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Two decades of STEM education studies in higher education: A bibliometric analysis

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ABSTRACT
STEM education is gaining more attention due to its significant contribution to educational development. The authors employed bibliometric analysis to determine how STEM education research was developing. The study aims to present an up-to-date overview of the STEM education research landscape in the context of higher education from 2002 to 2022. After applying inclusion and exclusion criteria, a total of 1,282 papers were downloaded from the Scopus database for further analysis. Data analysis included publications and citations, the most frequently cited documents, sources, institutions, the most influential countries, the most prolific authors, co-authorship for authors and countries, and co-occurrence of author keywords using VOSviewer software. There has been an increasing trend in the number of publications from 2002 to 2022, peaking in 2020 with 180 articles. The work by Henderson et al. (2011) is the most frequently cited document, with 554 citations to date. In terms of the most productive source, the ASEE Annual Conference and Exposition leads the field. The United States and Purdue University emerged as the most productive country and institution, respectively. Carmen C. is identified as the most active author, while Wang X. is the most influential. Frequently occurring keywords include "STEM education", "STEM" and "Higher education." The findings highlight the practical need for higher education institutions to prioritise active learning strategies, diversity, and international collaboration to advance STEM education globally.

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Introduction

STEM first emerged in the 1940s as the primary educational focus of the National Science Foundation (NSF) in the United States. The NSF provides encouragement to continue and develop educational programs in every field of science and technology (Ortiz-Revilla, 2020). Despite the fact that STEM was first developed in the year 1940, it wasn't until the year 2001 that Judith Ramaley, the assistant director of the NSF's Education and Human Resources Directorate, popularised the term STEM as an inquiry-based education that focused on solving problems in the real world. As a result of national evaluations conducted in the United States, it was discovered that STEM education in that country lagged behind that of other countries. Then, the United States realized that STEM education was needed to increase the country's competitiveness in the world and to become a leading country in this field (Daugherty, 2013; Gil-Doménech, 2020; Jamali, 2022). According to Martín-Páez (2019), individuals will understand the significance of STEM when they observe for themselves how quickly social, environmental, economic, and technical aspects are evolving to fulfill societal requirements. Currently, STEM education encompasses five fields (STEAM) rather than simply four (STEM) (Aguilera, 2021). The existence of art serves as evidence that pupils' inventiveness must be taken into account. The term "creativity" here refers to novelty and originality so that the end result is something brand-new, distinctive, and in line with standards. The constructivist method, which stresses that knowledge is constructed by individuals to account for variances in how people see the world, is used as a model for STEAM learning (Ozkan, 2020). Future occupations will demand improved job skills (such as flexibility, collaboration, and communication), which are projected to occur as a result of STEAM learning (Perignat, 2019).

The implementation of STEM gained a lot of attention in the last decade (Irwanto et al., 2022; Irwanto & Ananda, 2024; Marín-Marín et al., 2021). The study of STEM/STEAM research is important (Prabowo et al., 2024) because human life is continuously evolving and accompanied by technological advancements (Irwanto et al., 2023; Irwanto & Rini, 2024). Conducting scientific experiments alone is insufficient for developing 21st-century skills. It is necessary to apply scientific concepts in order to design and create new products/technologies that can address societal issues. The implementation of STEM plays a crucial role in enhancing 21st-century skills (Wahono et al., 2021) to overcome global challenges and promote national economic progress.

Every year, papers on STEM topics are consistently released and made accessible. A bibliometric analysis will be used in this study to examine the most recent developments in STEM/STEAM research. A thorough overview of the literature is provided by bibliometric analysis, which also gives data on research trends based on citation, co-citation, co-authorship, and co-occurrence (Donthu, 2021). The most frequently cited works that will ultimately be chosen as the most significant works in the topic of research under study can be identified using citation analysis (Irwanto et al., 2023). Co-citation analysis will reveal information about the connections between works and whether there are any thematic overlaps. An analysis of co-authorship will look at relationships or partnerships between authors or between countries (Prahani et al., 2024). Co-occurrence analysis was used to identify the authors' shared use of terms (Donthu, 2021; Van Eck, 2021). VOSviewer, a piece of software that allows for the visualisation of bibliometric networks as graphical maps, is the program utilized for this investigation (Zhang, 2022).

Bibliometric analysis has already been reported on STEM applications in the literature. In a research done by Gil-Doménech (2020), an overview of STEM education was given using the Web of Science database's quantity of publications and citations, citation thresholds, and h-index. The data revealed a rise in the number of papers on the subject, but no increase in the number of citations. Le Thi's (2021) paper also outlines a bibliometric examination of STEM education in secondary schools using the Scopus database. The most prominent authors, according to the quantitative study, are from the United States; yet, collaborative links between the United States and other nations appear to be poor. The growth of STEM education and high-quality education research at the school level from 1993 to 2020 was examined by Jamali in 2022. Trends in publishing and citation, commonly used keywords, and well-known authors and journals were all studied in the study. The findings showed that early childhood education, computing education, and environmental education are the main foci of STEM research, with the United States being the most prolific country for STEM publications.

Objectives and Research Questions

In this study, we examine publication and citation trends, documents that are frequently cited, sources, institutions, the most influential countries, the most productive authors, co-authorship for authors and countries, and the co-occurrence of authors. The results of this bibliometric study will provide a summary of the current state of scientific production in the STEM fields of higher education. In addition, based on data collected from the Scopus database, this study will be important in determining which research has been the most fruitful and impactful in the history of STEM education. Other researchers can use a bibliometric study to select the hottest topics for their field of study. In addition, readers can learn about the top universities, top journals, top authors in their field, and even where to get the papers most relevant to their research by reading this research.

The study is primarily centered around higher education institutions, as there has been a significant surge in the demand for STEM/STEAM disciplines, evident through the proliferation of seminars, webinars, workshops, and training sessions. These endeavors are conducted in partnership with both local and international universities or affiliated organizations, and are open to participation from students and educational staff. This research will serve as a valuable addition to prior bibliometric studies conducted by Aldás-Onofre & Cordero (2023), Marín-Marín et al. (2021), who utilized the Web of Science database as a solitary data source, as well as the investigation carried out by Thu et al. (2021), who relied on the Scopus database for their research in Middle Schools. This bibliometric study can be used as an early depiction of growing trends in STEM research. The questions for this research are:

RQ 1: What is the distribution pattern of publications and citations every year?
RQ 2: Which documents are the most cited, the most relevant sources, and the most productive institutions and countries?
RQ 3: Who is the most prolific author?
RQ 4: What is the status of the co-authorship for authors and countries, and the distribution of author keywords?

Methodology

Design

This research employed bibliometric analytical methods that are used to uncover developing trends in specific fields of study (Donthu, 2021). This method was performed to analyse large amounts of scientific data, such as the number of publications and citations, the most referenced documents, sources, institutions, the most influential nations, the most prolific authors, co-authorship for authors and countries, and co-occurrence of author keywords in this study. Because of its ability to uncover emerging trends in publication performance, we utilized bibliometric analysis to explore the growth of publications in STEM education in higher education.

The publications examined were taken from the Scopus database and covered the years 2002 to 2022. Document types included articles, book chapters, reviews, books, conferences, notes, errata, editorials, and letters. The following inclusion and exclusion standards were used when searching for documents (see Table 1).

Table 1

Inclusion and exclusion requirements

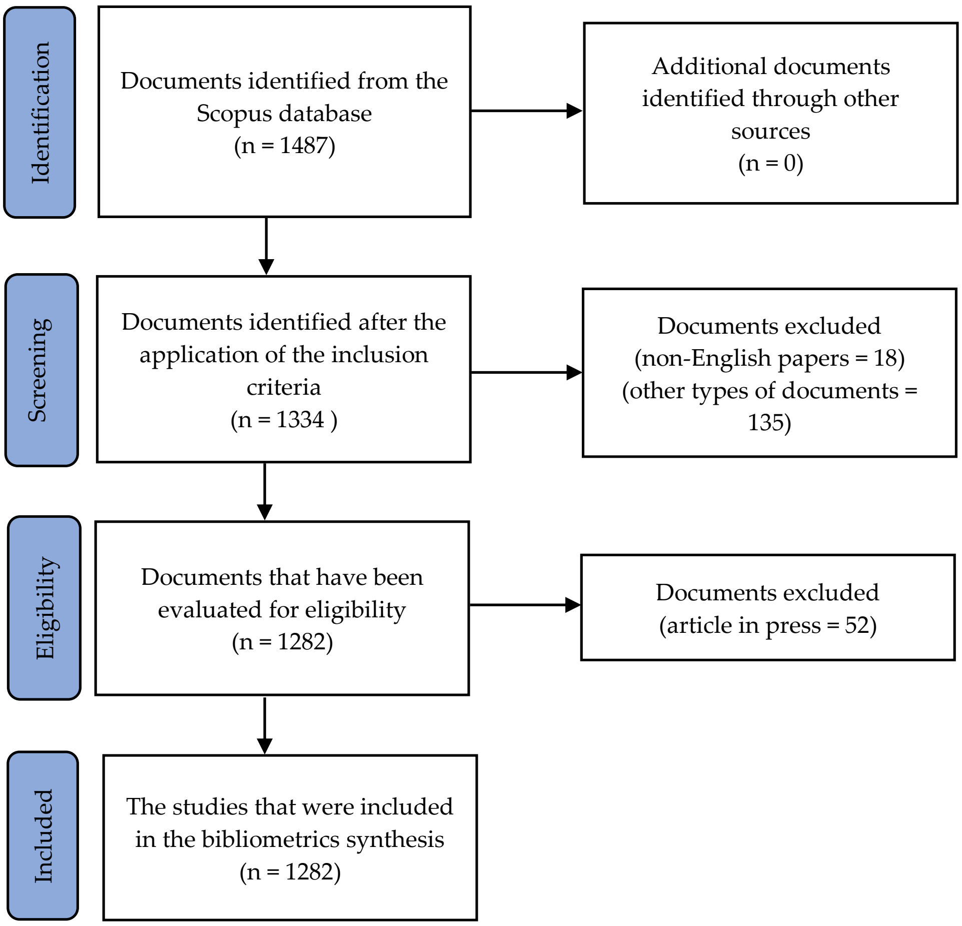
Inclusion Criteria
1. Documents published between January 2002 and September 2022
2. Documents related to STEM or STEAM education in higher education
3. Documents are written in English
4. Documents in the form of articles and conference papers
Exclusion Criteria
1. Documents published before January 2002 or after September 2022
2. Documents not related to STEM or STEAM education in higher education (e.g., secondary education, primary education, K-12, etc.)
3. Documents are not written in English
4. Documents other than articles and conference papers (e.g., books, book chapters, etc.)

Data Collection

TITLE-ABS-KEY ("STEAM education" OR "STEM education" AND "university" OR "college") were the search terms used, and 1487 documents were found as a result. The keyword search of STEM education is based on previous research (e.g., Batdi, 2019; Marín-Marín, 2021), so the researchers focused on the field of STEM/STEAM education. Because Scopus is the largest indexer in the world and one of the largest databases for abstracts and citations, it was selected (Osman, 2021). In addition to 77.8 million records (books and book series, trade publications, journals, and conference proceedings), the database also contains more than 25,100 journal titles from 5000 publishers, more than 70,000 affiliation profiles, and more than 16 million author profiles (Elsevier, 2021). Additionally, this database was chosen because Web of Science (WoS) can only export 500 records at a time, while Scopus can export up to 2000 records at once. Scopus data may be exported as CSV, BibTeX, RIS, Plain Text, and other file types (Agbo, 2021). In this study, the data were exported in CSV format, and the VOSviewer program (https://www.vosviewer.com/) was used to evaluate the data once it had been collected.

Figure 1

PRISMA flow: The research protocol



In the present study, the procedure for searching the study's data using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) is shown in Figure 1 (Moher, 2009). The graph illustrates a comprehensive overview of how the researchers gathered data, using the PRISMA flowchart as a guide throughout the process. During identification, researchers searched Scopus for publications by modifying search phrases in the title, abstract, and keywords. Keywords must appear in the title, the abstract, and the keywords of the selected publications. At this point, 1487 papers have been received. This is followed by the screening stage, in which the researchers select publications that meet the previously established inclusion and exclusion criteria. A total of 18 papers were not written in English, and 135 documents were in the form of a book chapter, review, book, note, erratum, short survey, letter, or editorial. There were 1334 qualified papers at that time. Published papers were selected by the investigators in the final step of the qualifying phase, at which time up to 52 articles were still under review. A total of 1282 eligible papers were collected in the last stage, which was the inclusion stage. This was done with Microsoft Excel.

Data Analysis

VOSviewer and Microsoft Excel were used to analyse and visualise the data collected in the study. VOSviewer is used for the analysis, construction, and visualization of bibliometric nets, while Microsoft Excel is used for the visualization of tables and charts regarding publication language, annual number of publications, most cited papers, and most productive sources, institutions, countries, and authors. The researchers first extracted data from the Scopus database in CSV file format to perform the analysis using the software. They then performed statistical analysis using frequencies and percentages, as well as citation, co-authorship, and co-occurrence analyses. Descriptive statistics were utilized to examine yearly publication growth, most referenced papers, sources with the largest publication volume, productive institutions, productive nations, and prolific authors. Citation analysis was used to determine the frequency with which a paper is cited by other researchers. Author cooperation was examined through co-authorship. Co-occurrence is used to examine the most important keywords and illustrate their relationships with other phrases related to STEM education. Co-authorship analysis requires at least two documents per author, while co-occurrence analysis requires at least five keyword occurrences. It should be noted that the full counting method was employed in this bibliometric analysis, meaning that a co-authored publication was counted with a weight of one for each co-author. To discover emerging topics in the STEM education field, the threshold "minimum number of occurrences of a keyword" was set to 5, and 88 items met the threshold. To determine the cooperation relationship among scholars, the minimum number of documents of an author was set at 2, and 337 authors met the threshold. To reveal the cooperation link among countries, the minimum number of documents of a country was set at 2, and 62 met the threshold.

The results of the study were presented in a network visualisation map, where nodes represent the total number of publications, lines between nodes represent the strength of relationships, and colors represent clusters. The size of nodes increases with the number of documents published, and the strength of the link between the two things is shown by a line connecting the nodes (Kushairi, 2021; Van Eck, 2021; Zhang, 2022).

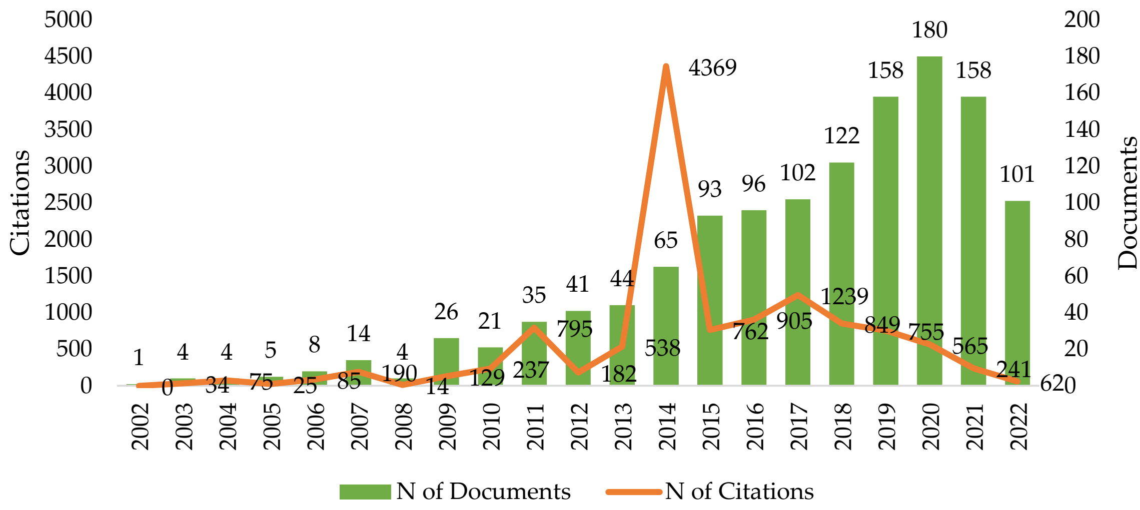
Results

Publication and Citation of Trends

After applying the inclusion and exclusion criteria, 1282 documents from 2002 through 2022 were included in the data analysis. Figure 2 displays the distribution of document publishing by year. The first STEM publications in colleges were published in 2002, with only one document. The overall number of STEM publications for the first ten years (2002–2011) was 122, with an average of 12 articles per year. However, this rise was not very substantial. This publication considerably expanded in the years that followed (2012–2021), reaching 1059 documents with an average yearly release of 105 documents. In 2022, there were 101 publications between January 1 and September 17, 2022. The number of these publications grew steadily between 2010 and 2020. The year with the most STEM publications was 2020, with 180 papers, 12051 citations, or 9 citations per paper made in total between 2002 and 2022.

Figure 2

Distribution of STEM publications 2002–2022



Frequently Cited Documents

The top 10 most frequently cited documents related to STEM in higher education are presented in Table 2 along with the number of citations (C) and the number of citations per year (C/Y). The authors of the most frequently mentioned works were Henderson et al. (2011) with 554 citations and an average of 50.36 each year. C/Y is a metric used to describe the impact of published articles in terms of the number of citations each year (Kaffash, 2021).

Table 2

Most frequently cited documents

Author(s)	Title	Source	C	C/Y
Henderson et al. (2011)	Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature	Journal of Research in Science Teaching	554	50.36
Dennehy & Dasgupta (2017)	Female peer mentors early in college increase women's positive academic experiences and retention in engineering	Proceedings of the National Academy of Sciences	183	36.60
Palmer et al. (2011)	A qualitative ınvestigation of factors promoting the retention and persistence of students of color in STEM	Journal of Negro Education	113	10.27
Matarić et al. (2007)	Materials for enabling hands-on robotics and STEM education	AAAI Spring Symposium – Technical Report	94	6.26
Shadle et al.	Faculty drivers and barriers: laying the	International Journal	81	16.20

(2017)	groundwork for undergraduate STEM education reform in academic departments	of STEM Education		
Madden et al. (2012)	Rethinking STEM education: an ınterdisciplinary STEAM curriculum	Procedia Computer Science	79	8.70
Rozek et al. (2015)	Gender differences in the effects of a utility-value intervention to help parents motivate adolescents in mathematics and science	Journal of Educational Psychology	78	11.14
Ertl et al. (2017)	The impact of gender stereotypes on the self-concept of female students in STEM subjects with an under-representation of females	Frontiers in Psychology	73	14.60
Beier et al. (2018)	The effect of authentic project-based learning on attitudes and career aspirations in STEM	Journal of Research in Science Teaching	70	23.30
Manduca et al. (2017)	Improving undergraduate STEM education: The efficacy of discipline-based professional development	Science Advances	68	13.60

Most Productive Sources

The most effective sources to publish STEM-related articles are listed in Table 3. It turns out that they originate from 524 distinct sources out of the 1282 papers that have been studied. Based on ranking the top 10 most prolific sources, it was discovered that the ten sources together produced 450 papers and were cited 2195 times. The *ASEE Annual Conference and Exposition*, which produces 226 documents with a total of 495 citations, is the source that publishes the most STEM-related documents. With 73 documents and a total of 183 citations, the *Proceedings-Frontiers in Education Conference* is ranked second. *The International Journal of STEM Education* came in third with 31 papers and 361 citations.

Table 3

Top 10 most productive sources

Source	A	C	C/A
ASEE Annual Conference and Exposition	226	495	2.19
Proceedings – Frontiers in Education Conference	73	183	2.50
International Journal of STEM Education	31	361	11.64
Proceedings of the International Astronautical Congress IAC	30	18	0.60
Journal of Physics: Conference Series	26	34	1.30
IEEE Global Engineering Education Conference Educon	15	70	4.66
Education Sciences	14	26	1.85
CBE Life Sciences Education	14	141	10.07
Lecture Notes in Computer Science	11	27	2.45
Journal of Research in Science Teaching	10	840	84.00

Most Productive Institutions

With 19 published papers and a total of 35 citations, Purdue University in the United States is the most prolific organization for STEM education research (see Table 4). With 10 published papers and 19 citations, Arizona State University is in second place. Khon Kaen University, located in Thailand, is in third place with 7 published documents and 13 citations. Overall, institutions from the United States dominate the list, with nine of them originating from this country.

Table 4

The most productive ınstitutions

Institution	Country	A	C
Purdue University	United States	19	35
Arizona State University	United States	10	19
Khon Kaen University	Thailand	7	13
University of Alabama in Huntsville	United States	5	8
Texas A&M University	United States	4	2
Utah State University	United States	4	28
Northwestern University	United States	4	27
College of Marin	United States	4	15
Skyline College	United States	4	15
New Jersey Institute of Technology	United States	4	9

The Most Productive Countries

A total of 123 different nations published the 1282 documents that have been examined. The top 10 nations for publishing STEM-related publications are listed in Table 5. The United States is in first place with a total of 834 publications published and 9853 total citations. The majority of the papers examined (65.05%) came from the United States. Australia (41) is in second place, followed by Thailand (33) in the ranking third place. 85,61% of all papers come from these ten nations. The United Kingdom has the most documents that are mentioned per document (C/A = 17.82), followed by Australia (17.58) and the United States (11.81).

Table 5

The 10 most productive countries

Country	A	%	C	C/A
United States	834	65.05%	9853	11.81
Australia	41	3.19%	721	17.58
Thailand	33	2.57%	135	4.09
China	32	2.49%	61	1.90
Canada	31	2.41%	141	4.54
Spain	29	2.26%	106	3.65
United Kingdom	28	2.18%	499	17.82
Germany	25	1.95%	157	6.28
Russian Federation	25	1.95%	115	4.60
Turkey	20	1.56%	199	9.95

Most Productive Author

Table 6 lists the top 10 authors who discussed STEM in higher education the most frequently between 2002 and 2022. With 13 publications and 23 citations, Carmen, from The University of Alabama in Huntsville, is the most active author. Enriquez (from Canada College, US) and Fontecchio (from Drexel University, US), who both have six documents, are in second and third place, respectively. However, Wang (with 164 citations) is the most influential author, with an average of 32.8 citations per document. The most active authors are primarily from the United States, according to this list of the top ten authors.

Table 6

The most productive authors

Author	Affiliation	Country	A	C	C/A
Carmen C.	The University of Alabama in Huntsville	United States	13	23	1.76
Enriquez A.G.	Canada College	United States	6	14	2.33
Fontecchio A.	Drexel University	United States	6	14	2.33
Yuenyong C.	Khon Kaen University	Thailand	6	13	2.16
Gharib M.	Texas A&M University at Qatar	Qatar	6	6	1.00
Wang X.	University of Wisconsin-Madison	United States	5	164	32.80
Micari M.	Northwestern University	United States	5	75	15.00
Davis K.C.	University of Cincinnati	United States	5	11	2.20
Creel B.	Texas A&M University at Qatar	Qatar	5	5	1.00
Bagiati A.	Massachusetts Institute of Technology	United States	4	55	13.75

Co-authorship for Authors and Countries

The study of links between authors is done through co-authorship analysis. The co-authorship network illustrates the relationships between authors and nations, based on the number of academic publications they have collaboratively produced. In this study, the minimum for an author was two documents, and the minimum for an author's citations was two. 337 out of the 4123 authors satisfied the criteria. However, only 15 were well related and created the 4 clusters shown in Figure 3.

It is crucial to remember that each node corresponds to one author. The node size indicates how many documents the author has published. The larger the size, the more documents that are published (Tsai, 2020). Clusters are defined as groups: the first cluster is red (5 authors), the second is green (4 authors), the third is blue (4 authors), and the fourth is yellow (2 authors). Posey with 2 documents and total link strength (TLS) 8, Dennin with 2 documents and TLS 4, Finkelstein, Smith, and Miller each provided 2 documents, with a total link strength of 5 comes from the first cluster. In the second cluster, there are Ebert-May, Urban-Lurain, and Stowe, with the number of each document being 2 and the total link strength 5, as well as Ralph has 2 documents and TLS 1. Henderson (documents 3; TLS 4), Cole (2; 3), Stains (2; 2), and Apkarian (2; 4) are from the third cluster. Matz (4; 7) and Jardeleza (2; 1) are from the last cluster, which is the fourth cluster.

A co-authorship analysis for countries was also used to research the connection between authors and countries. A country must have at least two papers and two citations. These are the minimal requirements. 62 out of the 123 countries matched the criteria. However, only 57 were interconnected and formed 13 clusters, as shown in Figure 4.

Nine countries are in the first cluster (red), with Portugal's most prominent node (number of documents 17, total link strength 14). Eight countries comprise the second cluster (green), with Malaysia having the most prominent nodes (documents 18; TLS 5). Seven countries are represented in the third cluster (blue), with Australia having the most excellent nodes (41; 8). Six countries are represented in the fourth cluster (yellow), with Thailand having the most excellent nodes (33; 3). Five countries are represented in the fifth cluster (purple), with Canada having the most excellent nodes (31; 18). Five countries are represented in the sixth cluster (gray), with Spain (29; 14) and the United Kingdom (28; 17) having the most excellent nodes. There are five countries in the seventh cluster (orange), with the United States having the most excellent nodes (834; 86). Four countries are in the eighth cluster (brown), with South Africa having the most excellent nodes (12; 5). Four countries are in the ninth cluster (pink), with China having the most excellent nodes (32; 15). One country in the tenth cluster is Croatia (2; 1), one country in the eleventh cluster is Ethiopia (2; 1), one country in the twelfth cluster is Northwestern (4; 3), and one country in the thirteenth cluster is Uruguay (2; 2). Figure 4 shows that the most prominent nodes are located in the United States, Canada, China, and Australia. This demonstrates that they are the country that collaborates with other countries the most.

Figure 3

Visualisation map of co-authorship for authors

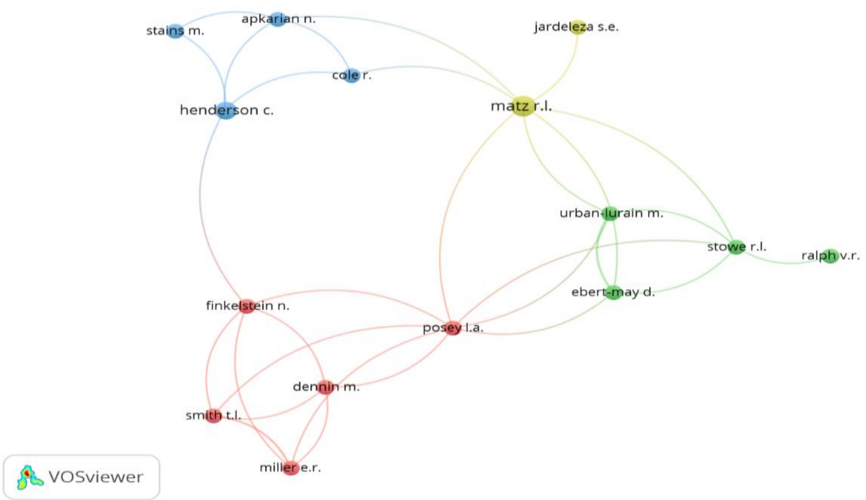
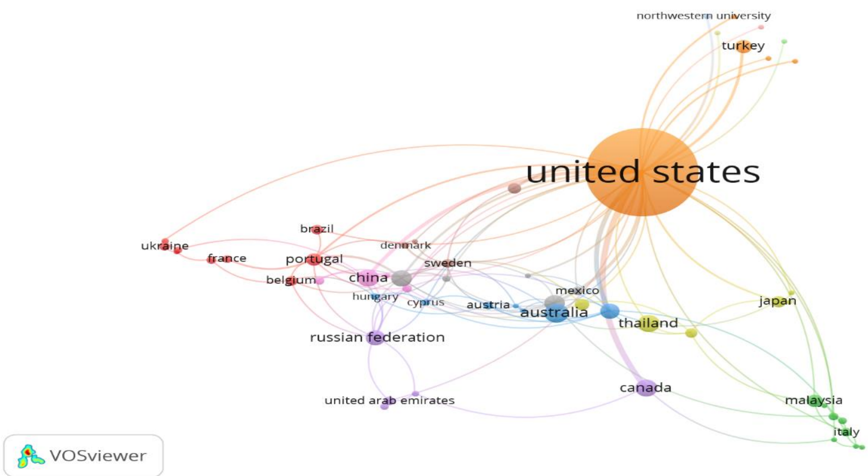


Figure 4

Co-authorship visualization map by country

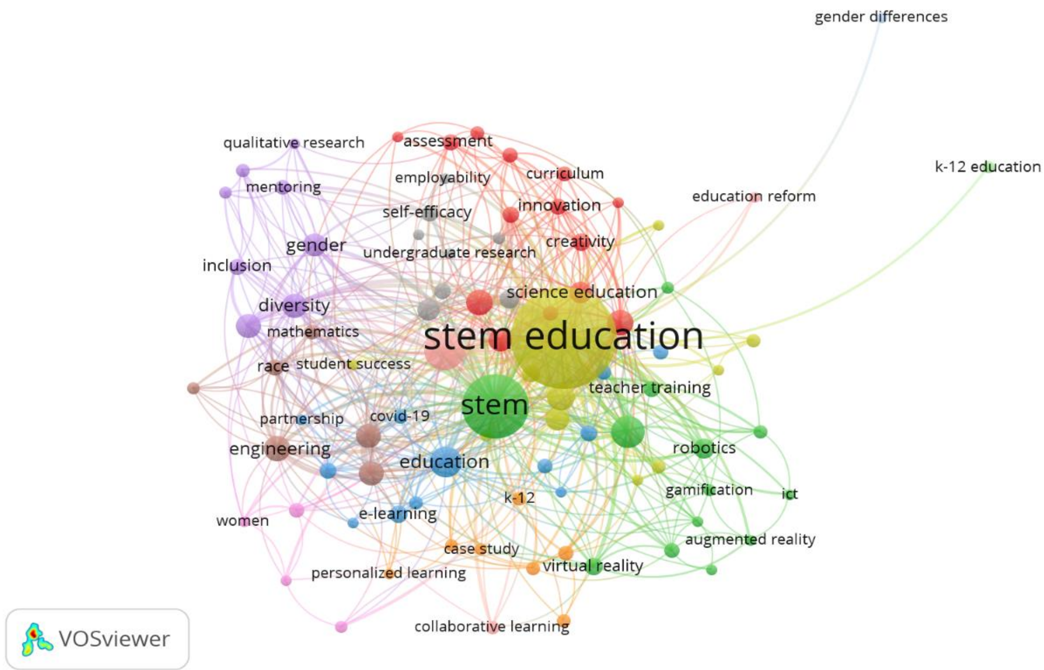


Co-occurrence of Author Keywords

The most frequently shared keywords used by authors while producing STEM articles are identified using the co-occurrence of author keywords. When two terms appear in an article simultaneously, this is known as co-occurrence (Kushairi, 2021). This explains why the two terms are related to one another. Out of the 2536 keywords present, 88 fall under the required minimum of 5 occurrences. In Figure 5, we can view the visualization map.

Figure 5

Visualisation map of author keyword co-occurrence



It is assumed that keywords with a tight link exist when they appear in the same color (Kushairi, 2021). Table 7 lists the top 10 keywords, some of which will set the direction of future studies.

Table 7

Top 10 most used keywords

Author Keywords	Occurrences	TLS
STEM education	382	352
STEM	152	192
Higher education	57	99
Engineering education	39	54
Education	37	67
Active learning	25	29
Diversity	23	51
Equity	22	41
Project-based learning	21	38
Gender	20	39

Discussion

Using bibliometric analysis, 1282 scholarly papers published between 2002 and 2022 were examined. The bibliometric analysis's findings reveal information on STEM trends in education. This knowledge may be utilised as literature to develop STEM instruction in a school or university setting. This document is continuously published annually. However, in the first ten years, the number of documents issued annually was less than 40. In the first ten years, 122 documents were published. Then, during the past ten years, STEM publications increased by ninefold (the total number of documents issued was 1059). This annual publication is proof that STEM research will continue to develop in the future. 2020 turned out to be a fruitful year since there were more publications than in previous years (180), while the year with the most citations was 2014, with 4369 citations and 67,21 citations per document (C/A). According to the graph of the distribution of publications per year in Figure 2, a comparison of the number of publications and the number of citations does not show a positive relationship, implying that there is no correlation between the increases in the number of documents and the increases in the number of citations. The year the document was issued is one element that affects the high number of citations. Older documents might garner many more citations than recently released publications.

The most often referenced article (554 citations) with the highest yearly citation total of 50.36 was Henderson et al.'s (2011) work. This article, published in the *Journal of Research in Science Teaching*, evaluated 191 publications published between 1995 and 2008. The objective is to pinpoint global shifts in STEM education to raise the standard of instruction. Reflective teachers, curriculum and pedagogy, shared vision, and policy are some of the transformation tactics covered in this article. Dennehy and Dasgupta (2017) investigated the role of female peer mentors in enhancing women's experience and retention in engineering. According to the research that was conducted, peer mentors were discovered to boost women's motivation, confidence, and retention in the engineering field. Additionally, more and more female students are continuing to plan to work in engineering. From these articles, it can be inferred that the STEM scientific areas are crucial to contemporary advancements. As a result, many activities are created to ensure students have a solid understanding of these four scientific disciplines. Therefore, STEM activities should be created to encourage student engagement and allow them to use their creativity to solve challenges across various disciplines (Jamali, 2022).

The *ASEE Annual Conference and Exposition* is the most fruitful venue for publishing STEM, with 226 documents published, 495 total citations, and an average citation rate of 2,19 per document. *The Journal of Research in Science Teaching* only published 10 articles, yet the average document received 84 citations, and the overall number of citations was relatively high (840). These two articles are United States publications. The *ASEE Annual Conference and Exposition* quartile had not yet been determined in Scimago at the time this research was written, but it had an h-index of 37, while *the Journal of Research in Science Teaching* is a Q1-indexed journal with an h-index of 139. In terms of the review process, articles published in journals differ from those presented at conferences. Because journal articles take longer to review than conference articles, academics prefer conferences over journals (Resurchify, 2022; Vrettas & Sanderson, 2015). Furthermore, the requirements for writing articles for conferences are simpler than those for journals. The CiteScores of the ten journals in Table 3 have been checked. The *Journal of Research in Science Teaching* ranks first with a score of 9.3, followed by the *International Journal of STEM Education* with a score of 8.8, and *CBE Life Sciences Education* with a score of 6.1. The Citescore is a metric for tracking the evolution of a journal's publication and citations over time. Citescore encourages an increase in the SJR score (Scimago Journal Rank) (Teixeira, 2020).

With 19 documents published, Purdue University is the most productive institution publishing papers related to STEM education in higher education. Arizona State University and Khon Kaen University are in second and third place, respectively. According to the paper by Gil-Doménech (2020) and Jamali (2022), similarly, Purdue University is the most productive university, with Arizona State University coming in second. The United States holds the top spot among the most productive nations for producing STEM content, providing 65.05% (834 documents) of the total data examined. There have been 9853 citations, with an average of 11,81 per year. Most studies on STEM education are published in the United States (Marín-Marín, 2021). Remember that STEM originated in the United States, where STEM research developed (Ortiz-Revilla, 2020). As for the factors causing STEM education to develop rapidly in the United States, it is one of the industrialized nations with significant financing for STEM programs (Ha, 2020). Furthermore, the availability of adequate infrastructure has an impact. As science and technology advance in the United States, new environmental problems arise that can pose a serious threat to society (Pengyu, 2021). The United States has finally recognized that there is a continuity between science, technology, and society. STEAM is therefore employed in an effort to address community-wide social issues. The following are some STEAM academic projects are underway in the United States, including The New School Project in North Carolina, Concordia University's teacher education program on STEAM education offers major courses such as Foundations of STEAM Education, STEAM Integration in K-12, and Developing STEAM-Enhanced Curriculum, and there are many more STEAM projects in the works. Various universities in the United States, including Harvard University, the Massachusetts Institute of Technology, Yale University, the Franklin Institute, the Rhode Island School of Design, and Boston University, are also involved in the STEAM project (Shashidhar, 2022).

Then the author with the most publications is Carmen, who is likewise American and has 13 documents published. Enriquez A.G. and Fontecchio A. from the United States are in second and third place, respectively. Up to eight authors on the list of the top 10 most productive authors are Americans. Christina Carmen is the most productive author in STEM education in higher education because she is an expert in the field. She earned a doctorate in mechanical engineering from the University of Alabama in Huntsville. Carmen is also the founder and CEO of The Talon Company, which provides STEM education and training to a variety of educational programs. Then, there is Xueli Wang, a professor at the University of Wisconsin-Madison, with the highest number of citations in the field. His research focuses on STEM education, and he has collaborated with a number of universities as well as on NSF-funded research projects.

Co-authorship analysis describes the connection between two authors who wrote for the same publication. Total link strength (TLS), on the other hand, shows the total strength of a co-authorship between two authors (Ali, 2021). Matz is an author with a significant network of collaboration with other writers, according to the study of co-authorship for authors (documents: 4; TLS: 7) (Figure 3). Meanwhile, according to the findings of the co-authorship for countries (Figure 4), the United States is the country that collaborates with other countries the most (documents: 834, TLS: 86). It might be argued that the United States has significantly contributed to the growth of STEM research. To learn the keywords that are used together by authors, use co-occurrence analysis of author keywords. According to the analysis's findings, the author frequently uses the terms "STEM education," "higher education," "engineering education," "active learning," and many more (Figure 5). These terminologies might signify current research trends regarding study variables, methods, and research topics.

Conclusions and Limitations

The study's bibliometric analysis of STEM from 2002 to 2022 is included. The search results produced data for 1487 documents extracted from the Scopus database and exported as a CSV. Once the inclusion and exclusion criteria have been applied, 1282 documents were further evaluated. According to the findings, an increase in the volume of publications in STEM education studies in higher education from 2002 onwards was observed, with a peak in 2020. The works of Henderson et al. (2011), Dennehy and Dasgupta (2017), and Palmer et al. (2011) received the highest number of citations. The sources with the highest number of documents were *ASEE Annual Conference and Exposition*, *Proceedings–Frontiers in Education Conference*, and *International Journal of STEM Education*. In terms of the most productive affiliations, Purdue University, Arizona State University, and Khon Kaen

University stand out. The most productive countries are the United States, Australia, and Thailand. This may be seen by the fact that the United States is the leading country with the most academic institutions publishing STEM-related research. According to an examination of co-authorship for countries, the United States also works with other countries the most. Furthermore, eight authors on the list of the top 10 most productive authors are are from the United States, including Carmen C. (The University of Alabama in Huntsville), Enriquez A.G. (Canada College), and Fontecchio A. (Drexel University).

The limitations of this study are that the only data used for analysis in this study came from the Scopus database, which may have influenced the findings. This is one of the study's shortcomings that should be considered. We recommend future studies to combine it with other databases, such as WoS. The current study was limited to documents published in the period 2002-2022 and only in English. Future studies should use a longer time frame and consider documents written in languages other than English to obtain more comprehensive findings.

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