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Implementation of STEM education: A bibliometrics analysis from case study research in Scopus database

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Abstract

In response to the long-term challenges of skills shortages and mismatches, many countries worldwide have made significant investments in STEM education. However, to obtain a comprehensive understanding of the progress of global research on the implementation of STEM education, it is essential to compile case studies on STEM education. Therefore, we conducted a bibliometric analysis of 750 publications from Scopus database to assess the bibliographic content of case studies on STEM education from 2006 to 2022. Our main findings show that the first case study on STEM education dates back to 2006, and research in this direction has grown enormously and continuously over the last five years (counting for 72.9%). The most influential articles in the field are cited mainly in the background citations section and help provide an initial perspective for readers to understand the insights discussed later in the study. The most popular journals publishing case studies in STEM education are of good quality, ranking highly in Scopus and Web of Science categories. The analysis results show three main research directions: STEM education in higher education, STEM education expands to STEAM, and STEM education activities in K12-education.

Keywords: bibliometric, Scopus, STEM, STEM education, case study

INTRODUCTION

In response to the long-term challenges of skills shortages and mismatches, many countries worldwide, including the USA, have invested in STEM education to preserve future employment opportunities (Friedman, 2005). This emphasis on promoting STEM education to enhance workforce capacity has become widespread among educators and policymakers in developed and emerging countries, such as the UK, Germany, Japan, Korea, and Israel (Drori, 2013; English, 2016; Marginson et al., 2013; Sanders, 2009)

Over time, STEM education has been extensively studied and developed, creating a widely-accepted definition and theoretical framework. Common themes from this body of research include a focus on mathematics and science, an emphasis on the relationship between these subjects, and a preference for authentic learning contexts. Additionally, STEM education frequently adopts a learner-centered approach and incorporates process engineering design into learning activities (Ha et al., 2020; Huong et al., 2021).

The case study method is a widely used research approach in academia for researchers who are interested in conducting qualitative research (Baskarada, 2014; Yazan, 2015). A case study is a research method that explores a phenomenon in some specific context (its natural occurrence) through various data sources. It discovers many different prisms that reveal many

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Contribution to the literature

- This article has reviewed the current state of STEM education case studies from 2006 to 2022.
- This research has identified significant countries, authors, and publications that have a lasting impact on research trends on this issue.
- This study has pointed out three main research directions: STEM education in higher education, STEM education expands to STEAM, and STEM education activities in K12-education.

aspects of the phenomena (Baxter & Jack, 2008; Kaarbo & Beasley, 1999). Case studies show many advantages in real-world research. One of those advantages is that it helps researchers to quickly approach the nature of social reality, allowing generalization of a case or being able to generalize from a case to a class and focus on the subtlety and complexity of the case as it is in real life (Brown & Rodgers, 2002). Case studies often answer the research questions 'how' and 'why', which are more explanatory and focus on phenomena that occur in real-life contexts. This type of research identifies the complexity and inclusion of social truths.

A collection of case studies on STEM education would facilitate a comprehensive review of the worldwide research landscape pertaining to the practical implementation of STEM education. Such an analysis is currently absent from the literature and would furnish valuable quantitative insights to scholars who wish to explore this topic in future research. However, most of the available quantitative studies on STEM education (Gil-Doménech et al., 2020; Ozkaya, 2019), the role of STEM education (Jamali et al., 2022), analysis of the global landscape on STEM education (Zhan et al., 2022), or focus on STEM quantification in middle school education (Huong et al., 2021), higher education (Kundu et al., 2022), STEM education in specific territories such as ASEAN (Ha et al., 2020). Various techniques are available for conducting reviews, such as citation network analysis, content analysis, and topic mapping. Among these, bibliometric analysis is a valuable tool for quantitatively assessing scientific activity by examining the form and content of scientific literature (Broadus, 1987). The bibliographic analysis results provide insight into several key areas:

(1) the annual growth rate of publications related to case studies in STEM education and corresponding citations,

(2) the countries and scholars with the most impactful case studies in STEM education,

(3) the most popular journals for publishing STEM education case studies,

(4) the most cited articles among case studies in STEM education, and

(5) analysis of the most significant research topics related to the implementation of STEM education worldwide.

METHODOLOGY

Bibliometric analysis was first introduced in the 1960s by Pritchard (1969) and has since been extensively utilized to examine scientific advancements across various fields, both at local and global levels. In this particular study, the methodology for data collection and analysis, as established by Ha et al. (2020), was employed to conduct bibliometric analysis. The data for this study were gathered from Scopus database, which is currently the largest and most widely used scientific database available.

As shown in **Figure 1**, all records in this database containing related keywords 'STEM education' and 'case study' in their title, summary, or keyword were searched. Keywords related to STEM are referenced by the research of Ha et al. (2020) and Huong et al. (2021), in addition, publications containing keywords related to the verb "stem" or the noun "stem cell" in the title, abstract, and keywords are also removed. The search query was then limited to articles, book chapters, conference papers, and reviews in the field of social science. Subsequently, we identified 806 records from Scopus database. The authors performed an abstract review of all of these publications to remove irrelevant research. The definitive collection of 750 articles was analyzed using the Biblioshiny and VOSviewer tools. Biblioshiny is an open-source tool that facilitates a comprehensive cartographic analysis of scientific literature. It has been designed and developed using R programming environment, which offers significant flexibility and seamless integration with other graphics and statistical packages. The tool is highly adaptable, allowing quick updates and incorporating new features (Aria & Cuccurullo, 2017). VOSviewer is a software application designed to construct and visualize bibliometric networks. In addition, VOSviewer provides text-mining capabilities that facilitate the development and presentation of co-occurrence networks comprised of significant terms extracted from the scientific literature (van Eck & Waltman, 2010). The necessary information on the relevant authors, affiliations, and journals is also added from Scopus database. The author also provided details regarding the citation count of the most impactful articles as identified by Semantic Scholar (https://www.semanticscholar.org/).

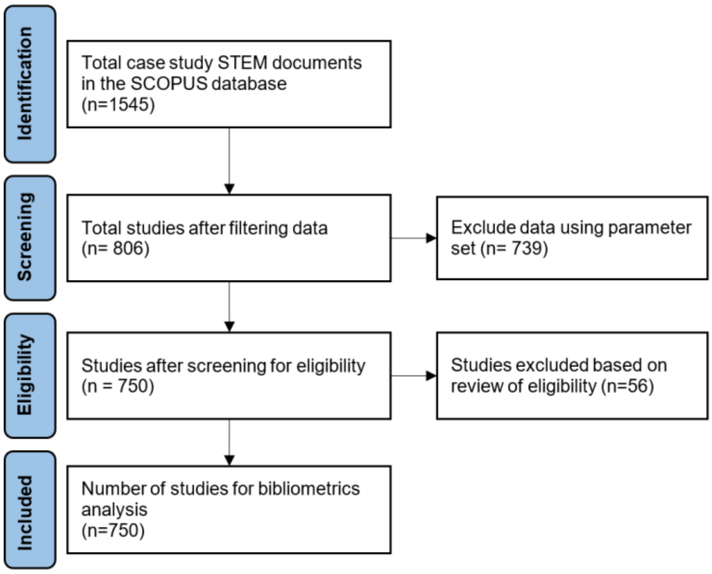

Figure 1. PRISMA diagram represents narrowing of analysis dataset of case studies in STEM (data collected from Scopus [https://scopus.com/] on 14 December 2022)

Table 1. Main information of the collection

Description	Results
Timespan	2006-2022
Sources (journals, books, etc.)	384
Documents	750
Annual growth rate (%)	30.470
Document average age	3.110
Average citations per document	6.317
References	32,448
Authors	2,223
Authors of single-authored documents	83
Single-authored documents	84
Co-authors per document	3.300
International co-authorships (%)	11.330

RESULTS AND DISCUSSION

General Information About Publication Collection

Table 1 presents the key findings from the analysis of 750 publications, which comprise 543 articles (72.4%), 146 conference papers (19.4%), 53 book chapters (7.1%), and eight reviews (1.1%). Notably, these publications were sourced from a total of 384 different sources. Articles using case studies in STEM education were published in 2006. However, in the next ten years, the number of studies on the same topic and research methods did not increase much. In the next three years, the number of articles was approximately 50, with 45 articles in 2015, 53 in 2016, and 47 in 2017. The number of papers published in the last five years has shown a rapid increase, with 60 articles published in 2018, 98 in 2019, 113 in 2020, 135 in 2021, and 141 in 2022 (as shown in **Figure 2**, bar chart). The annual growth rate recorded from 2006 to 2022 is 30.47%.

The growth model shown in **Figure 2** is similar to the growth model of STEM education research in middle school (Huong et al., 2021) or STEM education in ASEAN (Ha et al., 2020). The anthology has been written by 2,223 authors (each document has 3.3 co-authors on average). 83 single authors are publishing 84 single-author papers.

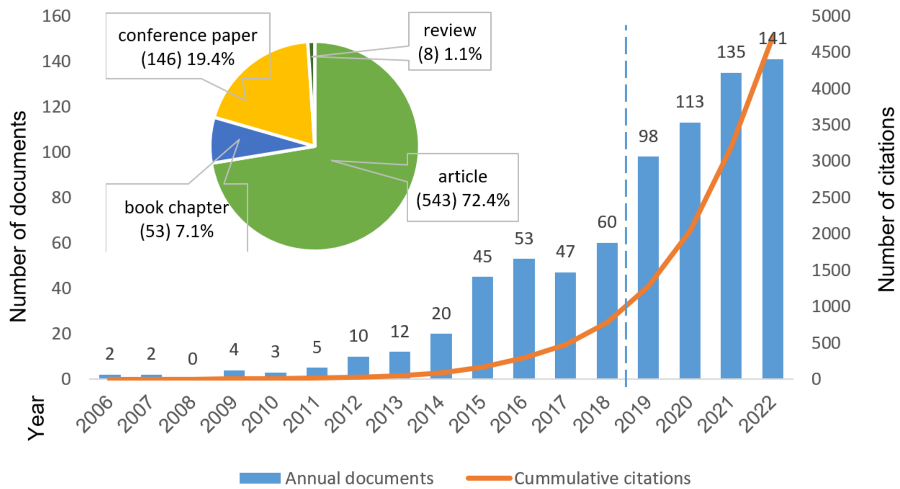

Figure 2. General information about publication collection (Source: Authors' own elaboration)

Table 2. Information on citation count of the collection

CC	NP	Percentage (%)	Citations	Percentage (%)
>100	2	0.27	243	5.10
50 to 99	10	1.33	659	14.00
21 to 49	45	6.00	1,344	28.50
7 to 20	138	18.40	1,578	33.40
1 to 6	346	46.13	895	19.00
0	209	27.87	0	0.00

Note. CC: Citation count & NP: Number of papers

Table 3. Top-10 most productive countries ranked on number of publications

Rank	Country	NP	%	TC	%	TC/NP
1	The USA	433	57.7	3,397	72.0	7.8
2	The UK	41	5.5	357	7.6	8.7
3	Turkey	36	4.8	242	5.1	6.7
4	Australia	36	4.8	188	4.0	5.2
5	Canada	22	2.9	107	2.3	4.9
6	China	22	2.9	60	1.3	2.7
7	Hong Kong	18	2.4	74	1.6	4.1
8	Spain	18	2.4	72	1.5	4.0
9	Ireland	14	1.9	78	1.7	5.6
10	South Africa	11	1.5	34	0.7	3.1
11	Portugal	11	1.5	33	0.7	3.0

Note. TC: Total of citations & NP: Number of publications

At the time of this study, the publication collection had amassed 4,719 citations, resulting in an average citation count of 6,317 per publication. The h-index of the collection was calculated to be 30, indicating that among the 750 documents evaluated for the h-index, 30 had been cited at least 30 times. However, it is noteworthy that 209 papers (27.87% of the collection) had not received any citations. Nearly three-quarters of publications (555 publications) have less than average citations. Other information on the annual citation and its cumulative number for the period 2017-2021 is shown in **Figure 2** and **Table 2**.

Most Productive Countries and Global Network of Cooperation

Table 3 presents the top ten most productive countries based on the number of publications and citations accumulated. The USA outnumber all other countries (n=433, accounting for 57.7% of total publications). Not only that, but the country also excels in total citations with 3397 citations (72.0% of total citations), equivalent to an average number of citations per document of 7.8. The second country in terms of publications is the UK (n=41, 5.5% of the total). With an impressive average of 8.7 citations per document and 357 citations, this country has the highest citation count among the countries examined in this study. The next are Turkey and Australia, with the same number of publications at 36 (5.5%) and the number of citations at 242 and 188, respectively. The two countries with 18 publications are Canada and China. The remaining countries on the list with corresponding publications are Hong Kong (n=18), Spain (n=18), Ireland (n=14), South Africa (n=11), and Portugal (n=11). Of the remaining countries on the list, only Canada has a citation count of 107; the rest have fewer than 60 citations.

The USA's superiority in publications compared with other countries is quite similar to the results of Assefa and Rorissa (2013) on the same topic or Marín-Marín et al. (2021) in the study of STEAM in education. Overall, except for the top three countries, the rest of the countries have a lower average citation count than the average of the entire collection of publications on case studies in STEM education.

According to data from Scopus, 84 countries have publications related to case studies in STEM education. **Figure 3** displays the transnational cooperation network comprising 36 partner countries. Each node in **Figure 3** represents a country, while the buttons' colors denote the clusters of links between the countries. The node size corresponds to the number of publications, and the thickness of the lines connecting the nodes reflects the strength of the transnational collaboration. The countries in this network have at least three publications related to the published research topic. The network built in **Figure 3** shows three main clusters: Red, green, and blue. The countries listed in **Table 3** all appear in this network. In the above analysis, the USA has a much higher number of publications than the rest, but transnational research collaboration is more expansive than in this country. The cooperation between the remaining countries is also prosperous and diverse.

Most Published Sources

The collection of publications has been published from 384 different sources, including journals, scientific conferences, and book chapters. The top-10 publications that have published the most articles related to case study research in STEM education are presented in **Table 4**. These top-publications published 152 studies (20.3% of the total) and were cited 1,441 times (equivalent to 30.5% of the total citations). In this list of 11 sources, there are three conferences and eight journals. Education Sciences (MDPI Publishing House) is the journal with the highest number of publications in this field (24 papers), followed by Proceedings of Frontiers in Education Conference FIE (23 papers) and International Journal of STEM Education (Springer Nature Publishing House) is the third (20 articles). The remaining sources publish between 10 and 12 publications. Of the top-8 journals, only Education Sciences is in Scopus Q2 group of journals. Furthermore, this journal is the sole one included in the Emerging Sources Citation Index (ESCI) of the Web of Science (WoS) core collection. The remaining seven journals are all in the journals ranked Q1 according to Scopus's ranking. These are also journals in the ISI category of the WoS core collection. Studies from the most published

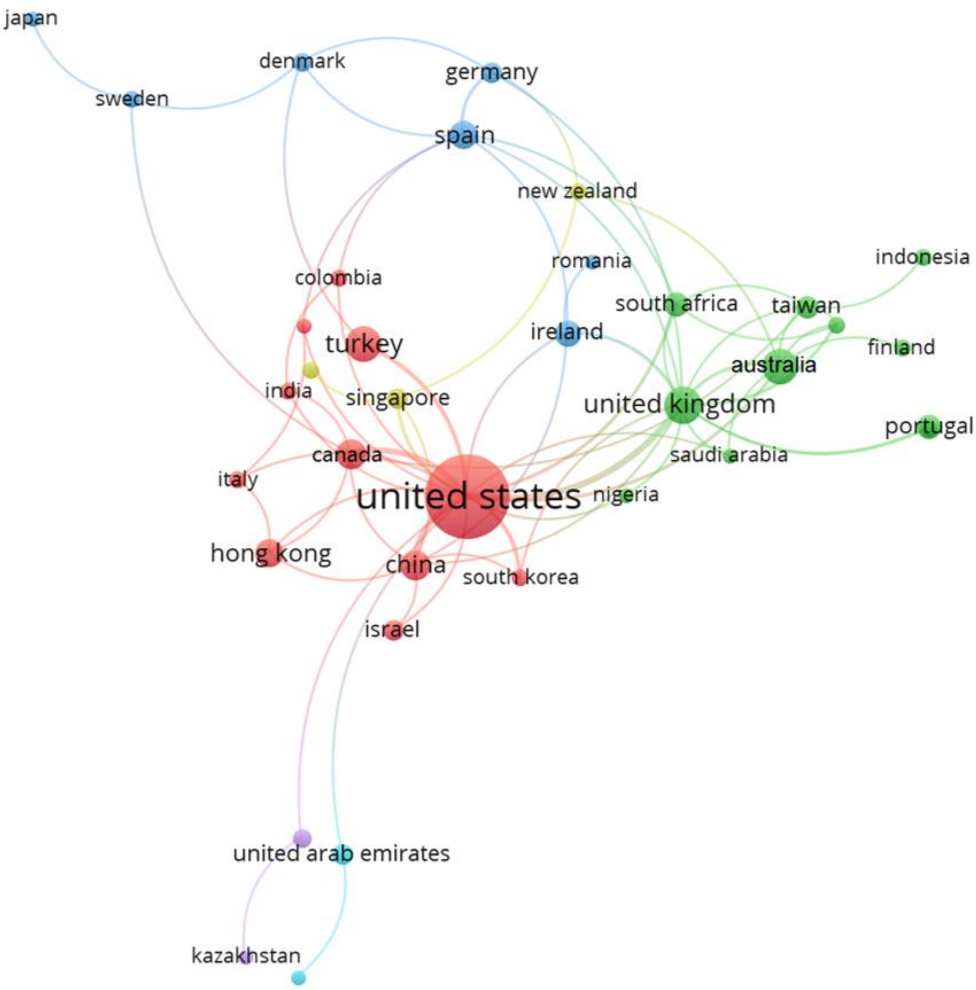

Figure 3. Transnational cooperation network of 36 partner countries (Source: Authors' own elaboration, using VOSviewer)

Table 4. Top-10 most frequently published sources ranked by number of publications

Rank	Source	Publishing house	ST	NP	TC	Scopus Q*	WoS core collection**
1	Education Sciences	MDPI	JN	24	80	Q2	ESCI
2	Proceedings of Frontiers in Education Conference FIE	-	CO	23	106	-	-
3	International Journal of STEM Education	Springer Nature	JN	20	293	Q1	SCIE/SSCI
4	Cultural Studies of Science Education	Springer Nature	JN	12	91	Q1	SSCI/AHCI
5	IEEE Global Engineering Education Conference	-	CO	12	43	-	-
6	Computer Supported Collaborative Learning Conference	-	CO	11	2	-	-
7	Journal of Research in Science Teaching	Wiley-Blackwell	JN	10	288	Q1	SSCI
8	Science Education	Wiley-Blackwell	JN	10	168	Q1	SSCI
9	Journal of Science Education & Technology	Springer Nature	JN	10	163	Q1	SCIE/SSCI
10	International Journal of Science & Mathematics Education	Springer Nature	JN	10	108	Q1	SSCI
11	International Journal of Science Education	Taylor & Francis	JN	10	99	Q1	SSCI

Note. ST: Source type; JN: Journal; CO: Conference; NP: Number of publications; TC: Total citations; Q: Quartile; *Data collected from https://scopus.com on 1 January 2023; & ** Data collected from https://mjl.clarivate.com on 1 January 2023

sources have a large number of citations. These resources are mostly of good quality, ranking high in Scopus and WoS catalogues.

Most Effective Authors

The total number of authors who participated in the case study in STEM education recorded in Scopus database is 2,223. Table 5 exhibits the rankings of the ten most prolific scholars, as determined by the number of articles produced. It is noteworthy that a given scholar may leverage affiliations with multiple institutions, however, the data presented in Table 5 pertains exclusively to their most recent publications. In general, the number of publications by leading scholars is not too disparate. There are 7/10 scholars from the USA (Moore, T. J. with seven papers, Guzey, S. S. with six papers, Roehrig, G. H. published five papers, Biswas, G., Glancy, A. W., Kier, M. W., and Siverling, E. A. each with four

Table 5. Top-10 authors ranked by number of publications produced

Rank	Author	Institution/country	NP	TC	TP/TC
1	Moore, T. J.	Purdue University, The USA	7	54	7.1
2	Guzey, S. S.	Purdue University, The USA	6	68	11.3
3	Muntean, C. H.	National College of Ireland, Ireland	5	38	7.6
4	Muntean, G. M.	Dublin City University, Ireland	5	53	10.6
5	Roehrig, G. H.	University of Minnesota Twin Cities, The USA	5	106	21.2
6	Biswas, G.	University of Pennsylvania, The USA	4	46	11.5
7	Glancy, A. W.	University of Minnesota Twin Cities, The USA	4	22	5.5
8	Kier, M. W.	The College of William and Mary, The USA	4	16	4.0
9	Siverling, E. A.	Minnesota State University, The USA	4	31	7.8
10	Altan, E. B.	Sinop Üniversitesi [Sinop University], Turkey	3	14	4.7

Note. TC: Total of citations & NP: Number of publications

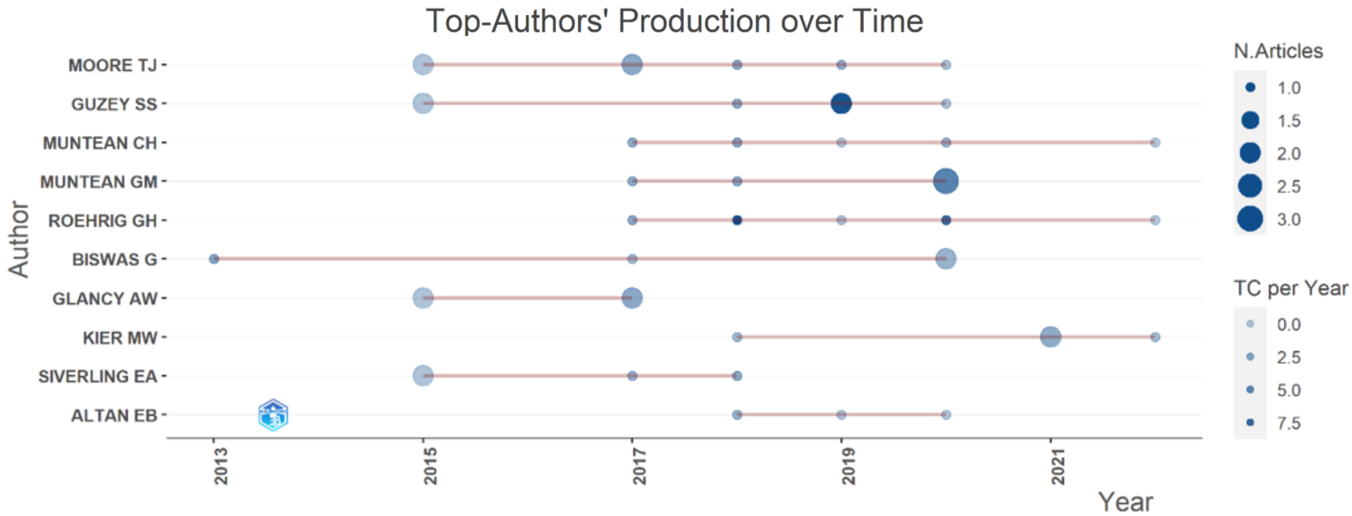

Figure 4. Production of top-authors over time (Source: Authors' own elaboration, using Biblioshiny)

papers), two academics from Ireland (Muntean, C. H., and Muntean, G. M. with five each), and one scholar from Turkey (Altan, E. B. with three papers). Based on citations, the highest is Roehrig, G. H. from University of Minnesota Twin Cities (n=106), this author has an average of 21.2 citations per paper–outperforming the rest, followed by two authors from Purdue University: Guzey, S. S. (n=68) and Moore, T. J. (n=54), one other author with more than 50 citations is Muntean, G. M. from Dublin City University. The remaining authors exhibit a citation number from 14 to 46.

The annual publications and citations of the top-10 authors are shown in Figure 4. Two authors, Moore, T. J. and Guzey, S. S., have a similar publication process. The first two papers by these two authors on case studies in STEM education were published in 2015 in Proceedings-Frontiers in Education Conference FIE (Moore et al., 2015a, 2015b). Additionally, these two authors also collaborated on four other studies on the same topic. Sharing the same research trend, Muntean, C. H., and Roehrig, G. H. was first published in 2017 and lasted until 2022; however, we did not record research collaboration between these two authors. The remaining authors have several publications that cannot reflect research trends adequately.

Most Influential Studies

The first study recorded in Scopus database on a case study in STEM education was an exploratory case study examining the self-definition of eight graduate students who participated in a GK-12 program published in May 2006 (Buck et al., 2006). Nevertheless, it is essential to note that this study does not hold significance, as it only garnered eight citations at the time of the investigation. In contrast, Table 6 provides information on the ten most frequently cited works from the 750 studies within the collection. Table 6 includes additional details on the authors and publishers of the selected works. Within this list, nine works are journal articles, while one is a conference paper with 795 citations at the time of this study. Collectively, these 10 works account for 16.8% of the total citation count for the anthology.

The paper with the highest citation count (139 citations) examines the articulation and negotiation of in-practice identities in science by middle school girls desiring a career in STEM-related fields (Tan et al., 2013). The second most cited paper (with over 100 citations) describes the use of flipped classroom modules for large enrolment general chemistry courses as a low-barrier approach to increase active learning and improve student grades (Eichler & Peeples, 2016). This paper has

Table 6. Top-10 most cited papers

CR	Document title	APA DC	First author's institution/ country	Source title	DT	TC	TC/Y	HIC*	BC*	MC*	RC*
1	Desiring a career in STEM-related fields: How middle school girls articulate and negotiate identities-in-practice in science	Tan et al. (2013)	University of North Carolina at Greensboro/The USA	Journal of Research in Science Teaching	AR	139	13.90	18	76	10	6
2	Flipped classroom modules for large enrollment general chemistry courses: A low barrier approach to increase active learning and improve student grades	Eichler and Peeples (2016)	University of California/ The USA	Chemistry Education Research & Practice	AR	104	14.86	7	38	2	6
3	Is science for us? Black students' and parents' views of science and science careers	Archer et al. (2015)	UCL Institute of Education/The UK	Science Education	AR	87	10.88	9	29	4	4
4	STEM related after-school program activities and associated outcomes on student learning	Sahin et al. (2014)	Texas A&M University/ The USA	Kuram ve Uygulamada Egitim Bilimleri [Educational Sciences in Theory & Practice]	AR	83	9.22	3	50	1	4
5	Integrating Internet of Things (IoT) into STEM undergraduate education: Case study of a modern technology infused courseware for embedded system course	He et al. (2016)	Kennesaw State University/The USA	Proceedings of Frontiers in Education Conference FIE	CP	81	11.57	3	42	10	3
6	In-service teachers' implementation and understanding of STEM project based learning	Han et al. (2015)	Sungkyunkwan University/South Korea	EURASIA Journal of Mathematics, Science & Technology Education	AR	65	8.13	12	48	5	7
7	Colorblind mentoring? Exploring white faculty mentoring of students of color	McCoy et al. (2015)	The University of Tennessee/The USA	Journal of Diversity in Higher Education	AR	65	8.13	6	30	1	1
8	Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study	Dare et al. (2018)	Florida International University/The USA	International Journal of STEM Education	AR	58	11.60	6	27	1	2
9	Coding as another language: A pedagogical approach for teaching computer science in early childhood	Bers (2019)	Tufts University/The USA	Journal of Computers in Education	AR	58	14.50	9	29	10	2
10	Active learning in flipped life science courses promotes development of critical thinking skills	Styers et al. (2018)	Birmingham Southern College/The USA	CBE Life Sciences Education	AR	55	11.00	2	27	5	3

Note. DC: Documents cite; DT: Document types; AR: Article; CP: Conference paper; TC: Total references; PY: Publication year; Y: Year; HIC: Highly influential citations; BC: background citations; MC: Methods citations; RC: Results citations; & * Information collected from Semantic Scholar (https://www.semanticscholar.org) on 26 December 2022

garnered considerable attention, with an annual citation count of 14.86. Two analytical papers examining black students' and parents' views of science and science careers (Archer et al., 2015) and the effects of STEM-related after-school program activities on student learning (Sahin et al., 2014) occupy the third and fourth positions, respectively, with 87 and 83 citations. The only conference paper on this list (He et al., 2016) reports on a case study of courseware that integrates modern technology for embedded system courses to incorporate the Internet of Things (IoT) into undergraduate STEM education. This paper has received 81 citations, equating to an annual citation count of 11.57. Two papers published in 2015 that explored in-service teachers' implementation and understanding of STEM project-based learning (Han et al., 2015) and white faculty mentoring students of color (McCoy et al., 2015) received 65 citations each. Only one paper on this list is single-authored, describing a pedagogical approach for early childhood computer science called "coding as another language" (Bers, 2019). This paper has 58 citations. The other two studies investigate the implementation of integrated STEM curricular units by science teachers through a phenomenological multiple case study (Dare et al., 2018) and active learning in flipped life science courses to promote the development of critical thinking skills (Styers et al., 2018).

Table 6 presents the citation counts for scientific publications based on their position within the article. Cohan et al. (2019) classify citation intents into three distinct types: background information, methods utilized, and comparison of results. The citation data was obtained from Semantic Scholar (https://www.semanticscholar.org). However, it should be noted that the total number of citations for each category may differ from those listed in the TC column. The citation count is limited to articles for which Semantic Scholar can access the full text (Thuan et al., 2022). As such, the total number of citations for the top-10 most frequently cited articles is as follows: background citations accounted for 396 (82.0%) of the total, methods citations for 49 (10.1%), and results citations for 38 (7.9%).

The most influential articles in research citations cover broad issues, not a particular topic. These studies had three authors per paper or more published between 2013-2019. The most influential studies are mainly published in scientific journals. This is consistent with the view that, in the social sciences, articles in scientific journals are often more interesting than conference papers (Fairclough & Thelwall, 2015). This is a suggestion for researchers when searching for materials in the field of STEM education. Eight of the ten first author's countries of the most cited papers are the USA, and the remaining two first authors are from the UK and South Korea. This is consistent with the analysis of the most published countries, where more than half of the publications come from the USA.

The citations of the most influential articles come mainly from the background of the articles (82.0% of the citations by content have been counted). This index is significantly more significant when compared with the number of background citations in the field of measuring efficiency in higher education (64.2%) (Thuan et al., 2022). It is safe to say that the most influential papers in the field help to provide an initial perspective to the reader's understanding of the insights discussed later in the study of this topic. STEM education topic. These articles also help clarify the importance and reinforce the authors' arguments (Thao et al., 2020).

Main Research Topics

Based on the keywords selected by the author in the articles, the author analyses the main research topics of the case studies on STEM education. The total number of keywords set by the authors was 2,034. We combined synonyms, singular, and plural keywords, and removed keywords that did not show research trends before analysis.

Figure 5 displays the co-occurrence network of 69 keywords, each appearing in at least five papers. The nodes in **Figure 5** represent individual keywords, with the size of each node proportional to the frequency of the corresponding keyword. The keywords are classified into four distinct clusters, with the most sizable cluster (denoted in red) centering on the examination of case studies in STEM education at the tertiary level. Issues related to gender (with a female focus), professional development, experience learning, diversity (Holgado et al., 2020; Shehab et al., 2012). In addition, there are also studies related to curriculum design, self-efficacy of students (Craig et al., 2022; McFadden & Roehrig, 2017). The red cluster has the highest keyword concentration, consistent with previous research that confirmed that STEM education is most implemented at the university level (Ha et al., 2020; Kundu et al., 2022). The green cluster: research interest in STEM education expands to STEAM (adds an A-art element). Research issues focus on specific teaching methods and techniques such as problem-based learning, project-based leaning, technology-enhanced learning, game-based leaning, and scaffold. In addition, many studies are interested in developing thinking and creativity for students such as computational thinking, design learning, creativity (Clark & Mahboobin, 2018; Han et al., 2015; Hathcock et al., 2015; Lou et al., 2017). The blue cluster including studies interested in STEM education activities in K12 education, specific issues discussed include curriculum, integrated teaching, pedagogical content knowledge, etc. (Mathis et al., 2017; Wang et al., 2020). Yellow cluster: This group does not focus on a particular topic. Nodes that are pretty far apart are not closely linked. This group includes keywords such as science education, middle school, and engineering.

Figure 6 depicts the yearly research trends in the field by identifying relevant keywords. A line represents the timeline of each keyword, and a bubble indicates the keyword's highest appearance frequency in a given year. The size of each bubble is proportional to the number of publications that contain the respective keyword (Thuan et al., 2022).

It is worth noting that we only included keywords that appeared in a minimum of five publications each

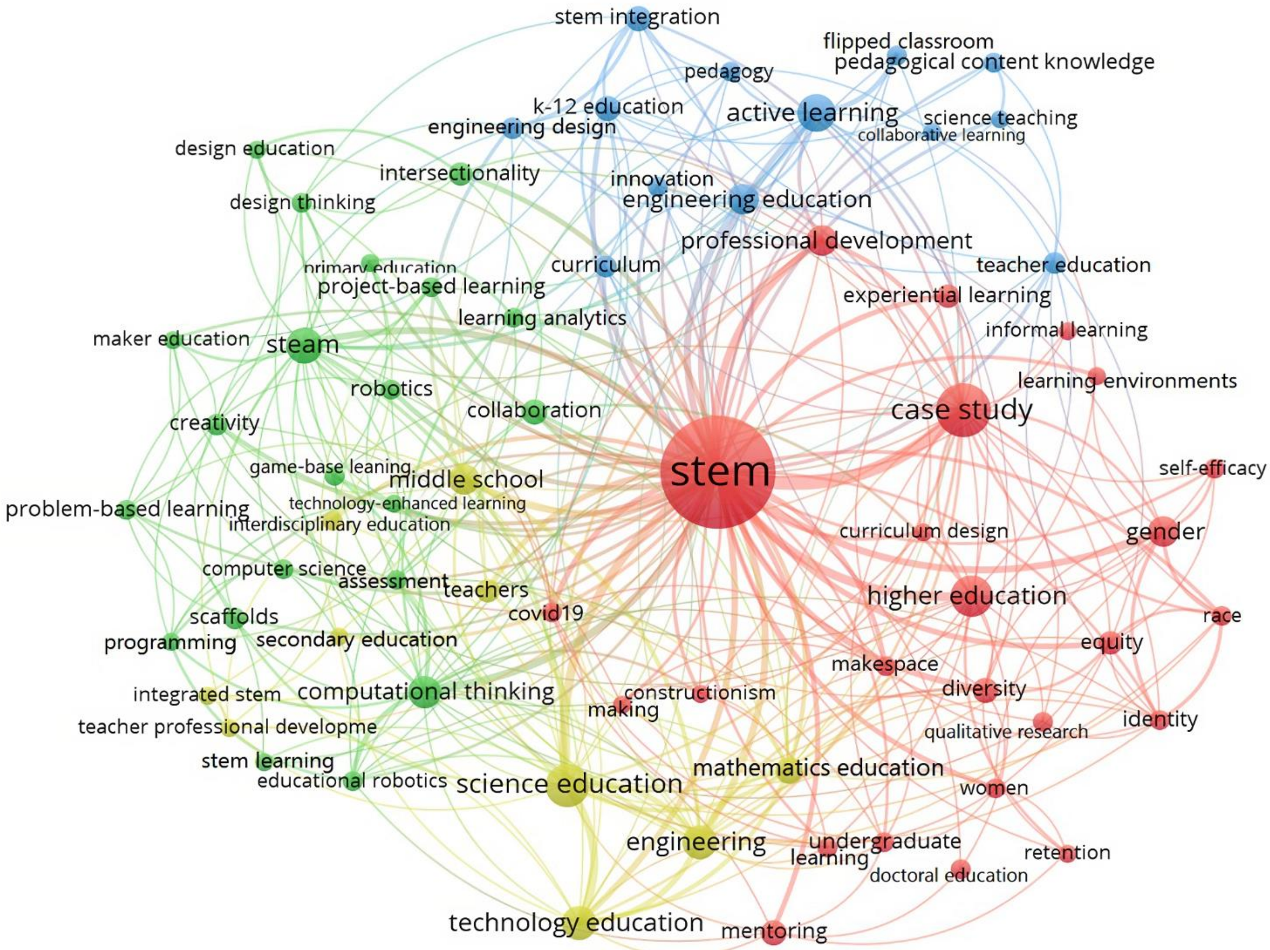

Figure 5. Co-occurrence network of 69 author keywords that appear together in at least five papers (Source: Authors' own elaboration, using VOSviewer)

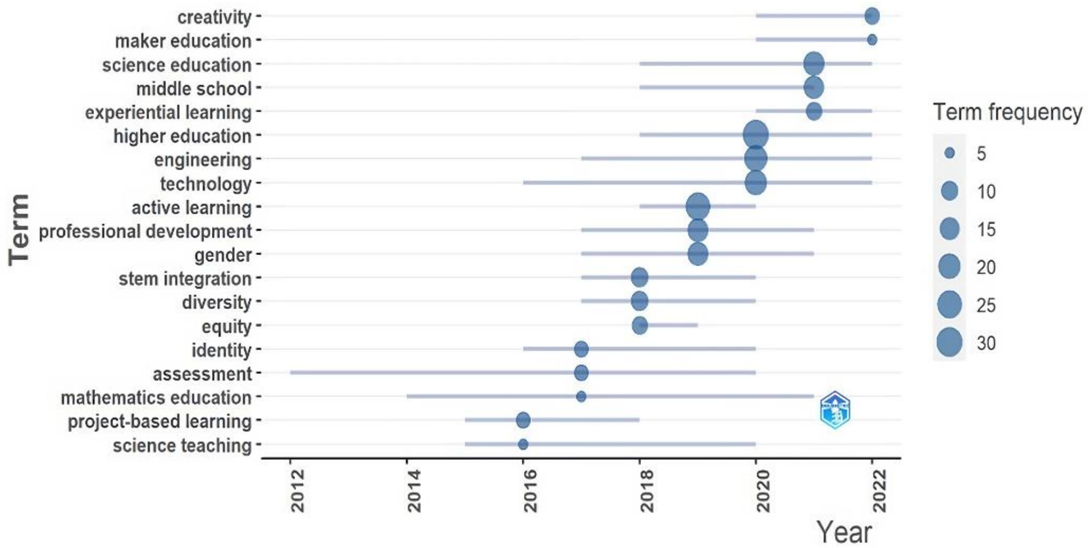

Figure 6. Trend topics of publication collection on authors' keywords (Source: Authors' own elaboration, using Biblioshiny)

year. Furthermore, up to three keywords with the highest frequency were selected to represent the identified trend. Notably, the keywords STEM/STEM education and "case study" were excluded as they did not provide information on research trends.

Although the time span of this collection is from 2006 to 2022, the trend topics appear only for the period from 2016 to 2022. Keywords that represent the last five years are 2018 (stem integration, diversity, and equity), 2019 (active learning, professional development, and gender), 2020 (higher education, engineering, and technology),

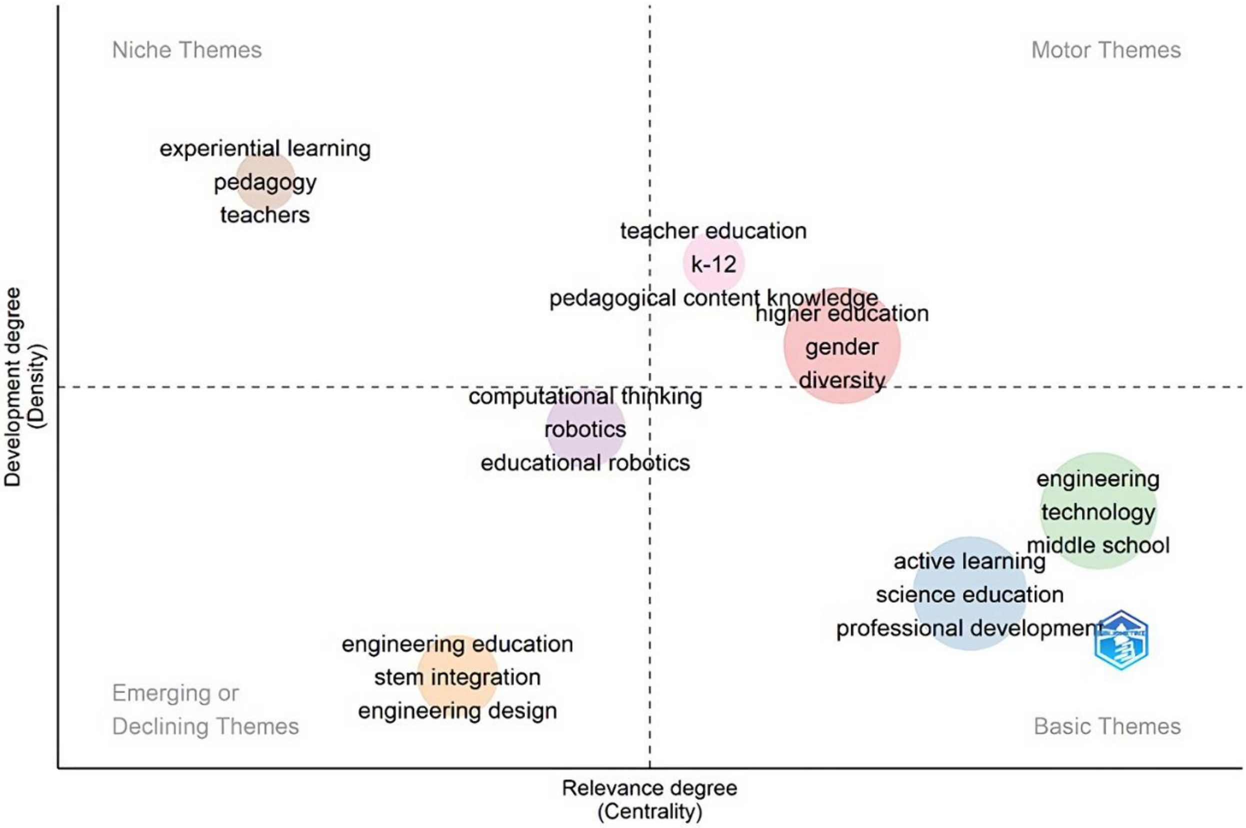

Figure 7. Thematic map of research directions related to case studies in STEM education (Source: Authors' own elaboration, using Biblioshiny)

2021 (science education, middle school, and experiment learning), 2022 (creativity and maker education). Assessment has the longest timeline of the keywords in **Figure 6** (from 2012 to 2020), followed by the keyword math education (from 2014 to 2021), but these two keywords have a low frequency. High-frequency keywords appear in the years 2019, 2020, and 2021. These keywords also appear in **Figure 5**, which is analyzed above.

Thematic maps illustrating the authors' chosen keywords were generated, as depicted in **Figure 7**. The maps produced facilitate the visualization of four distinct theme typologies. Particularly noteworthy is the upper right quadrant, which presents "motor themes" that exhibit high centrality and density, indicating their significance in the research field. The upper left quadrant, on the other hand, is characterized by high density but low centrality, signifying highly developed and isolated topics. In contrast, emerging or declining topics are situated in the lower left quadrant, while basic and transversal topics are found in the lower right quadrant (Cobo et al., 2011; Pham-Duc et al., 2020, 2021).

The themes in the lower left quadrant exhibit inadequate development, with some being marginally developed. These articles demonstrate low density and concentration, indicating emerging or disappearing topics. Includes two groups of keywords: technical education, original integration, and engineering design; and the group consists of keywords about computational thinking, robotics, and educational robotics. Themes are essential for this field, but are not developed, including keywords: active learning, science education, professional development, and a group of keywords: engineering, technology, and middle school. Themes that are considered to be niche typically possess strong internal ties, but they exhibit insignificant external ties, rendering them of marginal significance for the field. This is true of certain keywords, such as experiential learning, pedagogy, and teachers. The most important topics of research trends corresponding to the motor themes of the specialty include keywords higher education, gender, diversity, collaboration, and keyword group: teacher education, K-12, and pedagogical content knowledge.

These analyses corroborate the findings of the co-occurrence network analysis in **Figure 5** and the trend topics depicted in **Figure 6**.

CONCLUSIONS & FUTURE RESEARCH

This article examines the global research trends concerning the practical implementation of STEM education worldwide by analyzing data from Scopus database. Utilizing bibliometric techniques, the article highlights several key features of the literature on STEM education.

The first case studies on STEM education began in 2006, but the scientific results of case studies in STEM education have only been around for the past five years. Case studies of STEM education have continued to increase in the last five years (2019-2023). This can confirm that case studies of STEM education are still attractive to many scholars around the world. However, there is uneven development among countries around the world. The USA has a more significant number of publications than all other countries (n=433, 57.7% of total publications). The country also excels in total citations with 3397 (72.0% of total citations), equivalent to an average citation count per document of 7.8. However, the research cooperation between the countries revolves around the USA, and the other countries' collaboration is also diverse.

Looking at author contributions by volume, seven of the top ten best-performing authors are from the USA, and the other three are from Ireland and Turkey, respectively. Prominent scholars (top-10) in the field of research have published volumes of 3-10 articles, and collaboration between authors on this topic is neither clear nor compelling. The number of publications by author groups is not large enough to represent research trends. Upon examining the author's contribution based on the number of citations their articles have received, it is evident that authors from the USA still constitute the majority. Specifically, nine of ten primary authors of the most highly cited articles are from the USA. In one article, the other primary author is from South Korea. The most influential articles in the field are primarily cited in the background citations section and help provide an initial perspective for readers to understand the insights discussed later in the study. Research on STEM education topics. These articles also help clarify the importance and reinforce the author's arguments.

The most popular journals publishing case studies in STEM education are of good quality, ranking highly in Scopus and WoS database; out of the top-8 journals, only Education Sciences is in Scopus's Q2 group of journals, which is also the only journal in the ESCI list. The remaining seven journals are all in the journals ranked Q1 according to Scopus's ranking. These are also journals in the ISI category of the WoS core collection.

The reality of implementing STEM education worldwide through analyzing the most critical research topics about case studies in STEM education shows three main research directions. The first research direction focusses on analyzing case studies in STEM education in higher education. Issues related to gender (with a female focus), professional development, experience learning, and diversity. The second research direction interested in STEM education expands to STEAM (adding A-art elements). Research problems focus on specific teaching methods and techniques such as problem-based learning, project-based leaning, technology-enhanced learning, game-based leaning, scaffold. The third research direction is more interested in STEM education activities in K-12-education, specific issues discussed include curriculum, integrated teaching, pedagogical content knowledge. These research directions are still ongoing. continues to be of interest in the last five years when it comes to keywords representing research: 2018 (stem integration, diversity, and equity), 2019 (active learning, professional development, and gender), 2020 (higher education, engineering, and technology), 2021 (science education, middle school, and experiment learning), 2022 (creativity and maker education).

This study presents the world's first bibliographic analysis of case studies focused on STEM education. The research findings provide a comprehensive overview of the actual implementation of STEM education globally, including the development of the research field, primary contributors, and their collaborations. The study also offers valuable quantitative insights for scholars interested in conducting future research in this direction. Given the rapid development of STEM education, researchers frequently report on specific cases, making this analysis particularly valuable for closely monitoring developments in this field. Regular bibliographic analyses should be conducted to stay abreast of the rapidly evolving nature of STEM education research.

Limitations

This study has several limitations previously addressed in the literature (Ha et al., 2020; Huong et al., 2021). First, using only bibliographic data from Scopus database may result in a limited representation of publications in the STEM education field. Second, although we manually filtered irrelevant papers in various Scopus categories, our filtering process may require further improvement, which could lead to omissions. Thirdly, certain crucial pieces of information, such as author names and affiliations, necessitate standardization within Scopus database. As the manual correction is not feasible, this limitation could impact our findings since the accuracy of our analyses relies on the quality of the input information imported from Scopus database. Fourth, some types of analyses, such as gender-based statistics of scholars, could not be performed in this study due to the technical limitations of the Biblioshiny and VOSviewer tools.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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