM education centered on exploration and simulation activities.

Ong M. (2018), in the Journal of Research in Science Teaching, investigated how gender, race, and ethnicity do not significantly impact STEM learning (Ong et al., 2018). Subsequently, Borrego M. (2014) in the Journal of Engineering Education and Dennehy T.C. (2017) examined the effects of peer mentoring on women's experiences and retention in engineering, producing highly impactful findings (Dennehy & Dasgupta, 2017). Sintema E.J. (2020), writing for the Eurasia Journal of Mathematics, Science, and Technology Education, analyzed how COVID-19 became a key focus for researchers working on STEM education, emphasizing the challenges faced by countries newly adopting STEM initiatives (Sintema, 2020). Finally, Xie Y. (2015), in the Annual Review of Sociology, compared STEM and non-STEM education in the United States, identifying STEM education as a vital factor for long-term economic growth and national security (Xie et al., 2015).

Table 4. Most Cited STEM Education Articles from 2004 to 2024

Paper	DOI	Total Citations	TC per Year	Normalized TC
Freeman S, 2014, Proc Natl Acad Sci U S A	10.1073/pnas.1319030111	5575	506,82	54,20
Weintrop D, 2016, J Sci Educ Technol	10.1007/s10956-015-9581-5	900	100,00	21,16
Henderson C, 2011, J Res Sci Teach	10.1002/tea.20439	729	52,07	12,61
Potkonjak V, 2016, Comput Educ	10.1016/j.compedu.2016.02.002	602	66,89	14,16
Ibáñez Mb, 2018, Comput Educ	10.1016/j.compedu.2018.05.002	556	79,43	18,01
Ong M, 2018, J Res Sci Teach	10.1002/tea.21417	357	51,00	11,56
Borrego M, 2014, J Eng Educ	10.1002/jee.20040	308	28,00	2,99
Dennehy Tc, 2017, Proc Natl Acad Sci U S A	10.1073/pnas.1613117114	305	38,13	8,50
Sintema Ej, 2020, Eurasia J Math Sci Technol Educ	10.29333/EJMSTE/7893	297	59,40	18,33
Xie Y, 2015, Annu Rev Sociol	10.1146/annurev-soc-071312-145659	289	28,90	8,74

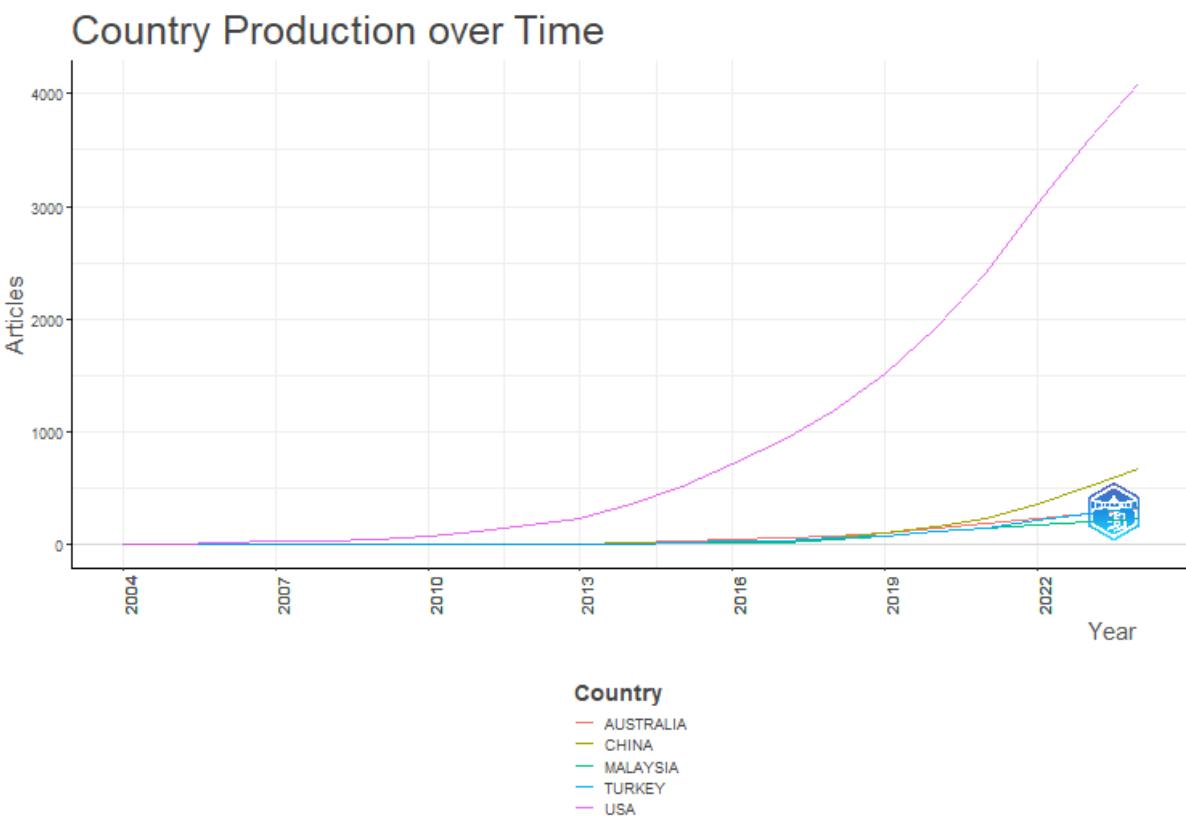
3.4 Leading Countries and Their Affiliations

Table 5 displays the number of scientific publications by country. The USA leads with 4,086 publications, followed by China and Turkey with 671 and 327, respectively. The USA is able to maintain this leading position due to its large research and development budget, supported by both the government and private sectors. This funding fosters innovative research in education. Researchers in the USA are often involved in cross-disciplinary and inter-institutional collaborations, which expand the reach of their research and increase publications. As we know, the USA, with its strong foundation for STEM literacy among its population, provides opportunities to master fundamental STEM concepts, including computational thinking, and promotes digital literacy to prepare for rapid technological changes (Science et al., 2018).

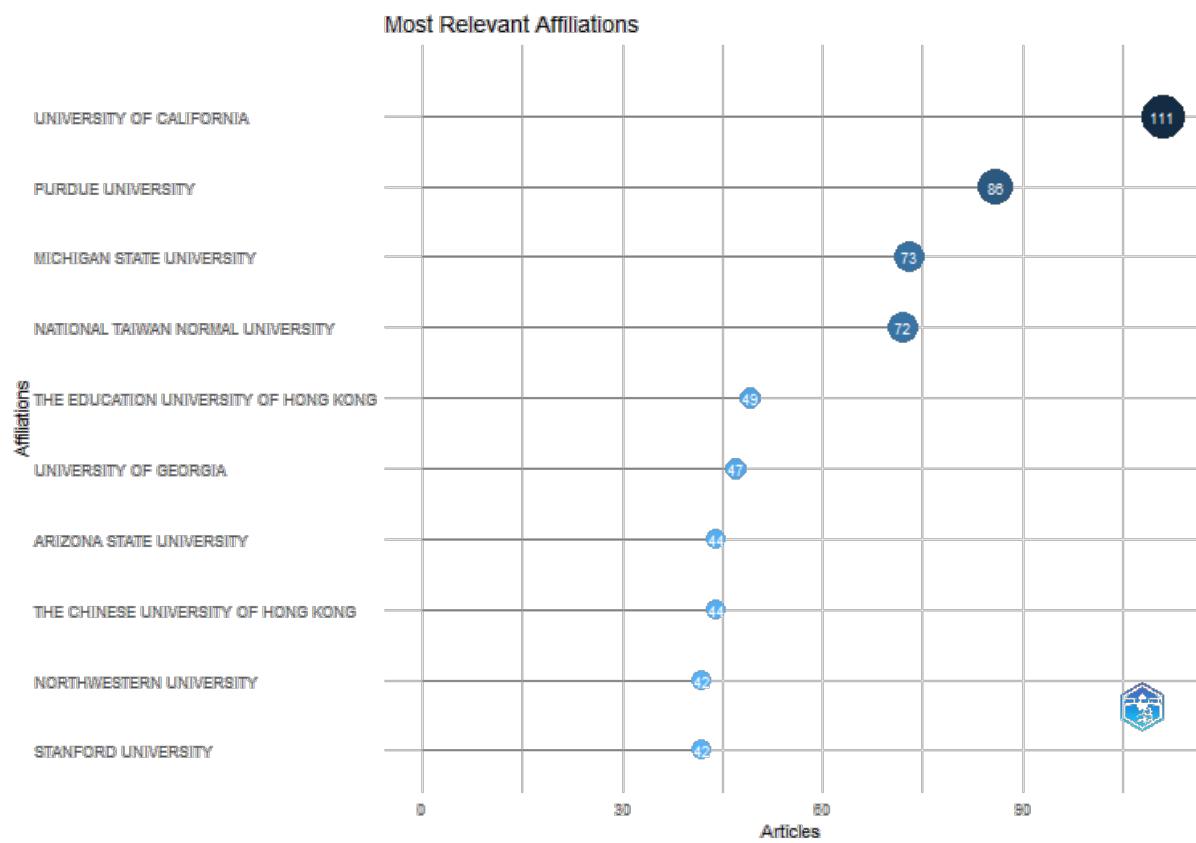
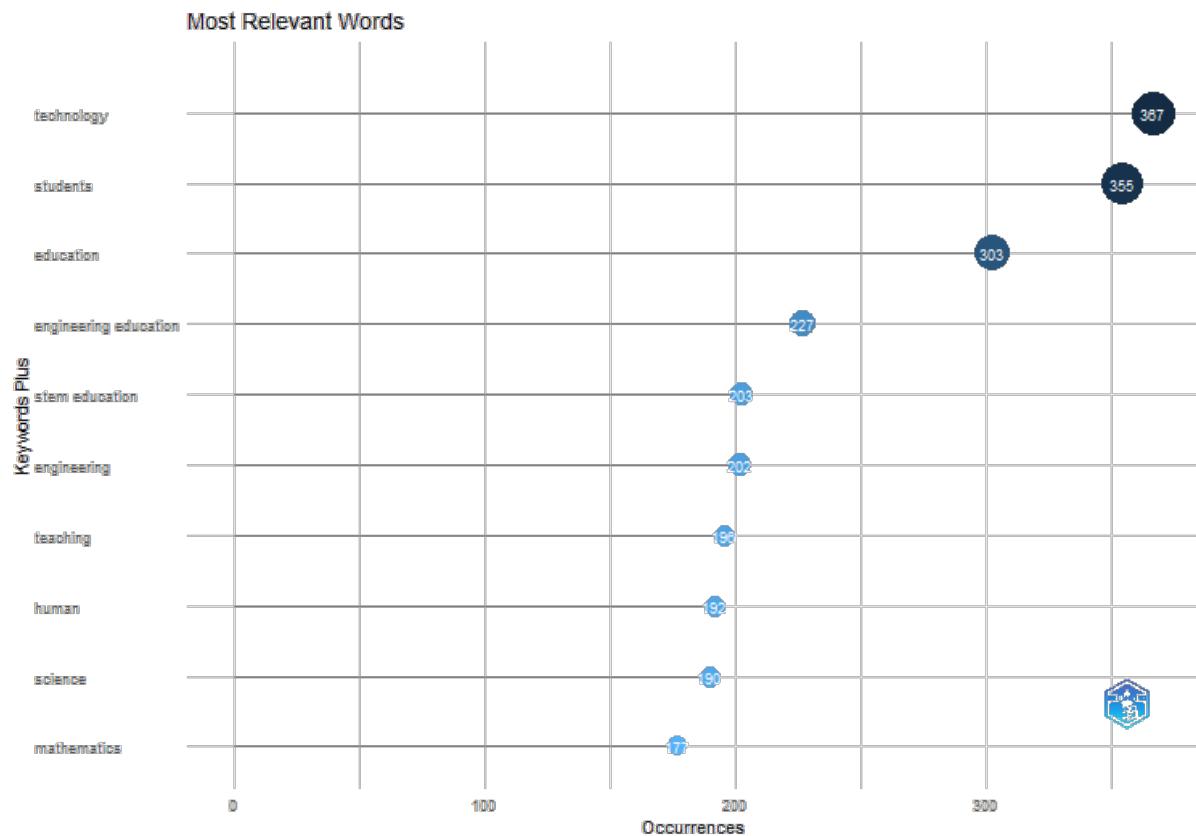
Figure 9 depicts the progression of STEM education across leading countries. The USA, which published its first article in 2004, has maintained its position as the top contributor over the past 20 years, with a total of 4,086 articles. Australia emerged as the second country to produce an article (2) in 2011. However, China surpassed Australia with a total of 671 articles, while Australia had 320 articles in 2024, followed by Turkey and Malaysia.

Table 5. Countries and Their Number of Article Citations

Country	Freg	TC	Average Article Citation
USA	4086	30900	24,1
China	671	2759	11,4
Turkey	327	1461	9,7
Australia	320	2269	17,2
Malaysia	237	858	9,4
Spain	225	2142	22,5
Canada	159	725	11,7
UK	158	1000	15,2
Indonesia	148	353	7,4
South Korea	137	879	12

**Figure 9.** Documentation of STEM Education Growth in Various Countries

As shown in Figure 10, universities in California play a leading role in STEM education research, producing a significant number of publications. Notable institutions include Purdue University (n=86), Michigan State University (n=73), National Taiwan Normal University (n=72), The Education University of Hong Kong (n=49), University of Georgia (n=47), Arizona State University, The Chinese University of Hong Kong (n=44), along with Northwestern University and Stanford University. Additionally, the term “STEM education” is prominently featured in publications from various universities across ASEAN countries. (Ha et al., 2020).

**Figure 10.** Top Affiliations**Figure 11.** The Most Frequently Appearing Words

3.5 Keyword Trends

Identifying keyword trends can detect current and past research topics, recognizing the most focused research areas in STEM education. Figure 11 shows the most frequently occurring words in STEM education research. Three keywords that frequently appear are technology, student, and education. This suggests that technology is the most recurring keyword.

The term “technology” emphasizes its role in enhancing the learning experience in STEM fields through tools such as educational software, digital learning platforms, and simulations. It also facilitates the adoption of innovative teaching approaches, including project-based and collaborative learning, which leverage digital tools to promote interaction, teamwork, and the development of 21st-century skills (Swaid, 2015).

The second most frequent keyword is students. Research in this area seeks to evaluate how student engagement in STEM learning can influence their learning outcomes. This analysis often includes factors such as motivation, participation, and interaction. Articles also frequently discuss how STEM curricula are designed to meet the needs and interests of students. Research also covers the development of teaching materials that are relevant and engaging for students.

The third top keyword, education, forms the foundation for understanding the various methods and approaches used in STEM teaching. Articles often define STEM education and examine its structure and objectives, as well as highlight pedagogical innovations applied in STEM education, such as project-based learning, active learning, and the use of technology to enhance the learning experience.

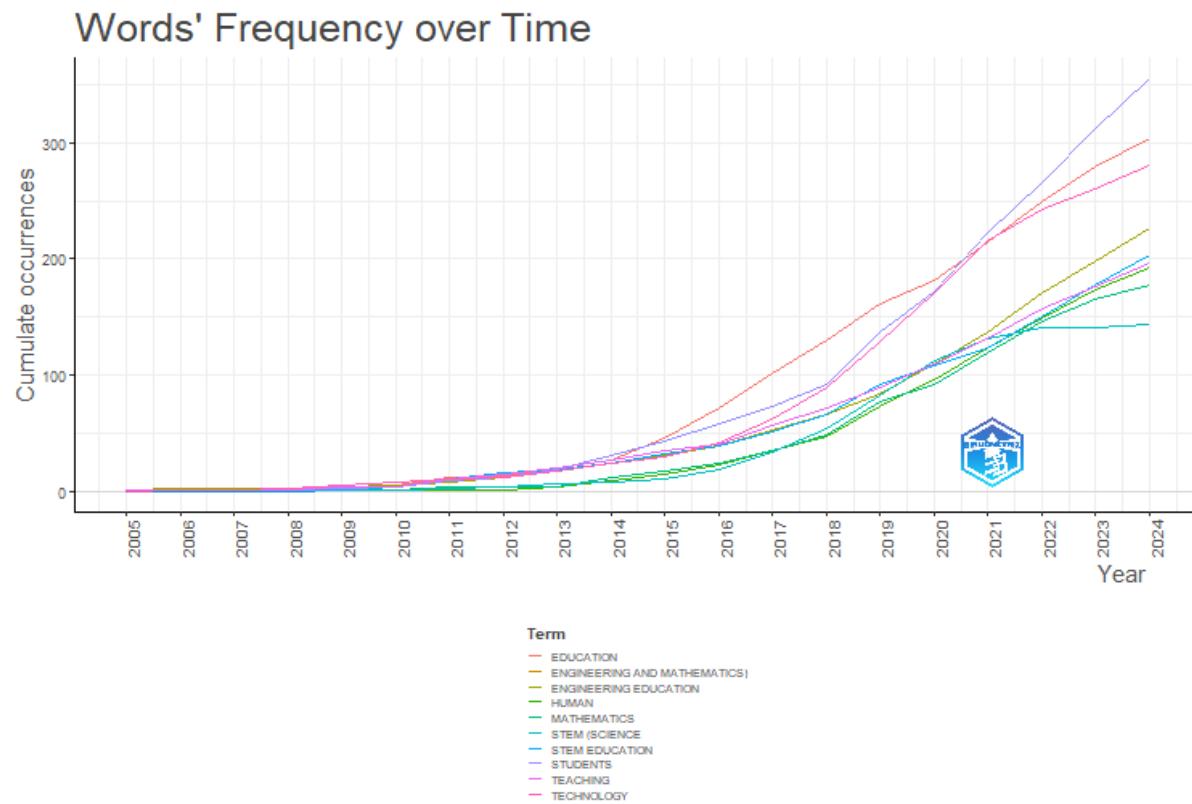


Figure 12. Word Frequency Over Time

Word frequency over time in a bibliometric context refers to the analysis of how often certain words or phrases appear in scientific literature over a specific period. It helps researchers observe trends in research topics, identify areas that require further exploration, and enable comparisons between various disciplines or research fields. Based on Figure 12, it can be explained that the frequency of the 10 most commonly appearing words has significantly increased from 2015 to 2024, with the word ‘students’

becoming the most frequently appearing word by 2024. However, between 2016 and 2020, the word ‘education’ held the first position.”

Figure 13 explains the pattern of development and changes in the focus of research in these fields over time. The topic ‘mathematical techniques’ became the first trending topic, appearing 6 times between 2007 and 2018, referring to the pattern or changes in attention and publications in a specific field or theme over time. Topic trend analysis can help researchers understand how research interests and focus have evolved.

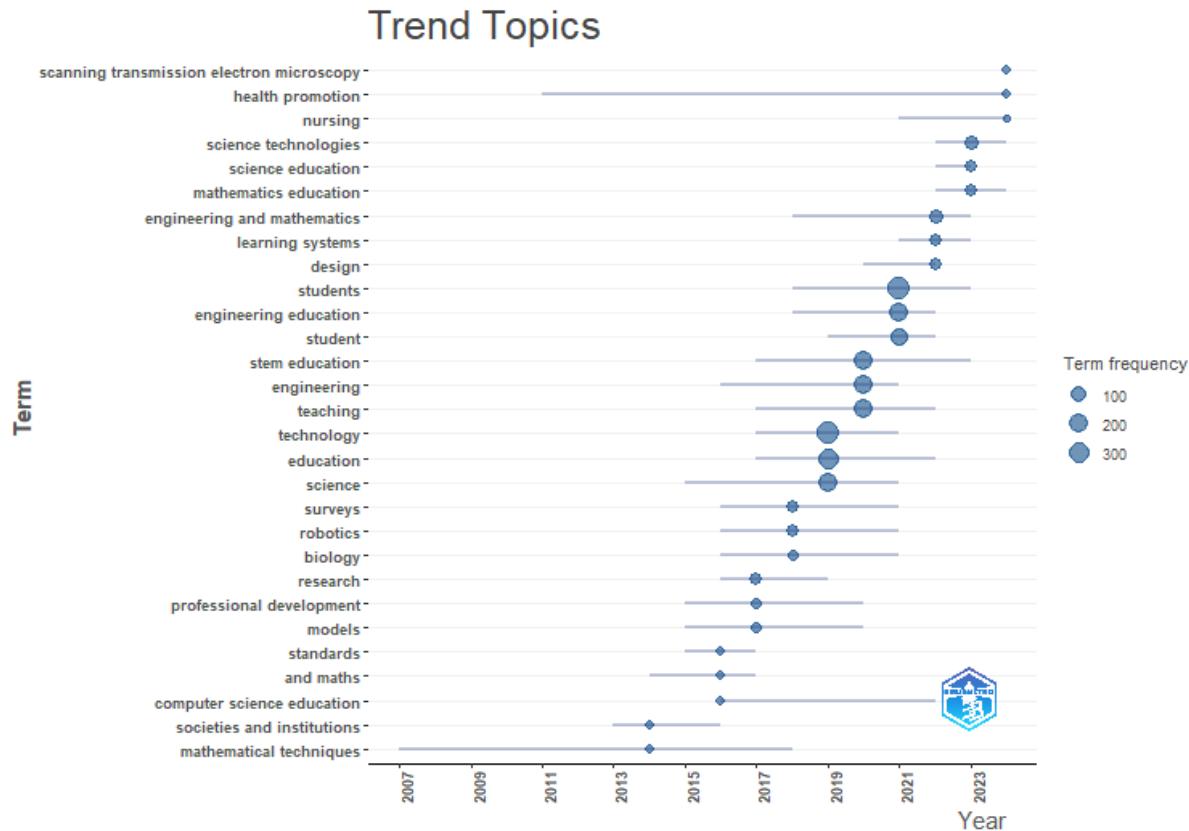


Figure 13. Topic Trend

3.6 Knowledge Structure Analysis

Bibliometric analysis for scientific mapping addresses three main categories of research questions, offering the following insights: (1) the conceptual structure, which explores the forefront of research within a particular theme or discipline; (2) the intellectual structure, which identifies the foundational knowledge base of the research field; and (3) the social network structure, which examines the results of specific scientific collaborations and communications. (Aria & Cuccurullo, 2017).

3.6.1 Conceptual Framework

Figure 14 presents a co-occurrence network of keywords in STEM education publications, providing a visual representation of how terms are interlinked across various studies (Siccardi & Villa, 2023). The network is composed of multiple thematic clusters, each grouping related keywords that underscore major research themes and emerging trends. The interconnected links within the network highlight the following prominent and significant clusters in STEM education research:

Cluster 1 (Red): The keyword “STEM education” forms a denser node group that is more interconnected than other networks, indicating a diverse theme or topic analyzed from several interconnected perspectives. Among the connections, the terms “Project-Based Learning,” “Active Learning,” and “Informal Learning” are key. These learning methods encourage students to actively engage

and learn through hands-on experiences, often interconnected within the context of curriculum and pedagogy development.

Curriculum and Pedagogy: These terms reflect the development and application of innovative teaching methods, where active and project-based learning approaches are often integrated.

Artificial Intelligence and Educational Robotics: With technological advancements, the use of AI and robotics in education has been increasing. This creates connections with terms such as Arduino, which is often used in technology learning projects.

Virtual Reality: The use of VR in education as a learning tool has grown, creating synergies with active and project-based learning methods.

Changes in Learning Context: The term “Covid-19” during the pandemic accelerated the adoption of remote learning methods and digital technologies. This led to increased interest in informal learning, project-based education, and the use of technologies like VR and robotics.

Diversity: The focus on diversity in education is becoming more important, creating the need for curriculum adjustments and inclusive pedagogical approaches.

Assessment: In the context of active and project-based learning methods, assessments must also be adjusted to measure students' skills and understanding in a more holistic and diverse way.

The co-occurrence network encompassing these terms shows the interconnections between various aspects of modern education, including teaching methods, technology, diversity, and responses to global challenges like COVID-19. Analyzing this network provides deeper insights into the evolving direction of education, as well as the challenges and opportunities faced by educators and students today. Analyzing changes in keyword or author co-occurrence over time can reveal how the focus of research has evolved during the pandemic and up to the present (Sousa Neto et al., 2023).

Cluster 2 (Blue): The connections between engineering, technology, science, and mathematics show how these fields interact and support each other in teaching and research. Educational approaches that integrate these disciplines are essential to equip students with relevant and holistic skills. In the context of secondary education, teaching that encompasses engineering, technology, science, and mathematics becomes crucial to preparing students to face global challenges and careers in STEM fields. The co-occurrence network including the terms “engineering,” “technology,” “science,” “mathematics,” and “secondary education” demonstrates a close relationship between these disciplines in education. This connection reflects the need for integrated and innovative educational approaches and the importance of preparing students with relevant skills for the future in STEM fields.

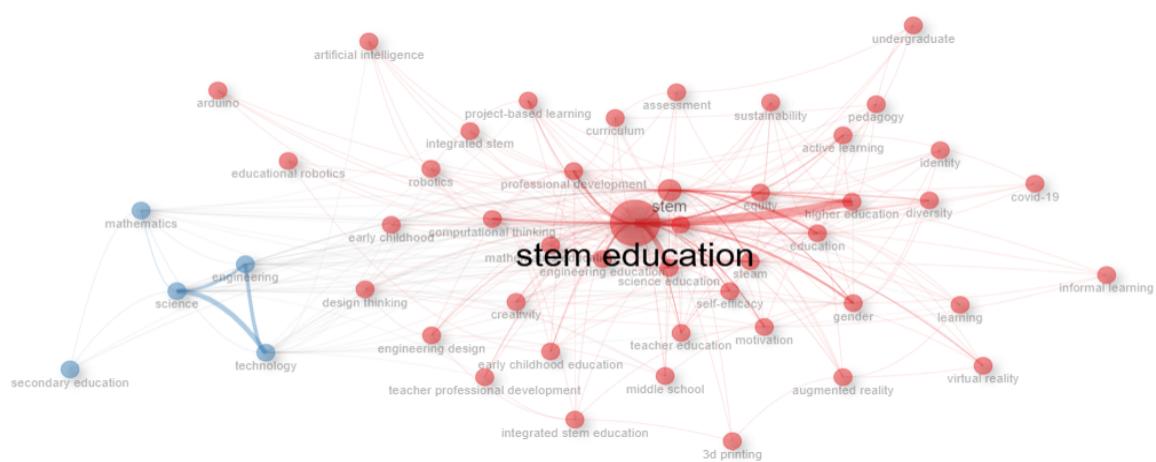


Figure 14. Co-Occurrence Network

Another method to illustrate the conceptual structure is through a thematic map, which highlights various dominant themes in the field (Bonilla-Chaves & Palos-Sánchez, 2023). Based on (Fig. 15), it can be divided into four themes: Niche theme: A theme with few publications but high potential for growth. This

theme may not have been widely explored or may have unique connections with other themes. Motor theme: A theme with many publications and high citations. This theme is typically a driving force in the research field and often influences other themes. Basic theme: A theme with many publications but no significant impact or high citations. This theme is generally fundamental and often serves as a basis for further research. Emerging theme: A newly emerging theme showing rapid growth in publications and citations. The keyword “curriculum” reflects the latest developments in the research field.

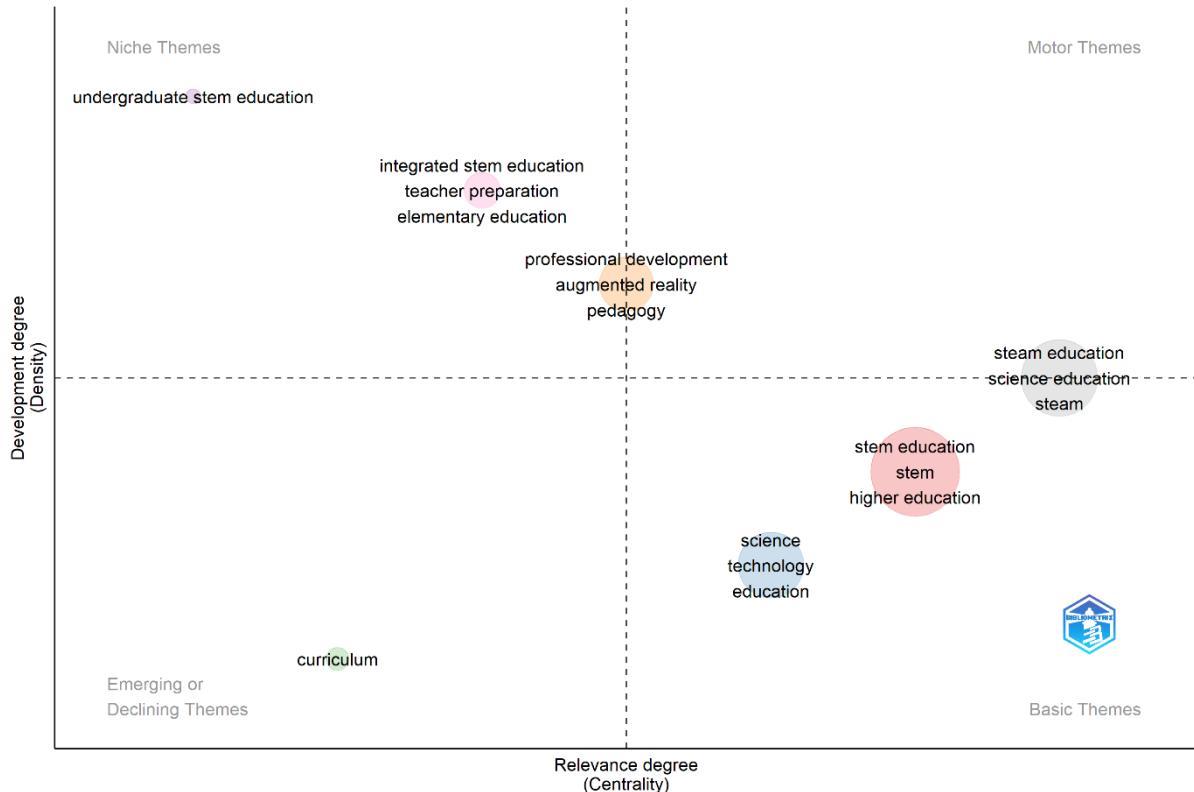


Figure 15. Thematic Map

Figure 16 illustrates the thematic evolution in STEM education from 2003 to 2024, highlighting a notable progression. The focus initially shifted from the introduction and integration of STEM concepts to curriculum development and teacher training. More recently, attention has moved toward adapting to emerging challenges, including the impact of the pandemic and advancements in technology..

From 2003 to 2014, research largely concentrated on integrating STEM concepts into educational curricula, especially at the elementary and secondary school levels. Significant efforts were directed toward creating approaches that unify science, technology, engineering, and mathematics into a comprehensive learning framework. During this time, project-based learning methods became increasingly popular, promoting active student participation and facilitating the practical application of STEM concepts through real-world projects.

Between 2015 and 2019, the focus transitioned to the development and implementation of more integrated STEM curricula. Research began to examine the effectiveness of various STEM curriculum models. There was an emphasis on teacher training to enhance their ability to teach STEM concepts. Research explored effective ways to prepare teachers to face challenges in STEM education. The increased use of digital technology and online resources in STEM education was also noted.

From 2019 to 2024, the focus shifted towards leveraging artificial intelligence and data analysis to enhance the learning experience in STEM education. This includes the use of analytical tools to understand student learning patterns and the integration of technology-based learning tools such as software and interactive applications like Arduino (Prabowo & Irwanto, 2023). There has been a push to integrate the arts (turning STEM into STEAM), creating a more holistic and creative approach to learning.”

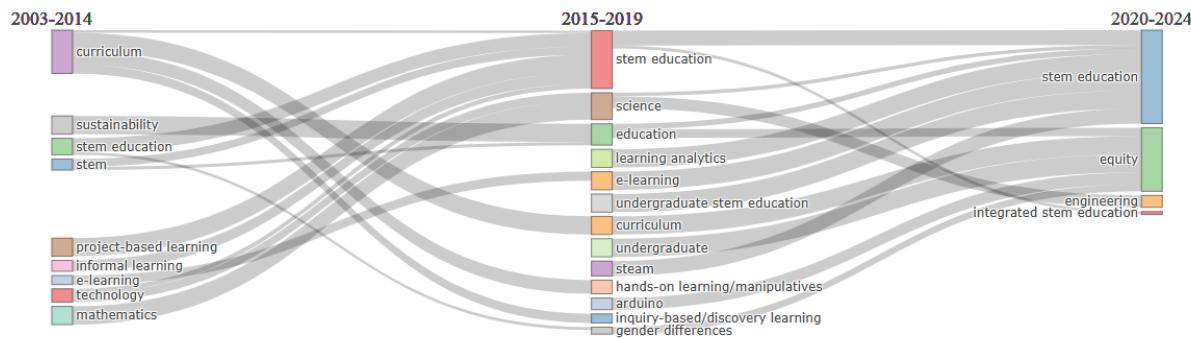


Figure 16. Thematic Evolution

Confirmatory Factor Analysis (CFA) was employed to define the dimensions, complemented by Multiple Correspondence Analysis (MCA). As an extension of correspondence analysis, MCA is utilized to examine the relationships between various categorical dependent variables. The findings of the MCA, presented in Figure 17, showcase the two dimensions that were analyzed.

Aligned with the first dimension (55.36%), the negative side is more broadly represented by keywords such as “STEM education.” In contrast, the positive side is more specifically characterized by terms like “artificial intelligence,” “secondary education,” “middle school,” and “technology,” highlighting the growing influence of these approaches in secondary education, particularly regarding artificial intelligence.

Conversely, the second dimension (15.84%) indicates that STEM education is also prevalent in higher education. This dimension reveals various themes, such as ‘problem-based learning’ and ‘STEM.

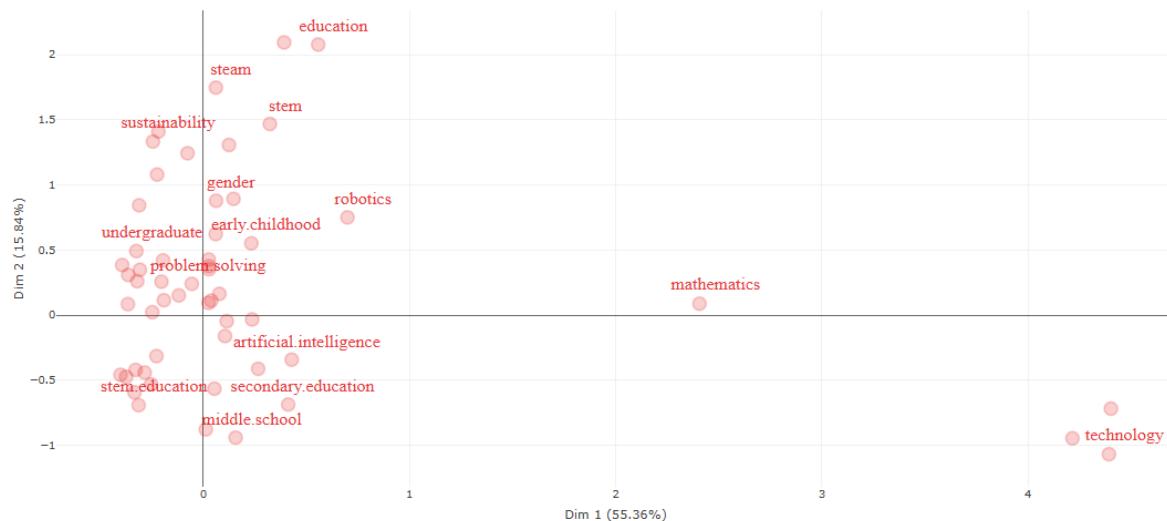


Figure 17. Factorial Analysis using MCA

The thematic dendrogram in Figure 18 effectively demonstrates the separation of dimensions, in line with the findings from the research (Petchey & Gaston, 2007a). The initial branches represent core terms associated with STEM education, reflecting their central role in the research. Subsequent sub-branches, although covering a range of themes, maintain consistent prominence, indicating an ongoing focus within the same domain. In contrast, branches containing terms such as “specificity of creativity” and “Torrance test” are more distantly spaced, highlighting the distinct separation of these dimensions. This distinction emphasizes that these terms represent unique facets of the research. The visualization provided by the dendrogram reinforces the identified dimensionality, showcasing how “STEM education” remains closely connected while also revealing the distinctiveness of certain terms and concepts, thus offering a clearer understanding of the research’s structure.

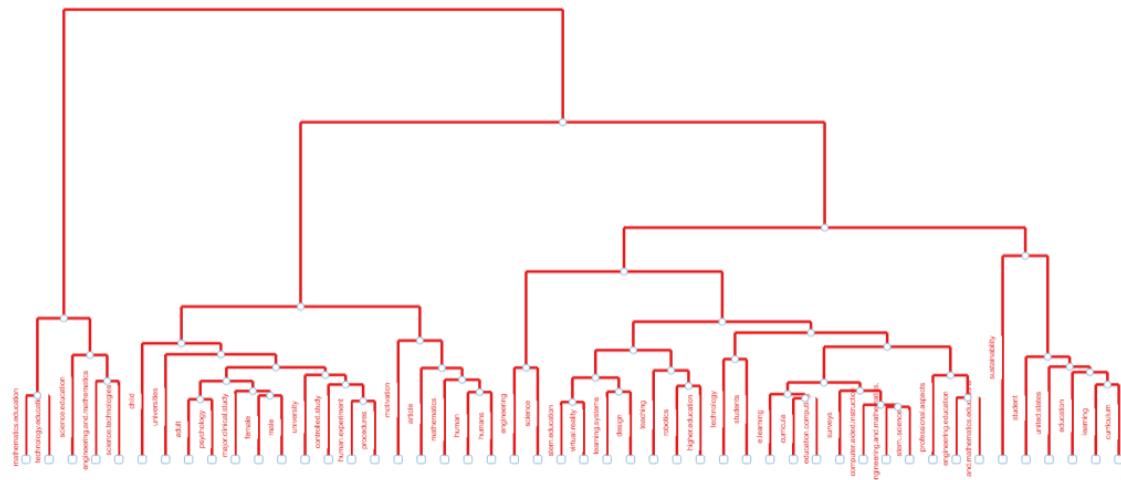


Figure 18. Thematic Dendrogram

3.6.2 Social Structure

The social structure is analyzed through co-authorship networks and the collaborative relationships between countries. Figure 19 illustrates the collaboration network among authors, showcasing the intricate connections within the field of STEM education. The analysis identifies 10 distinct clusters, with two being particularly notable. The first major cluster features authors like Lavicza, Chen, and SC, who represent a group of highly productive authors that have maintained consistent collaboration throughout the studied period. The second key cluster highlights the partnerships between Roehrig GH and Dare EA. The third and largest cluster includes authors such as Sun D, Ly Y, Yang Y, Chiang FK, Li L, and Wang Y, all of whom have formed numerous collaborative relationships, positioning them as highly influential figures in the research landscape during the period examined.

Figure 20 presents a map illustrating international collaboration in STEM education publications, with red lines indicating the connections between countries. The data highlights extensive global collaboration, with the USA emerging as the most prominent country. The top 10 countries exhibiting the highest levels of collaboration include the USA, China, Turkey, Australia, Malaysia, Spain, Canada, the UK, Indonesia, and South Korea. These countries are integral to the social structure of STEM education research, playing a key role in fostering international partnerships and contributing significantly to the field.

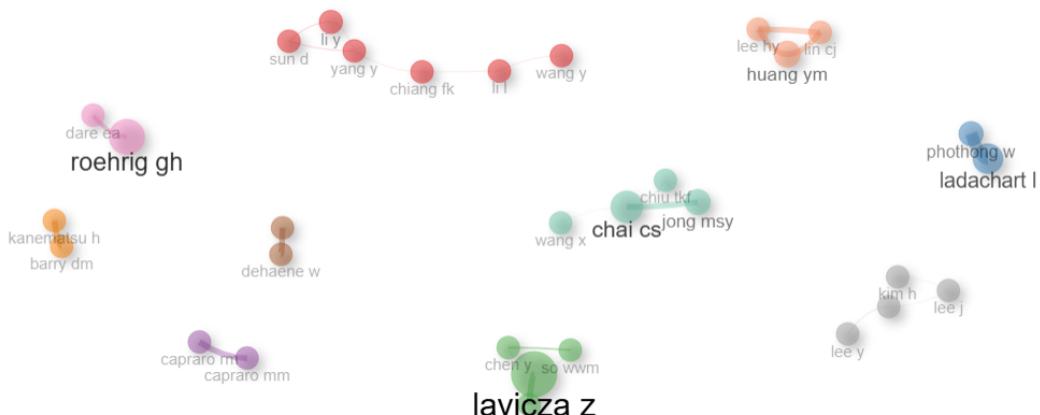


Figure 19. Collaboration Network



Figure 20. Country Collaboration Map

4. CONCLUSION

In relation to Table 6, this bibliometric study provides key information regarding the trends in STEM education research over the past few years

Table 6. Summary of Findings

Parameter	Information
Number of documents	3769
Number of authors	10128
Top authors	Roehrig GH
Number of sources.	18
Most productive sources	Education Science
Most cited article (DOI)	10.1073/pnas.1319030111
Country with the most articles	USA
University with the most documents	University of California
Most favored keywords	Technology, students, education, engineering education, engineering, STEM education

The study demonstrates significant growth in STEM education research, with projections indicating continued expansion. The USA has emerged as the leading contributor to this field, reflecting a growing interest in STEM education among researchers and educators. Recent increases in STEM-related publications emphasize the connection between STEM education and the development of essential 21st-century skills, such as problem-solving, creativity, and critical thinking, which are crucial for preparing students to navigate contemporary challenges. The analysis highlights that STEM research is concentrated in certain countries and institutions, offering valuable insights into regions and organizations driving innovation in education. Through this bibliometric approach, the study provides a comprehensive overview of STEM education's development, challenges, and areas for future exploration.

4.1. Benefits of the Research

For researchers, bibliometric analysis provides valuable insights into trends within STEM research, helping to identify emerging or underexplored areas. By analyzing citations and publications, researchers can assess the impact of existing studies in the STEM field. The findings from such analysis can also inform the development of educational and research policies, supporting strategic decisions in advancing STEM education and research initiatives.

For students: Students can gain easier access to a variety of literature sources relevant to their interests in STEM. By studying existing literature, students can understand the relationships between different disciplines within STEM. Students involved in this research will enhance their scientific literacy, which is important for career development in STEM fields.

Acknowledgment. Not Applicable.

Research Ethics. Not Applicable.

Data Availability Statement. All data can be obtained from the corresponding author.

Conflicts of Interest. The author declares no conflicts of interest.

Funding. Not Applicable.

REFERENCES

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, 11(4), 959–975. <https://doi.org/10.1016/J.JOI.2017.08.007>

Baas, J., Schotten, M., Plume, A., Côté, G., & Karimi, R. (2020). Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. *Quantitative Science Studies*, 1(1), 377–386. https://doi.org/10.1162/qss_a_00019

Bonilla-Chaves, E. F., & Palos-Sánchez, P. R. (2023). Exploring the Evolution of Human Resource Analytics: A Bibliometric Study. In *Behavioral Sciences* (Vol. 13, Issue 3). MDPI. <https://doi.org/10.3390/bs13030244>

Chasokela, D. (2025). Role of Technology Integration in the Development of 21st-Century Skills STEM University in Zimbabwe. *Journal of Research in Education and Pedagogy*, 2(1), 124-135. <https://doi.org/10.70232/jrep.v2i1.36>

Chen, H. E., Sun, D., Hsu, T. C., Yang, Y., & Sun, J. (2023). Visualising trends in computational thinking research from 2012 to 2021: A bibliometric analysis. *Thinking Skills and Creativity*, 47, 101224. <https://doi.org/10.1016/J.TSC.2022.101224>

Ciucu-Durnoi, A. N., Delcea, C., Stănescu, A., Teodorescu, C. A., & Vargas, V. M. (2024). Beyond Industry 4.0: Tracing the Path to Industry 5.0 through Bibliometric Analysis. *Sustainability*, 16(12), 5251. <https://doi.org/10.3390/su16125251>

Dennehy, T. C., & Dasgupta, N. (2017). Female peer mentors early in college increase women's positive academic experiences and retention in engineering. *Proceedings of the National Academy of Sciences of the United States of America*, 114(23), 5964–5969. <https://doi.org/10.1073/pnas.1613117114>

Di Nardo, M., & Yu, H. (2021). Special issue “industry 5.0: The prelude to the sixth industrial revolution.” In *Applied System Innovation* (Vol. 4, Issue 3). MDPI AG. <https://doi.org/10.3390/asi4030045>

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the United States of America*, 111(23), 8410–8415. <https://doi.org/10.1073/pnas.1319030111>

Ghafrooni, R. . (2024). Trends of Design Thinking Research in STEM Education: Bibliometric Analysis. *Journal of Research in Environmental and Science Education*, 1(1), 12-28. <https://doi.org/10.70232/fbzh395>

Ha, C. T., Thao, T. T. P., Trung, N. T., Huong, L. T. T., Dinh, N. Van, & 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). <https://doi.org/10.29333/ejmste/8500>

Hebebci, M. T., & Usta, E. (2022a). The Effects of Integrated STEM Education Practices on Problem Solving Skills, Scientific Creativity, and Critical Thinking Dispositions. *Participatory Educational Research*, 9(6), 358–379. <https://doi.org/10.17275/per.22.143.9.6>

Hebebci, M. T., & Usta, E. (2022b). The Effects of Integrated STEM Education Practices on Problem Solving Skills, Scientific Creativity, and Critical Thinking Dispositions. *Participatory Educational Research*, 9(6), 358–379. <https://doi.org/10.17275/per.22.143.9.6>

Kong, S.-C., & Abelson, H. (n.d.). *Computational Thinking Education*.

Madsen, D. Ø., Berg, T., & Di Nardo, M. (2023). Bibliometric Trends in Industry 5.0 Research: An Updated Overview. In *Applied System Innovation* (Vol. 6, Issue 4). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/asi6040063>

Manokore, K., & Sibanda, L. (2024). National STEM Education Framework: Teachers' Perspectives on the 2015-2022 Curriculum Cycle. *Journal of Research in Education and Pedagogy*, 1(2), 98-106. <https://doi.org/10.70232/jrep.v1i2.12>

Nwune, E. C., Oguezue, N. K., & Nwosu, K. C. (2024). Implementing Cooperative Learning for Sustainable STEM Education in Nigeria: Preservice Science Teachers' Knowledge and Beliefs. *Journal of Research in Mathematics, Science, and Technology Education*, 1(2), 117-126. <https://doi.org/10.70232/jrmste.v1i2.8>

Ong, M., Smith, J. M., & Ko, L. T. (2018). Counterspaces for women of color in STEM higher education: Marginal and central spaces for persistence and success. *Journal of Research in Science Teaching*, 55(2), 206-245. <https://doi.org/10.1002/tea.21417>

Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Mckenzie, J. E. (2021a). PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. In *The BMJ* (Vol. 372). BMJ Publishing Group. <https://doi.org/10.1136/bmj.n160>

Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Mckenzie, J. E. (2021b). PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. In *The BMJ* (Vol. 372). BMJ Publishing Group. <https://doi.org/10.1136/bmj.n160>

Petchey, O. L., & Gaston, K. J. (2007b). Dendrograms and measuring functional diversity. *Oikos*, 116(8), 1422-1426. <https://doi.org/10.1111/j.2007.0030-1299.15894.x>

Prabowo, N. K., & Irwanto, I. (2023). The Implementation of Arduino Microcontroller Boards in Science: A Bibliometric Analysis from 2008 to 2022. *Journal of Engineering Education Transformations*, 37(2), 106-123. <https://doi.org/10.16920/jeet/2023/v37i2/23154>

Prahani, B. K., Rizki, I. A., Suprapto, N., Irwanto, I., & Kurtuluş, M. A. (2024). Mapping research on scientific creativity: A bibliometric review of the literature in the last 20 years. *Thinking Skills and Creativity*, 52. <https://doi.org/10.1016/j.tsc.2024.101495>

Pranckuté, R. (2021). Web of Science (WoS) and Scopus: the titans of bibliographic information in today's academic world. In *Publications* (Vol. 9, Issue 1). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/publications9010012>

Samara, V., & T. Kotsis, K. (2025). The Use of STEM as a Tool for Teaching the Concept of Magnetism in Kindergarten. *Journal of Research in Environmental and Science Education*, 2(1), 1-17. <https://doi.org/10.70232/jrese.v2i1.1>

Science, N., Council, T., & on STEM Education, C. (2018). *CHARTING A COURSE FOR SUCCESS: AMERICA'S STRATEGY FOR STEM EDUCATION*. <http://www.whitehouse.gov/ostp>

Selvan, P. T., & Kalaiyaran, G. . (2024). STEM Knowledge Awareness among Higher Secondary School Students. *Journal of Education for Sustainable Development Studies*, 1(2), 89-96. <https://doi.org/10.70232/jesds.v1i2.14>

Setiani Hasanah, S., Kaniawati, I., & Permanasari, A. (2022). Bibliometric Analysis of The Literature on Science, Technology, Engineering, and Mathematic-Pedagogical Content Knowledge (STEM-PCK) for The Years 2011-202. In *Jurnal Inspirasi Pendidikan* (Vol. 12, Issue 1).

Siccardi, S., & Villa, V. (2023). Trends in Adopting BIM, IoT and DT for Facility Management: A Scientometric Analysis and Keyword Co-Occurrence Network Review. *Buildings*, 13(1). <https://doi.org/10.3390/buildings13010015>

Simamora, A. M. (2024). A Decade of Science Technology, Engineering, and Mathematics (STEM) Project-Based Learning (PjBL): A Systematic Literature Review. *Journal of Computers for Science and Mathematics Learning*, 1(1), 58-78. <https://doi.org/10.70232/pn3nek61>

Sintema, E. J. (2020). Effect of COVID-19 on the performance of grade 12 students: Implications for STEM education. *Eurasia Journal of Mathematics, Science and Technology Education*, 16(7). <https://doi.org/10.29333/EJMSTE/7893>

Sousa Neto, A. R. de, Carvalho, A. R. B. de, Ferreira da Silva, M. D., Rêgo Neta, M. M., Sena, I. V. de O., Almeida, R. N., Filha, F. S. S. C., Lima e Silva, L. L., Costa, G. R. da, Lira, I. M. da S., Portela, D. M. M. C., Oliveira e Silva, A. T., Rabêlo, C. B. de M., Valle, A. R. M. da C., Moura, M. E. B., & Freitas, D. R. J. de. (2023). Bibliometric Analysis of Global Scientific Production on COVID-19 and Vaccines. *International Journal of Environmental Research and Public Health*, 20(6). <https://doi.org/10.3390/ijerph20064796>

Swaid, S. I. (2015). Bringing Computational Thinking to STEM Education. *Procedia Manufacturing*, 3, 3657–3662. <https://doi.org/10.1016/j.promfg.2015.07.761>

Xie, Y., Fang, M., & Shauman, K. (2015). STEM Education. *Annual Review of Sociology*, 41, 331–357. <https://doi.org/10.1146/annurev-soc-071312-145659>