A bibliometric analysis of the global landscape on STEM education (2004-2021): towards global distribution, subject integration, and research trends

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Abstract

Purpose – This study aims to provide a comprehensive review and bibliometric analysis of the literature in the field of science, technology, engineering and mathematics (STEM) education over the past 15 years, with a specific focus on global distribution and research trends.

Design/methodology/approach – This study collected 1,718 documents from the Web of Science (WOS) database and analyzed their timeline distribution, geographical distribution, research topics, subject areas, learning stages and citation burst using a bibliometric approach with VOSviewer and Citespace.

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Authors' contributions: ZZ identified research ideas, designed and facilitated this research, wrote the draft and made substantial revisions to this work. WS analyzed the data, wrote the draft and revised the manuscript. ZX designed the research and contributed to data processing including collection, refinement and visualization, provided adequate supervision. SN assisted in analyzing data and revising manuscripts. GY assisted with data collection and provided advice on revisions.

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Findings – Results indicated that: overall, STEM education has increasingly gained scholarly attention and is developing diversely by emphasizing interdisciplinary, cross-domain and regional collaboration. In terms of global collaboration, a collaborative network with the USA in the center is gradually expanding to a global scope. In terms of research themes, four key topics can be outlined including educational equity, pedagogy, empirical effects and career development. Social, cultural and economic factors influence the way STEM education is implemented across different countries. The developed Western countries highlighted educational equity and disciplinary integration, while the developing countries tend to focus more on pedagogical practices. As for research trends, eastern countries are emphasizing humanistic leadership and cultural integration in STEM education; in terms of teachers' professional development, teachers' abilities of interdisciplinary integration, technology adoption and pedagogy application are of the greatest importance. With regards to pedagogy, the main focus is for developing students' higher-order abilities. In terms of education equity, issues of gender and ethnicity were still the hottest topics, while the unbalanced development of STEM education across regions needs further research.

Originality/value – This study provides a global landscape of STEM education along the timeline, which illustrates the yearly progressive development of STEM education and indicates the future trends.

Keywords STEM education, STEAM education, Bibliometrics, VOSviewer, Citespace

Paper type Literature review

1. Introduction

In recent years, the global education community has attached great importance to science, technology, engineering and mathematics (STEM) education since it was proposed. For example, in the USA, the clear and systematic STEM education policies and strategies promoted have become a model for the other countries (Chen *et al.*, 2017). In the UK, STEM education is also at the forefront of the field, with the government establishing the National STEM Strategy Group, which placed a high priority on training a comprehensive workforce with STEM skills (Livingstone and Hope, 2011). Australia has shifted from implementing STEM education at the state level to implementing a national strategy promoting STEM education at four levels: national policy, social participation, resource integration and teacher training (Frieze and Quesenberry, 2015). In China, STEM education focuses primarily on K-12 education, integrating multidisciplines and exploring localized implementation (Liang *et al.*, 2017).

A variety of policies have been introduced to promote STEM education. Originated from the USA, the report of "Undergraduate Science, Mathematics and Engineering Education" issued by the National Academy of Sciences in 1986, was regarded as a milestone in STEM education. The primary reason for the birth of STEM education was an awareness of the lack of scientific and technological talent and the weak rise of the manufacturing industry in the USA (Yang *et al.*, 2020). In 1996, the National Science Foundation released "Shaping the Future: Strategies for Revitalizing Undergraduate Education," which summarized STEM education conducted over the previous 10 years, and a new effort to promote interdisciplinary science education was launched in 2001 (Ramaley, 2007). In 2007, the National Science Committee published "A National Action Plan for Addressing the Critical Needs of the US Science, Technology, Engineering and Mathematics Education System." This expanded STEM education beyond the undergraduate level to include elementary schools. In 2013, US President Barack Obama promoted the federal government's "Federal Science, Technology, Engineering and Mathematics (STEM education 5-Year Strategic Plan)." A more systematic and comprehensive blueprint was thus formed for STEM education implementation. In 2015, New Media Consortium and EDUCAUSE Learning Initiative jointly released the "Horizon Report: 2015 K-12 Edition," which mentioned the application of STEAM education and added "A" (Arts) to STEM. In 2016, "STEM 2026: A Vision for Innovation in STEM education" was released (Tanenbaum, 2016). This report outlined the directions and challenges of STEM education for the next decade and offered suggestions for future development.

As can be seen, globally, STEM education has become a major trend in many countries all around the world. For example, in the UK, STEM education has penetrated into all stages of the education system and is developing at a fast speed. In Germany, the needs of industrial development guide the implementation of the STEM education strategy, which highlights the employment-oriented education goals and emphasizes the practicality of teaching. In Australia, the core goal of STEM education in is to cultivate students' interest in STEM subjects and encourage them to pursue deeper research or engage in STEM-related careers (Australian Government Department of Education and Training, 2015). In China, scholars pay most attention on the integration of multidisciplines in K-12 STEM education and were committed to exploring the localization development of STEM education suitable for the country (Li and Huang, 2018).

Numerous studies have been published in various international journals. It would therefore be beneficial to conduct a systematic bibliometric analysis of the global research in STEM education from the beginning of publication to 2021 with a focus on the global distribution and development, as well as to sort out the major trends in the field. Specifically, this paper would try to answer the following seven research questions:

RQ1. How is the timeline distribution (growth rate) of publication in STEM education?

RQ2. What is the geographical distribution (countries involved) of publication in STEM education?

RQ3. What are the research topics most frequently mentioned by authors in STEM education research?

RQ4. Is there any difference in research topics across different countries?

RQ5. How do the subject areas integrated in STEM education?

RQ6. Is there any difference existing in research topics related to K-12 and higher education?

RQ7. What is the strongest citation burst in STEM education research?

2. Methods

2.1 Keyword search

A keyword search was conducted on July 23, 2021. Papers related to STEM education were retrieved from the WOS Core Collection. The searched query was TS = ("STEM education" OR "STEAM education") from inception (TS is a combination field, the search results will be matched in title, abstract, author, keywords), which yielded a total of 99,623 publications. Various indexes were used (such as Science citation index expanded, Social Sciences citation index and Arts & Humanities citation index). This volume of documents was further refined by limiting the search to the WOS categories focused on the educational field (education educational research, psychology education, education special, education scientific disciplines), leaving 12,784 publications. After filtering the document types into articles and review articles, 8,243 publications were left. Additionally, we removed duplicates, poorly indexed documents and documents that did not consistent with STEM Education/STEAM Education research, reducing the number of publications to 1,718 (poorly indexed documents are those where, although STEM education appears in the title, abstract, keywords (author keyword, keyword plus) and other fields, the document is actually not correspond to the documents needed for this study). Each bibliography entry includes author, institution, abstract, WOS category, research topics, publication year, issue (volume) and references.

2.2 Research process

To provide a complete sample of scientific production within the current literature and to identify the trends in STEM education, WOS was chosen as a desirable database because of its high scientific impact the diversity of journals and the wide coverage of themes (Martin-Paez *et al.*, 2019). Then, according to a previous study (Zhao and Strotmann, 2015), the following steps were adopted for data analysis.

Step 1. Data collection. The syntax of the search criteria implemented corresponds to the following research terms: "STEM education" and "STEAM education." The search was carried out on the field "topic," as it is the widest offered by the database and searches for these terms in the title, abstract, authors keywords and keywords Plus. No filters were applied by date or document type, so all available bibliographies in the WOS related to the term were included in the database. The scope of the literature and the specific search format is described in Section 2.1 (keyword search). The result of this search generated a data set of 1,718 documents, ranging from 2004 to July 23, 2021.

Step 2. Data standardization. Some areas are not standardized and may affect the reliability of the analysis, such as variations in the nomenclature of one author being interpreted as two independent authors; some differences in the definition of keywords with the same paraphrase by different authors; statistics and collaboration indices of the number of multi-author collaborations and single-author publications. Given the large sample size, it was necessary to conduct the data analysis with the support of the open-source module Pandas, Version 3.3, which standardized the WOS literature data through a data science approach. This process yielded the table of calculation results in the study.

Step 3. Construction of a synonym data thesaurus library. Given the expansion of the analyzed sample, this study constructed a dictionary of synonyms for correlation of the data, which allowed us to select the nodes with a high number of occurrences in the corresponding analysis, determining the optimal number of occurrences to align as much information as possible through a correct map visualization.

Step 4. Information extraction. The purpose of information extraction was twofold – first to conduct a descriptive study of the sample, including the historical evolution of scientific production in "STEM education," as well as the typology of records and the distribution of thematic categories by WOS. Second, performing a bibliometric analysis allowed us to understand the links among keywords, authors, the research networks of thematic clusters and the evolutionary trends of research hotspots.

Step 5. Data visualization. Visualization of bibliometric and sociometric networks usually adopted the following approaches: distance-based, graphical and time-based methods (Van Eck and Waltman, 2014). VOSviewer (Version 1.6.17) was used to analyze the global distribution, author collaboration and thematic cluster analysis. As a compliment for timeline dynamic analysis, CiteSpace (Version 5.8.R3) was used to analyze the process of topic evolution, knowledge structure, hot topics and development trends and to visualize the dynamic multidimensional network and the corresponding knowledge map. The distance and associative power were used to approximate nodes with smaller geodesic distances indicating the similarity of the two nodes. For the calculation of the network, the input is a normalized covariance matrix on which the correlation power index or proximity index is calculated based on the cooccurrence variables between nodes. The research process and core output are demonstrated in Figure 1.

3. Results

3.1 Timeline distribution

Figures 2 and 3 illustrate the timeline distribution of publications and citations from 2004 to (July) 2021. As can be seen, the growth of publications was generally consistent with the citations trend and is represented as two stages (i.e. slow growth and rapid growth), and the cutoff point is the year 2015. The first stage (from 2004 to 2015) started from the initial appearance of the term "STEM education" in the field; the number of publications slowly increased, at a rate of less than 100 per year; the citations were fewer than 1,000. In the second stage (from 2015 to 2021), the number of publications grew rapidly, then reached a peak of more than 400 in 2020; the number of citations increased significantly and exceeded

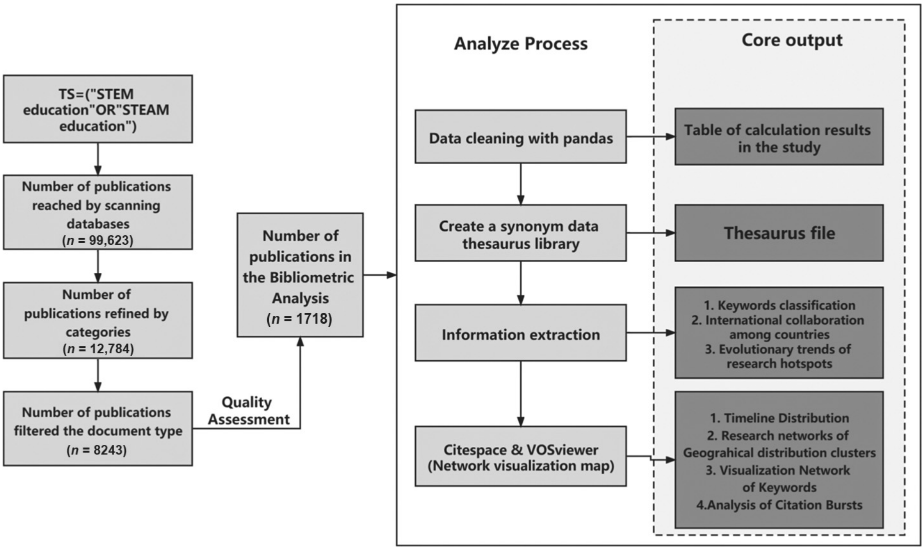


Figure 1.
Research process and core output

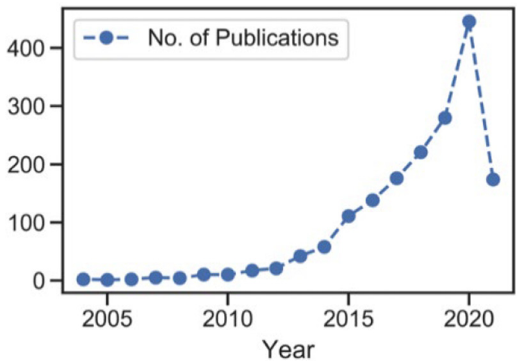


Figure 2.
Publication distribution from 2004 to 2021

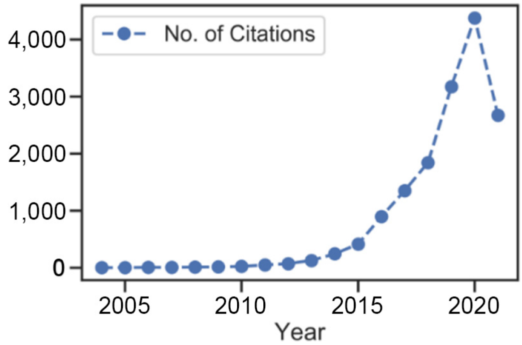


Figure 3.
Citations distribution from 2004 to 2021

3,000 by 2018, and in 2020, citations increased to over 4,000. As the data in this study covers the period up to July 2021, the number of STEM Education research publications and citations is expected to remain at a higher level in 2021.

3.2 Geographical distribution

Table 1 lists 12 countries with the most publications from 2004 to 2021. Concerning global distribution, authors from the USA have 974publications in this field, which have been cited 11,611 times. The total link strength is 1,014, ranking first in the world, accounting for 56.794% of the 1,718 publications collected in this study and each indicator is far ahead of the other countries. China, Australia and Turkey, ranked second, third and fourth place, respectively, in terms of the number of publications, but the citation frequency of the three countries differs greatly. Citation frequency is one of the commonly used indicators to measure the influence of research. Australian publications were cited 949 times, while those from China and Turkey had only 612 and 371 citations, respectively, indicating that although these two countries have among the highest number of STEM education publications internationally, there is still a gap in terms of their influence. It is noteworthy that although there were only 61 publications by authors from the UK, accounting for a

Table 1.
Countries with the most publications in the field of STEM education (2004–2021)

Rank	Countries/Regions	Articles	% $N = 1{,}718$	Citations	Total link strength
1	The USA	974	56.69	11,611	1,014
2	China	110	6.4	612	493
3	Australia	86	5.01	949	322
4	Turkey	80	4.66	371	251
5	The UK	76	4.42	799	175
6	Spain	65	3.78	418	232
7	Canada	56	3.26	298	151
8	Malaysia	36	2.1	145	76
9	South Korea	32	1.86	228	77
10	Germany	27	1.57	221	66
11	Greece	26	1.51	91	68
12	Russia	19	1.11	38	30
13	Sweden	17	0.99	83	45

small proportion of total publications, the citation frequency was 799, indicating that their research is widely recognized internationally.

Figure 4 shows a network visualization map of international collaboration among countries. The connection between each point represents the cooperation among countries in STEM education research and the frequency and thickness of the connection reflect the range and intensity of various degrees. In terms of connectivity, there are dense connections between nodes in all countries, indicating that there is a largely cooperative relationship among countries in STEM education. As can be seen from the figure, the USA is at the center of a collaborative network and has close ties with many other countries, some of which are increasingly active in STEM education.

Figure 5 shows the geographic distribution heat map for STEM education publications, revealing the distribution of the top 10 countries by annual publication volume. As can be seen, as the birthplace of STEM education, authors from the USA had 13 publications in 2011; then, the annual number showed a slight increase from 2011 to 2014, followed by a large increment annually since 2014. After 2018, the annual output of more than 130 publications has been maintained (although the data for 2021 is incomplete). Among the earliest countries to participate in STEM education, Australia, the UK and Germany started their research in 2011. However, it is noteworthy that after a few STEM education publications from the UK in the early stage, there was a gap between 2012 and 2014. After

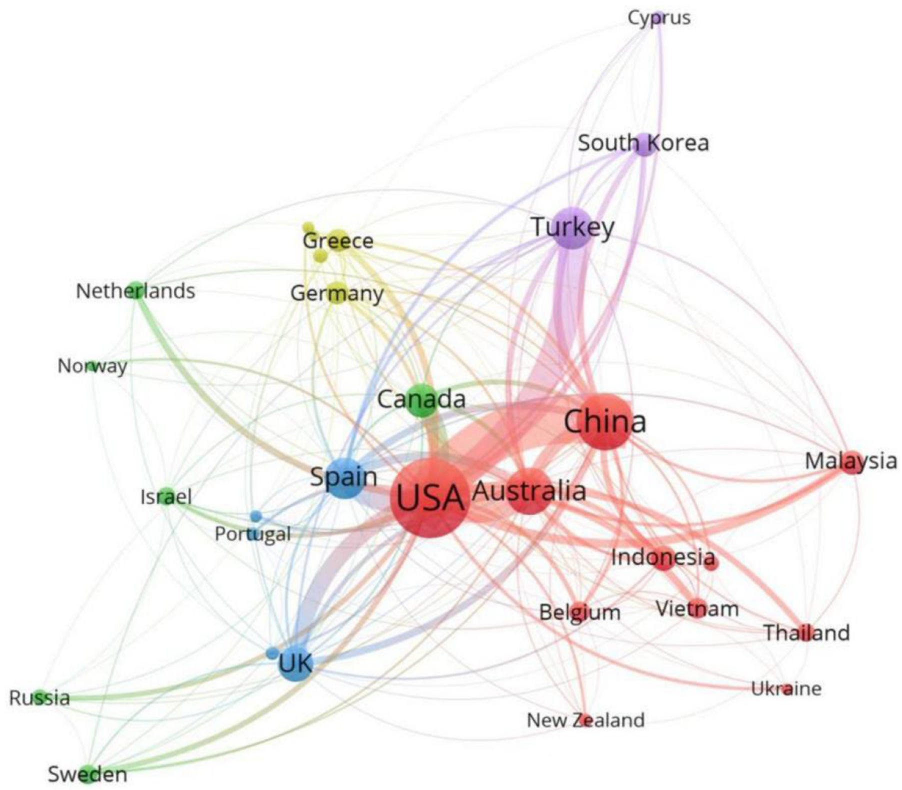


Figure 4. Network visualization map of international collaboration among countries

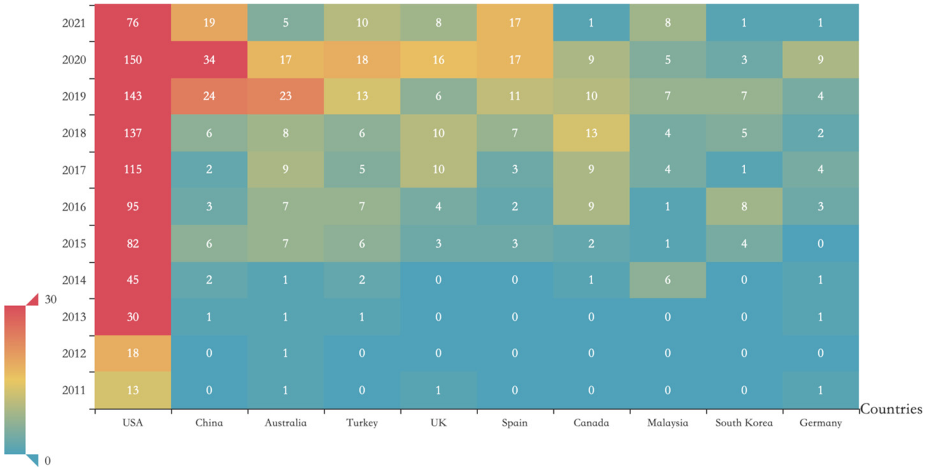


Figure 5. Geographical distribution of publications on STEM education (heatmap)

2013, China, Turkey, Malaysia, Canada and other countries have successively produced relevant researches. The number of literatures in China has a most rapid growth trend, and the annual distribution is second only to the USA since 2019.

3.3 Research topics analysis

Keywords represent the core topics of publications and were analyzed to identify important research themes. Keyword cooccurrence analysis can identify what words appear more frequently in publications about STEM education and which terms link the themes in the field more strongly. Figure 6 shows the network visualization map of research topics in STEM education. Four distinct clusters are depicted in different colors, including educational equity and STEM diversity (in green), career development (in yellow), pedagogy (in red) and empirical effects (in blue).

3.4 Research topics across different countries

A comparative analysis of the keyword occurrences in STEM countries found strong commonalities in the focus on STEM student engagement across countries, but there are still significant differences in the emphasis on policy and practice. This also makes the clustering maps of research topics distribution in various countries show significantly varying focus and clustering trends, from which we can summarize the differences in STEM education between countries. Our analysis focused on the top six countries with the most publications in STEM education in Figure 7.

3.5 Subject area analysis

Figures 8 and 9 show the evolution of the subject area in STEM education. It illustrates the disciplinary trend of STEM education from its origin to diversified expansion. The first stage was from 2004–2007, when the earliest STEM research focused on educational research. This is the beginning stage of STEM education, guided by policy and societal needs and the attempts at STEM education began in higher education in the USA.

The second stage was from 2008 to 2012; the interdisciplinary integration of STEM education became the focus. In addition to the four disciplines of science, technology,

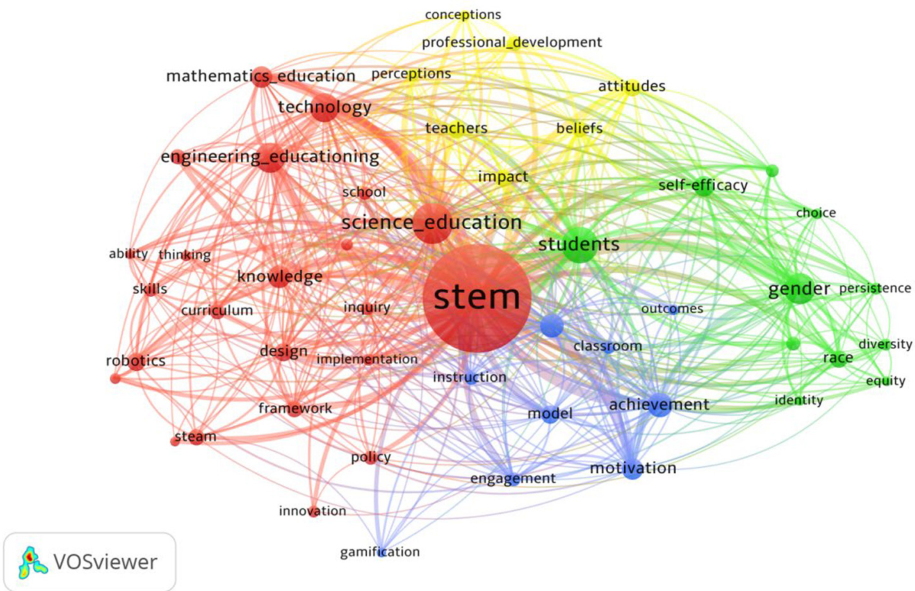


Figure 6.
Network visualization map of research topics in STEM education

engineering and mathematics, the influence of other disciplines on STEM education began to be explored, including biology, green and sustainable science, robotics, social sciences and multidisciplinary chemistry.

The third stage was from 2013 to 2017; the third stage focused on integrating environmental studies, computer science, business and economics, interdisciplinary applications, multidisciplinary sciences, experimental psychology and other subject areas with STEM education.

The fourth stage is from 2018 to the present. As well as continuing to focus on disciplines with an established research basis, such as computer science and multidisciplinary sciences, new technologies provide opportunities for multidisciplinary integration of STEM education.

In general, the evolution of research themes in STEM education can be summarized as follows: participating disciplines are increasing and disciplinary development and STEM education are mutually reinforcing; focus on combining knowledge from several disciplines with consideration of the holistic development of humanity and concern about student learning; technological advances are spurring STEM education growth.

3.6 Learning stage analysis

Table 2 shows the differences among the focus areas and research topics of STEM education from the perspective of learning stages, which are roughly divided into two stages, one for K-12 (total), including the stages of K-12, elementary school, secondary school and high school and the other for higher education. There are certain commonalities and differences in the research topics and areas covered by these two stages. Concerns of STEM education at both stages include pedagogy, professional development, equity and effect. However, differences exist in the focus of STEM education research in K-12 and higher education because of the diversity of teaching targets and goals.

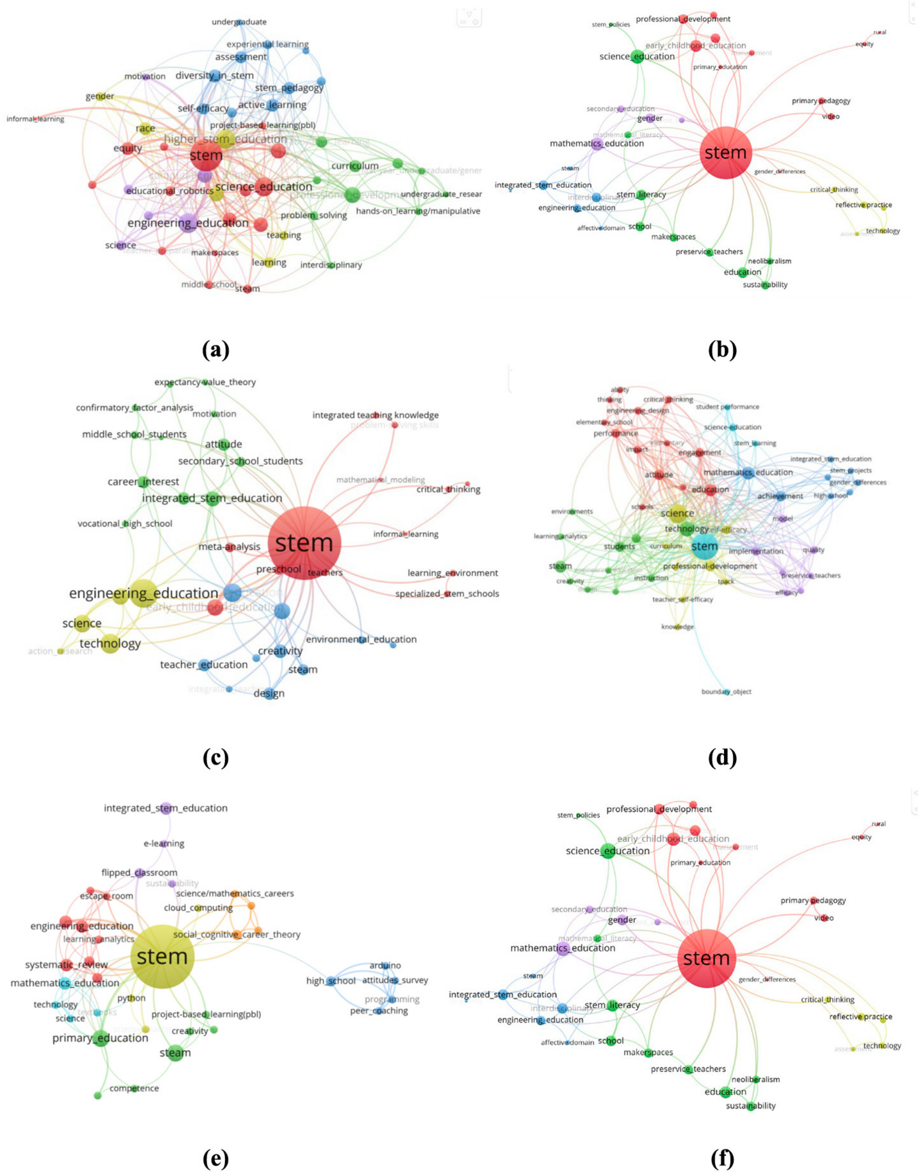


Figure 7. Network visualization map of research topics in STEM education across different countries

Notes: (a) USA; (b) Australia; (c) Turkey; (d) China; (e) Spain; (f) UK

3.7 Research trends analysis

Figure 12 shows the temporal variation of the research topics, and Figure 13 shows the top 25 most cited keywords. With emerging word measurement techniques, we can grasp the frontiers of STEM Education through short-term surges in new words or significant

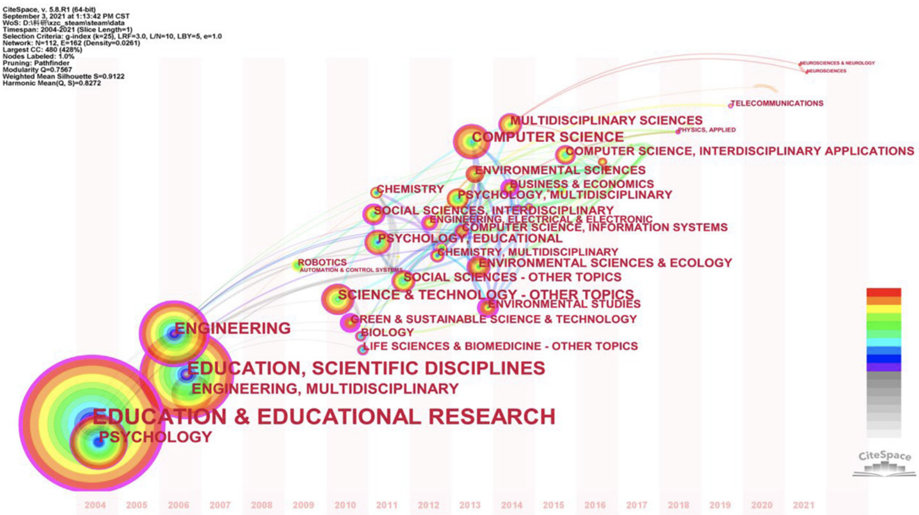


Figure 8. Evolution trend of STEM education in discipline categories

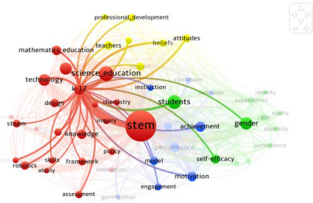
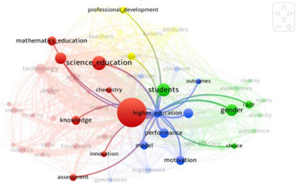
Top 18 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2004 - 2021
PSYCHOLOGY, DEVELOPMENTAL	2004	1.82	**2004**	2013	
ENGINEERING, MULTIDISCIPLINARY	2004	2.08	**2006**	2011	
ENGINEERING	2004	1.61	**2006**	2013	
BIOLOGY	2004	5.72	**2010**	2015	
LIFE SCIENCES & BIOMEDICINE - OTHER TOPICS	2004	5.72	**2010**	2015	
CHEMISTRY	2004	2.57	**2011**	2014	
PSYCHOLOGY, EDUCATIONAL	2004	2.19	**2011**	2016	
ENGINEERING, AEROSPACE	2004	1.88	**2011**	2013	
PSYCHOLOGY	2004	2.68	**2012**	2013	
ENGINEERING, ELECTRICAL & ELECTRONIC	2004	2.41	**2012**	2014	
URBAN STUDIES	2004	1.8	**2012**	2014	
PSYCHOLOGY, MULTIDISCIPLINARY	2004	4.65	**2013**	2018	
CHEMISTRY, MULTIDISCIPLINARY	2004	2.28	**2014**	2016	
COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIONS	2004	3.42	**2015**	2016	
SOCIAL SCIENCES - OTHER TOPICS	2004	2.75	**2015**	2017	
PSYCHOLOGY, EXPERIMENTAL	2004	4.17	**2016**	2017	
COMPUTER SCIENCE	2004	2.82	**2019**	2021	
MULTIDISCIPLINARY SCIENCES	2004	2.6	**2019**	2021	

Figure 9. Top 18 keywords with the strongest citation bursts in discipline categories

changes in word frequency dynamics over time. As can be seen from the figure, keywords with strength >4 include minority, race, inquiry, policy, program and gamification, demonstrating that they have attracted more attention in the recent past. The duration of each keyword varied, indicating that the breadth and depth of discussion varied according to the research topics. Words such as women (2011–2016), sex difference (2012–2017), minority (2013–2018) and inquiry (2016–2019), are biased to explore the problems in STEM

Table 2.
Distribution of STEM research topics in K-12 and higher education

Period		Occurrences		Related keywords	Visual figure
K-12(total)	K-12	36	129	professional development, beliefs, virtual reality, design, inquiry, perceptions, stem, achievement, science education, problem-solving, curriculum, mathematics education, robotics, race, skills, motivation, Engineering education, assessment, computational thinking	**Figure 10.** STEM education keywords in K-12(total) 
	Elementary school	29		conceptions, efficacy, professional development, attitudes, implementation, teachers, beliefs, literacy, knowledge, impact, inquiry, perceptions, engagement, stem, achievement, ability, thinking, curriculum, steam, robotics, engineering education	
	Secondary school	26		attitudes, beliefs, impact, design, perceptions, stem, gender, participation, choice, mathematics education, motivation, self-efficacy	
	High school	38		Attitudes, design, impact, perceptions, engagement, model, achievement, retention, gender, race, identity, stem, science education, robotics, experiences, elf-efficacy, motivation	
Higher education		146		professional development, classroom, pedagogy, meta-analysis, active learning, impact, design, model, outcomes, predictors, achievement, gender, diversity, race, choice, equity, mathematics education, science education, stem, engineering education, assessment, motivation, self-efficacy, experiences, innovation, entrepreneurship	**Figure 11.** STEM education keywords in Higher Eduction 

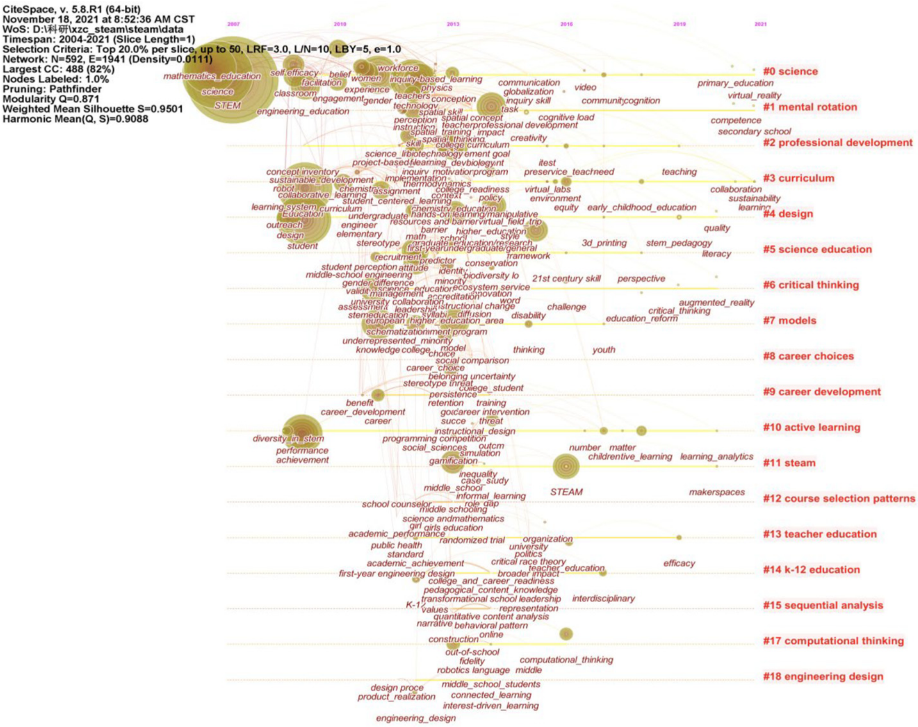


Figure 12.
Timeline visualization of research topics

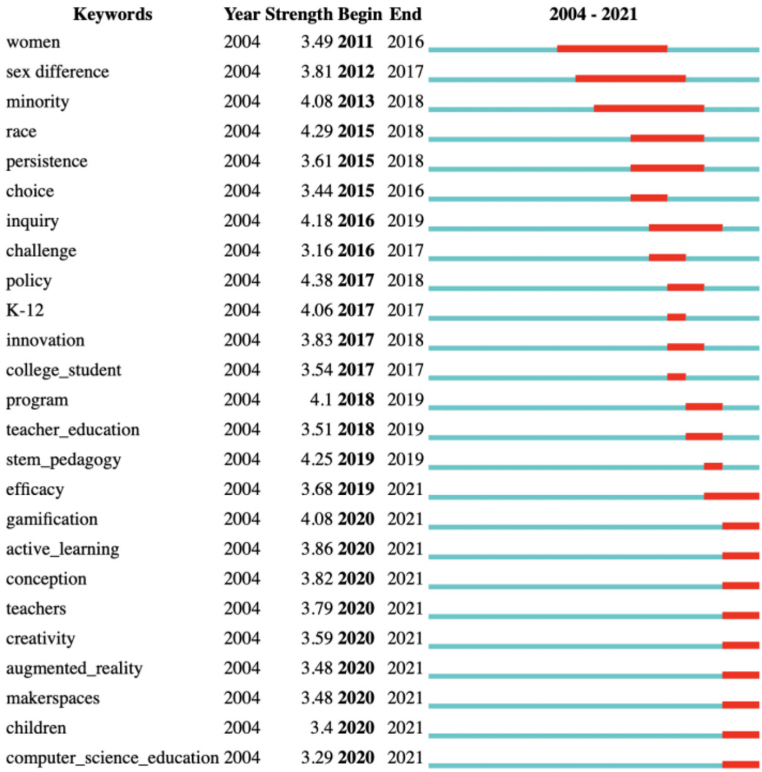


Figure 13.
Top 25 keywords with the strongest citation bursts

education at a macro level that lasted for a longer time. Some burst cycles are short, such as K-12 (2017) and college students (2017), reflecting the focus and development of STEM education during different learning stages in 2017. In general, we can divide STEM education into three evolutionary stages based on the burst keywords.

4. Discussion

4.1 Timeline distribution

With respect to *RQ1* on the timeline distribution of STEM educational research, we found an exponential increase in the growth rate since it emerged. During the first period of its promotion and development (2004–2015), STEM education research was growing at a slow increase rate. Then, both publication and citations grew rapidly since countries gradually implemented STEM education policies (2015 to present). It is revealed that the growth rate of publications tended to be stable and maintained a positive trend, while the development of STEM education was not straightforward. After being proposed, the growth rate of STEM education was limited initially from 2004 to 2006; it did not begin to receive continuous attention and recognition until 2010. It is evident from the timeline distribution of publications that STEM Education has experienced precipitation and accumulation in the early stages, and that it has sustained attention and development with continual practice and research as time progresses.

An essential factor contributing to the significant changes in 2015–2016 is that numerous countries released relevant national policies to promote the development of STEM education. For example, the USA proposed STEM 2026: A Vision for Innovation in STEM Education (Tanenbaum, 2016); the UK proposed DFE Strategy 2015–2020 World Class Education and Care (Morgan, 2016); Australia proposed National STEM School Education Strategy 2016 – 2026 (Education Council, 2015). These national policies have provided necessary guidance and increased social awareness of STEM education, thus greatly stimulating research on STEM education.

4.2 Geographical distribution

With regard to *RQ2*, according to heat maps and international collaboration network visualization, we found that STEM education publications are widely involved in STEM research across a variety of countries, with the USA leading the way. As the birthplace of STEM education, the USA occupied a central position in the global research network. The number of STEM education publications in the USA is much higher than that of other countries, reflecting its outstanding achievements in STEM education. Because of the gradual implementation of STEM education in the 1980s, the USA has taken STEM education as a national strategy and given sufficient support to it in terms of policy guarantee, social participation, resource integration and talent cultivation (Chen and Buell, 2018). Aside from this, the current STEM education research experience in the USA may also serve as a template for other countries to learn from and implement STEM education.

Besides, the UK, Turkey, Australia and China have also performed actively in the global network, and the development of STEM education research is not regionally homogeneous. The UK is one of the earliest countries to start STEM education after the USA. After a brief stagnation in development, the British Ministry of Education issued the DfE Strategy 2015–2020 World-Class Education and Care, in which the quality of the STEM curriculum was explicitly emphasized to help the UK develop as a country with a high-quality education system; the literature related to STEM education then resurfaced (Morgan, 2016). The early research on STEM education in Australia was also limited, and it was not until 2015 that more publications were generated, but still with limited quantity.

Turkey and China started STEM-related research in 2013, and the number of publications exhibited a slight increase annually. Taiwan district was the first to explore STEM education in China, and relevant policies were analyzed to study students' participation in STEM in different levels of education, and strategies for promoting STEM were discussed (Gao, 2013). To meet the needs of scientific and technological innovation and industrial development of talent demands, China promoted STEM education as an important national strategy, issued a series of policies to promote STEM education in an all-round way. China's investment in STEM research continued to increase, and the number of published documents from 2019 illustrates a significant increase compared with the previous period; it is predicted that investment in STEM education will continue expanding in the near future. On the contrary, the research development of Korea is characterized by a large number of STEM publications at the beginning but with a gentle decline over time.

Overall, the USA cooperated most closely with Australia, Turkey, Spain, China, Canada and the UK which performed actively and contributed to closer international collaboration among other counties. Some countries and regions like Turkey and China have been publishing more publications, but the citation influence of publications remains low. Though STEM education publications are concentrated in the west and developed countries, it is glad to see the eastern and developing countries got started and become more engaged in STEM education research since 2017.

4.3 Research topics analysis

With respect to *RQ3* on analyzing the relevant themes in STEM education research. Other than terms related to STEM Education subject categories like engineering education and science education, the top four most popular research themes were identified as: educational equity, pedagogy, empirical effects and career development.

The theme of educational equity covered keywords such as gender, race, equity, diversity, persistence and choice. Although STEM education started in the USA, the contradiction between the incredible socioeconomic prospects of STEM fields and the disadvantage of women in STEM fields has constrained economically and technologically sustainable development in the country. Researchers have been continuously involved in research related to gender and racial equality to address the social problems in STEM education and industry. Like the intersection of racial power and STEM education themes from the perspective of the racial politics of American STEM education (Vakil and Ayers, 2019), certain ideas are provided in the direction of psychological interventions (Casad *et al.*, 2018), opportunity structures (Lynch *et al.*, 2018) and expanding STEM opportunities to build comprehensive STEM high schools (Means *et al.*, 2016). Research also paid attention to the important role of women in STEM fields and seeks to decipher this dilemma, such as providing space for women of color in STEM higher education (Ong *et al.*, 2018), potential interventions to attract professional women's interest in STEM education (Su and Rounds, 2015), exploring the potential role of parental motivation in increasing girls' motivation for STEM courses (Rozek *et al.*, 2015) and providing role models to inspire girls to pursue STEM careers (Bamberger, 2014). From a diversity perspective, increasing the participation of underrepresented groups in STEM by addressing their educational needs (Allen-Ramdial and Campbell, 2014) and building more inclusive STEM schools (Lynch *et al.*, 2018) are also important directions to increase the participation of different types of workers in STEM fields. Research in this category emphasizes the learning performance and development opportunities for special groups to support higher-level STEM education.

The theme of Pedagogy refers to the integration of emerging technologies in STEM education, such as gamified learning, robotics education, maker education, project-based learning (PBL) and active learning, which also covers the cultivation of thinking skills. First, the goals of STEM education emphasize using emerging technologies (e.g. digital games, robotics and virtual reality) to cultivate students' higher-order abilities (e.g. critical thinking, problem-solving and creativity). For example, researchers established game-based environments (Lester *et al.*, 2014; Zhan *et al.*, 2022c), unplugged teaching aids (Zhan *et al.*, 2022a), virtual simulation platform (Zhan *et al.*, 2022d), aerospace-related games (Peng *et al.*, 2017) to implement STEM instruction and explored how robotics and games can foster STEM attitudes (Leonard *et al.*, 2016). Second, maker education is one of the prevailing teaching methods in STEM, which aims to turn ideas into reality, requiring students to integrate knowledge from multiple disciplines in their projects. For example, combining STEM disciplines with the arts to develop maker centers (Clapp and Jimenez, 2016) and creating maker spaces geared toward STEM education (Sheffield *et al.*, 2017) are major directions for STEM implementation. Third, PBL was regarded as the vehicle or platform for fostering students' STEM competencies. PBL can integrate multiple disciplines effectively, stimulate students' motivation with authentic projects and enhance students' creativity by providing authentic issues of concern (Kuo *et al.*, 2019). Fourth, active learning was also a highly emphasized approach to enhance students' engagement and learning performance (Chen and Buell, 2018) and motivation (Julià and Antolí, 2019). Besides, intelligent technology can also be integrated with active learning to enhance the learning effect in science and engineering (Yannier *et al.*, 2020).

The theme of empirical effects refers to the factors that affect the development of STEM education and how STEM education impacts student learning, including attitude, skills, achievement, motivation and other outcomes. From the perspective of attitude, both teachers' attitudes toward STEM education and students' attitudes toward learning are considered:

- Teachers' attitudes have been explored from a bidirectional perspective, and scholars have also investigated the school environment and personal factors that influence their attitudes (Thibaut *et al.*, 2018), indicating that teachers' attitudes can affect the transformation of STEM education (Besterfield-Sacre *et al.*, 2014).
- Student motivation and attitudes are significant factors that revealed the effectiveness of STEM learning. Therefore, researchers tried to propose an instructional design to foster positive attitudes and intrinsic motivation, such as outreach activities (Vennix *et al.*, 2018), peer tutoring (Martín-Ramos *et al.*, 2017), exploring methods of motivation decline and recovery (Young *et al.*, 2018) and fostering intrinsic motivation in STEM education (Jones *et al.*, 2018).

From the perspective of learning achievement, various studies discussed whether learning achievement corresponds to mastery of competencies (Öner and Capraro, 2016), the role of peers (Thomas and Watters, 2015) and the impact of STEM education on students' academic performance and career interests (Çevik, 2018). From the perspective of thinking cultivation, researchers paid attention to artificial intelligence thinking (How and Hung, 2019), spatial thinking (Janelle *et al.*, 2014), computational thinking (Lee *et al.*, 2020a, 2020b), critical thinking (Pearl *et al.*, 2019), creativity and innovative thinking (Zhan *et al.*, 2022a, 2022b, 2022c, 2022d), etc. STEM education emphasizes a lot on the cultivation of thinking, and its interdisciplinary qualities enable the collaboration of flexible multidisciplinary knowledge so that a variety of thinking skills can be developed.

The theme of Career Development refers to teachers' professional development and students' future career choices. Teachers are required to meet new requirements for comprehensive quality from the perspective of STEM education because of its interdisciplinary and practice-based learning features. Therefore, teacher development research can be categorized into two types:

(1) The first type provides effective conceptual change and instructional guidance for preservice teachers, such as discussions of STEM content and pedagogy (Radloff and Guzey, 2016), experiences that build on specific approaches to teaching practice (Radloff and Guzey, 2017) and using STEM teaching beliefs to enhance preservice teachers' self-efficacy in STEM (Chen *et al.*, 2021).

(2) The second type examines teacher professional development in real-world settings, such as using case studies to investigate how teachers internalize professional development content (Fore *et al.*, 2015), teachers' evolution of the concept of STEM integration influenced by professional development experiences (Ring *et al.*, 2017), integrating theory to propose innovative approaches to teacher education, reciprocal teacher relationships and resource sharing from a common community of teachers (Jho *et al.*, 2016) and the feasibility of researching STEM teacher professional development using the technological pedagogical content knowledge model (Chai, 2019).

Students' future career choices are closely related to STEM education, as STEM education stems from a lack of top talent in the science and engineering fields in many countries. Researchers also provide insights from different perspectives into students' career development, such as exploring variations in career choices between STEM and Non-STEM students (Xu, 2013), correlates of learning choices and career development in STEM fields (Van Tuijl and Van der Molen, 2016) and so on. Furthermore, the combination of gender differences and female perspectives in STEM career choices remains a current research trend. For example, Wegemer and Eccles (2019) analyzed the impression factors of STEM career trajectories based on gender differences in STEM discipline choices, while Xu (2017) explored the impact of female attrition and gender inequality on STEM career development.

4.4 Research topics across different countries

With respect to RQ4 on research topics among different countries, although global STEM education showed similar trends, diversity existed and the research in different countries was influenced by social, cultural and economic factors. Overall, in Western countries, because of racism and the trend of STEM specialization, special attention is given to educational equity, integration of disciplines and core competencies (Carter *et al.*, 2019; Marginson *et al.*, 2013; Takeuchi *et al.*, 2020). In contrast, researcher studies on STEM education in developing countries are more inclined to discuss the empirical effects (Teo *et al.*, 2021).

Rooted in the realities of racism, class disparity and gender imbalance in STEM education, the USA has a heightened focus on keywords such as gender, race and women with regard to educational equity. The trend of diversity and inclusion in STEM is more generalized with a focus on the implementation of educational equity, which is also found in developed Western countries such as Australia and Spain. In addition, with the shift in the workplace with technological advances, internationalization and economic drivers, STEM education is increasingly concerned with the development of core competencies and interdisciplinary thinking(Freeman *et al.*, 2019) and the keywords such as achievement, integrated stem education and stem literacy are receiving more attention in the USA and Australia. In the study of STEM practices in Spain, pedagogical discussions have been prioritized alongside women's empowerment. A series of experiments have been conducted with a variety of integrated technologies, including educational robotics, flipped classrooms and Arduino (Freeman *et al.*, 2019).

In contrast, countries such as China and Turkey pay more attention to the STEM effect, and keywords such as attitude, professional development and conception appear more frequently. Educators in China are constantly exploring the local paths to improve the effectiveness of teaching and the recognition of STEM education(Freeman *et al.*, 2019). In Turkey, STEM education aims to foster students' interest in STEM fields(Akgunduz, 2016), which is why it focuses on enhancing the STEM effect and creating a STEM-oriented workforce. In the UK, the two main goals of STEM education are to get qualified people into the STEM workforce and STEM literacy for the general population(Skills, 2006). Currently, the UK is noted for being one of the best countries for science and mathematics education in the world, which enables students to study STEM courses and foster their creativity, problem-solving capabilities and technical skills. Thus, keywords related to the STEM effect, such as design and technology, STEM careers and creativity, are common (Freeman *et al.*, 2019).

4.5 Subject area analysis

With respect to *RQ5* on the subject areas integration trend in STEM education, as shown in Figures 8 and 9, the earliest STEM research focused on Educational Research, such as the accessibility of the STEM pipeline, the level of broad-based interdisciplinary publications (Van Langen and Dekkers, 2005), the role of real-time interactive teaching and interdisciplinary applications (Kahveci, 2004), as well as exploring the broad array of explanations for the absence of women in STEM (Blickenstaff, 2005). Several factors contribute to this, including international economic ambitions plus acute shortages on the STEM labor market, declining interest among students and long-lasting under-representation of women (Jordan and Yeomans, 2003).

From 2006 to 2007, the focus of research in STEM slowly shifted from educational disciplines to developing integration between engineering and science. In the category of scientific disciplines, which includes a focus on preparing students for careers in science and engineering through diverse education resources (Dudas and Su, 2007). STEM education is inextricably linked to science education, while engineering design was also emphasized. Research during this period integrated the engineering design process and innovative approaches to transfer theory to engineering applications (Kezerashvili *et al.*, 2007) and using product development methods to promote fundamental engineering learning (Kline *et al.*, 2006). Rapid advances in technology and the movement toward a global economy have increased the importance of knowledge in general and in science and mathematics specifically (Friedman, 2005). Science and mathematics course-taking is a key component on the pathway toward STEM careers (Tyson *et al.*, 2007). There appears to be a decline in technology and engineering education in secondary schools, so STEM education is one way to integrate these disciplines into the classroom.

From 2008 to 2012, the interdisciplinary integration of STEM education became the focus. Although the STEM acronym is coined up as the first letters of Science, Technology, Engineering and Mathematics (Jayarajah *et al.*, 2014), several researchers believed that STEM covers a larger and more comprehensive understanding than these individual disciplines. There is much more to STEM education than merely integrating four disciplines, but instead involving "real-world, problem-based learning" that brings disciplines together in a cohesive and active manner (STEM Task Force Report, 2014). Examples include the integration of biology (Dutnall *et al.*, 2013; Riechert and Post, 2010), sustainability (Hopkinson and James, 2010; Massa *et al.*, 2011); climate change (Gieskes *et al.*, 2010); chemistry (Ashe *et al.*, 2012; Latch *et al.*, 2011), electrical engineering (Cheville, 2012), robotics (Nelson *et al.*, 2012; Saygin *et al.*, 2012), etc. Meanwhile, during this period, the exploration of aerospace, such as the NASA project (Carmen, 2012), school transformations of aerospace engineering (Fairburn, 2011), become popular.

From 2013 to 2017, research continued to focus on integrating green and environmental studies (Sumen and Calisici, 2016; Ismail *et al.*, 2017; Wagner *et al.*, 2017), computer science (August *et al.*, 2015; Potkonjak *et al.*, 2016) and robotics (Kim *et al.*, 2015). As STEM education has developed vigorously, the lack of STEM talent has not been adequately addressed. Researchers increasingly advocate STEAM education, integrating arts and humanities and social sciences into STEM education to improve the integration of science, technology, engineering and mathematics (Liao, 2016; Root-Bernstein, 2015), combining topics such as social sciences, evaluating the relationship between STEM education and economic performance (Greenseid and Lawrenz, 2011; Yu *et al.*, 2012) and looking at social cognitive factors (Soldner *et al.*, 2012) .

From 2018 to the present, intelligence technologies provide new opportunities for multidisciplinary integration of STEM education. As education evolves, traditional teaching pedagogy will be replaced with technology, especially for students entering STEM fields, as they are more likely to engage in advanced technology (Angel, 2012). In a wide range of subject areas, student development levels and educational settings, these new technologies appear to offer extraordinary opportunities for improving student motivation and learning (Petrov and Atanasova, 2020). Examples include telecommunications-related educational activities (Spyropoulou *et al.*, 2020) and Web-based internet of things programs (Cornetta *et al.*, 2019). In this stage, neurosciences and neurology are also increasingly linked to STEM education (Saravanapandian *et al.*, 2019), including training students' brain structures for learning effectiveness (Khan *et al.*, 2021) and integrating neuroscience for the implementation of comprehensive undergraduate STEM education (Basu *et al.*, 2021).

4.6 Learning stage analysis

With respect to *RQ6* on the difference of research topics across learning stages. According to Figure 10 in Table 2, K-12 STEM practices focus more on multidisciplinary integration and keywords tend toward teaching-related content. In the STEM curriculum for teaching impact and facilitation, researchers have focused on integrating technologies such as robotics education and programming (Kopcha *et al.*, 2017), digital resources (Flemming *et al.*, 2020) and virtual reality (Huang, 2019). Other perspectives include integrating thinking training with K-12 STEM education (Lee *et al.*, 2020a, 2020b), exploring educational assessment methods for the impact of STEM teaching (Saxton *et al.*, 2014) and examining student participation (Herro *et al.*, 2017). As a whole, STEM education at the K-12 stage focuses more on pedagogical-related research, exploring what teaching strategies and pedagogical approaches can facilitate the effective implementation of STEM curricula.

According to Figure 11 in Table 2, STEM education at the high education stage covers a wide range of science and technology disciplines such as engineering, biological sciences, mathematics, physics, computer science and aerospace. Since higher education is oriented toward careers, STEM education is primarily focused on cultivating the STEM knowledge, literacy and entrepreneurship that are needed for entering the workforce and becoming STEM professionals who can adapt to society's development through a high-quality curriculum. Compared to K-12, STEM education research at higher education is more concerned with promoting student motivation (Young *et al.*, 2018) and curriculum sustainability (Suh and Han, 2019). Meanwhile, designing STEM education within the future career formation, concern about the position of STEM talent in the labor market (Kersanszki and Nadai, 2020), and the attrition of STEM majors (Shmeleva and Froumin, 2020) have been discussed. The incorporation of technology is also more relevant for advanced learning resources in universities, such as the design of game-based STEM activities in virtual worlds. Furthermore, it involves the establishment of links with outside classroom learning, such as field trials (Nepeina *et al.*, 2020) and industrial visits (González-Peña *et al.*, 2021). Career orientation is also more prominent at this stage, with researchers focusing on STEM graduates' career goals (Smith and White, 2017) and career preparation (Rezayat and Sheu, 2020) from the reality of a shortage of highly skilled workers.

4.7 Research trends analysis

With respect to *RQ7* on the strongest citation burst of global publications. Words with strength greater than 4 include Policy (4.38), Race (4.29), stem pedagogy (4.25), inquiry (4.18), program (4.1), gamification (4.08) and K-12 (4.06). Burst keywords vary in duration, with some occurring within a year or two (i.e Policy, stem pedagogy, program, k-12), indicating concentrated attention on the topic; keywords that have a longer burst stage (i.e race, inquiry and gamification), demonstrating the sustainability of such themes in STEM education and widespread interest from researchers. Among the keywords that burst in 2020, more focus was on pedagogy (i.e. augmented reality, maker spaces and active learning). The focus and evolutionary trends of each stage can be discerned from this.

Within the stage from 2011 to 2015, participation of specific groups in STEM education is focused and a significant outbreak of women, sex differences, minorities and race can be noted in the burst words map, which is maintained through time. It concentrates on the potential for women(3.49) to enter STEM fields and break through the stereotypes generated by the sex difference(3.81). In addition, burst words such as minority(4.08) and race(4.29), with intensity over 4, indicate a concern with inclusion, and the need to value the engagement of students of all races and ethnicities in STEM. For example, researchers have discussed how to increase the persistence of female and minority students in STEM (Griffith, 2010), the threat of gender stereotypes in racial diversity to STEM students (Cromley *et al.*, 2013), the influence of college experience and institutional settings on undergraduate women of color in STEM majors (Espinosa, 2011) and female representation in STEM careers (Xu, 2015).

Meanwhile, the high-tech talent shortage and the demands of social and economic development raise the need for the cultivation of scientific and innovative talent in higher education. Thus, encourage researchers to pay attention to career development, choices (3.44) and persistence (3.61) in STEM education. The research includes an overview of the relationship between learning choice and career development(Van Tuijl and Van der Molen, 2016), factors influencing persistence in professional fields and career choices and enhancing students' STEM persistence(Graham, 2021), among others.

Between 2015 and 2019, social practices of rewarding STEM education proposers and implementers have increased and governments have developed policies to facilitate STEM education. Policy implementation led to the burst of inquiry (4.18), policy (4.38) and challenge (3.16), which researchers have actively discussed as a theoretical aspect of STEM education. Research including experiments and evaluations of inquiry-based methods in STEM education (Psycharis, 2016), the interaction between creativity and motivation and inquiry-based learning (Conradty *et al.*, 2020) challenge the thinking methods required for STEM education.

Practicing and developing STEM subjects has led researchers to conclude that STEM education should begin at an early age. A critical period of STEM education exploration requires not only integrating STEM education into K-12 (4.06) education but also understanding STEM education in K-12 (Holmlund *et al.*, 2018*)*. Additionally, this stage of STEM education also focuses on the development of college students (3.54) in STEM within a short period of burst, such as analyzing the relationship between high school learning experiences and the selection of STEM majors in college (Sahin *et al.*, 2014), examining STEM education reform at the college level (Kezar *et al.*, 2015). K-12 and college integration of STEM education is on the rise, and at the practical level, it entails the implementation of teaching activities involving programs (4.1). This involves exploring how afterschool STEM programs foster motivation (Chittum *et al.*, 2017) and the analysis and comparison of STEM outreach programs (Sadler *et al.*, 2018).

The third period is 2019–2021, which includes a focus on how new technologies can lead to new possibilities for STEM education. Figure 8 illustrates virtual reality, augmented reality(3.48) and gamification(4.08) are emerging at this stage, repositioning schools with the help of emerging technologies and tools, ensuring that curriculum content is relevant to modern industries and promoting innovation(3.83) and creativity(3.59). This includes the implementation of augmented reality for the acquisition of STEM skills (Ibáñez and Delgado-Kloos, 2018), improving learning motivation(Restivo *et al.*, 2014) and exploring the prospects for its educational application (Kramarenko *et al.*, 2019).

Besides, integrated multidisciplinary knowledge, as well as diverse forms of disciplinary integration, are becoming prominent features of interdisciplinary integration. The concern is growing about integrating computer science education (3.29) and maker spaces (3.48) to develop inquiry activities. Researchers are discussing STEM-driven computer science education in terms of facilitating students' computational thinking (Burbaitė *et al.*, 2018) and how STEM knowledge and skills are developed in maker spaces. As STEM becomes more regularized, teacher education requirements are increasing and educational participants and creators need more input to innovative practices. Teachers must develop not only an integrated view of the curriculum but must also be able to use new technologies effectively for teaching and learning with the development of technology and the continuous integration of disciplines(Kim *et al.*, 2015; Kopcha *et al.*, 2017).

5. Implication

According to the research findings presented in this study, some highlighted trends could be further elaborated. First, the most obvious trend is the rapid development of STEM education all around the world. While countries promote STEM education for various reasons and with different focuses, many countries and regions are emphasized developing STEM education and regard it as an essential component of their talent strategy. The USA is always in the leading position since the initial stage. Since 2015. Australia, Turkey, China and the UK districts started to produce intensive research in this field. Through STEM education, it is hoped to cultivate interdisciplinary talents who meet the requirements of the times, so as to ensure core competitiveness against the background of the knowledge economy and globalization and to prepare for the changes and challenges in the future.

The second trend is characterized by STEM teachers' professional development. Because of the interdisciplinary, innovation-oriented and practice-oriented nature of STEM education, teachers' understanding of STEM, knowledge reserve of relevant disciplines and STEM teaching ability have a profound impact on the effectiveness of STEM teaching. On the one hand, educators and policy developers are pinning their hopes on STEM education to address future social and economic challenges (Margot and Kettler, 2019; English, 2016); on the other hand, teachers' practice and concern for students call for curriculum and teaching reform in STEM education (Wang *et al.*, 2020). For countries such as the USA, UK, Australia and Canada, because of the specialized nature of STEM future careers, cultivating a highly qualified STEM teacher workforce is essential to promoting STEM professional development and ensuring integrated STEM. In eastern countries such as China, South Korea and Singapore, where STEM development started later, they are slowly realizing the importance of STEM teachers and exploring their competence compositions and training paths to lead STEM education. Consistently, STEM teachers' pedagogical knowledge was the major research issue in 2019–2020, as teacher training is essential for preparing teachers to help students to handle problems they may encounter in the future, as well as social and economic development (Marín-Marín *et al.*, 2021). Margot and Kettler (2019). Also claimed that improving the implementation of STEM education for teachers requires peer cooperation, a high-quality curriculum, professional development and other support.

The third trend is characterized by the intelligent technology enhancement in STEM education. Technologies have highly facilitated smart and personalized learning for STEM education research (Uskov *et al.*, 2019). With the gradual deepening of the integration of SMART education and STEM, the trend of cross-regional cooperation with curriculum design and talent cultivation received greater attention. The USA is again the center of the cooperation network and has cooperative relations with most countries, including Australia, Turkey, Spain, China and Canada.

The fourth trend is characterized by a humanistic shift in STEM. Science education needs to be complementary and integrated with humanities education. By integrating art as a flexible and integrated disciplinary element, esthetic creation, humanistic care and social responsibility can be incorporated into scientific and technological innovation while making interdisciplinary learning more engaging and stimulating learners' initiative (Marín-Marín *et al.*, 2021). Numerous STEM education publications emphasize the integration of cultural studies and science education, which also confirms that researchers are gradually becoming more concerned with the integration of culture and STEM education. Compared to the western countries, the eastern countries place greater emphasis on cultural integration and humanistic leadership in STEM education, owing to their deep cultural heritage and commitment to traditional culture. As an example, in Korea, some programs have developed STEAM programs that incorporate traditional Korean instruments and some researchers have included the humanities (i.e. history, geography and bibliography) in the five STEAM subjects (Kim, 2016). In China, some authors proposed C-STEAM (i.e. Cultural STEAM) emphasized applying interdisciplinary knowledge to explore traditional cultures, cultivating students' humanistic spirit and enhancing cultural understanding and heritage, which opens up new possibilities for the localization of STEAM Education (Guan and Zhan, 2021; He *et al.*, 2022; Huo *et al.*, 2020; Wu *et al.*, 2022; Zhan *et al.*, 2020, 2021).

The fifth trend is characterized by the change in pedagogy focus. In terms of content, it concentrates on the use of technology, while in terms of goals, it emphasizes cultivating students' high-level thinking. STEM education aims to cultivate students' key competencies in the process of applying interdisciplinary knowledge to solve real-life problems. The interdisciplinary characteristics of STEM are not simply to combine knowledge of different disciplines into the same theme. Rather, the disciplinary boundaries should be removed, so that we can integrate the knowledge of various disciplines and realize the mutual integration of disciplinary thoughts. Hence, a STEM class should not only teach knowledge and skills but also serve as a student-centered, project-based exploratory adventure, where students can integrate multiple disciplines and gives full play to their autonomy in the practice. Besides, the application of gamified learning and active learning have been attached with great importance. Cho *et al.* (2021) proposed that the use of concept-point-recovery (CPR) pedagogy can improve students' participation, motivation and achievement. Moreover, Leung (2020) proposed an interactive pedagogical framework as a boundary-crossing tool in STEM education. Developed Western countries generally lead the world in both science and technology, as well as creativity and innovation, which has laid a solid foundation for STEM education development under technological integration across various disciplines.

The sixth trend is characterized by educational equity. The issue of educational equity is a common concern in STEM education and the most prominent issue is a gender difference. Women are severely underrepresented in STEM fields and the scarcity of female science and engineering talent has become a global phenomenon. Information in the academic environment devalues women and underrepresented groups in STEM, creating a cold and hostile educational environment (Clark *et al.*, 2021). Therefore, researchers are committed to eliminating the phenomenon that gender is used as the criterion for judging whether to stay in or leave STEM fields and emphasize that men and women should have an equal voice. Besides, race is another issue of STEM education equity, which is largely concentrated in diverse Western countries. At present, ethnic minority groups now make up a growing percentage of the population in many western countries, but their proportion in STEM fields is particularly low and students of color lack a sense of belonging in STEM majors (Rainey *et al.*, 2018). Absorbing students of different ethnic groups into STEM education and increasing their opportunities for STEM careers can lift minority groups out of poverty and improve their income level and social status, which will contribute to racial equality. At the same time, STEM education also differs by region. While wealthy countries are better developed, most regions have not fully implemented the STEM education approach and some regions have not even implemented it at all. The unbalanced development of STEM education among regions is also an important direction for future research.

6. Conclusion

A bibliometric analysis of global research results in STEM education was performed based on literature published through the Web of Science between 2004 and 2021, using preestablished criteria and filtering methods to collect 1718 publications. This paper analyzed the overall volume of publications, illustrated geographical publication distributions and represented the author keyword clusters by co-word analysis, which reflected an overview of global STEM Education research and helped to understand the hotspots and research themes over time.

A macro perspective is taken in this study of STEM education. Based on the analysis of the growth rate of publication, academic activity in STEM education appears to be on the rise, with STEM education research in both developed and developing countries showing great potential for growth. Identifying geographical publication distribution helps identify potential collaboration opportunities among different countries and regions, facilitates knowledge co-authorship and expands academic dissemination. Differences because of different policy orientations, economic bases, social environments and cultural backgrounds may bring conflicts to cooperation, but they may also create STEM education ecologies with different geographical characteristics. It is through the evolution of subject areas that scholars from diverse fields can come together to collaborate and promote the integration of different disciplines. In addition, research differences between the K12 level and higher education provide a basis for the Bridging of Educational Stages. While demonstrating the current situation and development of STEM education in the past 15 years, we also summarize future research directions and characteristics of STEM education so that scholars would understand the research hotspots and determine the subsequent research themes. The knowledge structure provided in this study presents a variety of aspects of STEM Education research that can be a useful base for future research.

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