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An Integrative Review with Word Cloud Analysis of STEM Education

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Abstract
In the twenty-first century, the effectiveness of science, technology, engineering, and mathematics (STEM) courses is an issue of significant concern for educators internationally. This article analyzed STEM articles published in the journals included in PubMed, Scopus, Web of Science (WoS), Embase, CINAHL, and Medline databases from 1999 to 2023 and explored the trends in educational research and educational scientific disciplines. The primary analyses and findings are as follows: (1) the major cooperative institutions identified were Michigan State University; (2) knowledge construction tools, inquiry-based learning, and peer competition or gaming were identified as the top three learning strategies; (3) four keyword clusters covering students, science, literacy, and performance were categorized. These results hold implications for researchers, school district administrators, and policymakers who are endeavoring to introduce STEM education into the curriculum for higher education teachers.

Keywords Education · Educational research · Higher education · Science · Social science

Introduction

STEM education refers to the technical disciplines of science, technology, engineering, and mathematics. STEM is a cross-disciplinary and subject-integrated teaching model (Martín-Páez et al., 2019; Siregar et al., 2019). STEM education originated in 1986 when the National Science Board (NSB) proposed a set of educational proposals integrating science (S), mathematics (M), engineering (E), and technology (T), which was referred to as SMET at the time (Waite & McDonald, 2019). In 1996, the National Science Foundation (NSF) proposed a policy to change the SMET acronym to STEM (Fomunyam, 2020). Bryan and Guzey (2020) later proposed joining cross-domain and cross-cultural cooperation, which has become the goal of today's STEM-based K-12 and higher education curricula. Regarding a country's global competitiveness, Loyalka et al. (2021) proposed that one of the educational goals in the knowledge-based economy era should be to cultivate students with STEM qualities. Loyalka et al. referred to STEM education as an essential element of competitiveness in a globalized world.

The goal of STEM education is to encourage a desire to learn as well as active learning. It differs from traditional teaching as STEM education discourages the one-way, teacher-to-student classroom style. STEM guides students to think critically and combine comprehensive knowledge and skills to solve problems that may occur in the real world (Kennedy & Odell, 2014). According to Martín-Páez et al. (2019), STEM education is an educational approach that aims to address real-life issues through the core activities of engineering design, production, and refinement. This approach integrates science, mathematics, mathematical thinking, technology, tools, and other relevant subjects into an interdisciplinary curriculum and pedagogy with the intent to foster students' interest in STEM subjects and to prepare students to apply modern science and technology to the resolution of practical problems. Additionally, STEM education focuses on diversity across fields, the education of men and women, and equal educational rights across socioeconomic groups (Loyalka et al., 2021). Through STEM education, students can be well prepared to enter the job market, thereby strengthening their international competitiveness.

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With the rapid development of information technology, education has changed from teacher-centered to learner-centered learning (Hsiao et al., 2022). Advances in mobile and wireless communication technologies have also provided learners with new learning possibilities. For example, learners can observe, collect information, and solve problems in real environments with the support of digital systems (Hwang et al., 2020). Additionally, these technologies can promote peer interaction and cross-environmental learning, providing new perspectives and opportunities for STEM activities and research design. Researchers have paid attention to the introduction of digital technology tools into courses and found that these tools can diversify and improve students' STEM learning goals and learning motivation, improve students' knowledge comprehension, and develop students' problem-solving skills (Teasdale et al., 2020). Educators have pointed out that it is challenging for learners to acquire knowledge from different disciplines to solve practical problems when they have not experienced interdisciplinary task training and learning (Loyalka et al., 2021). Additionally, when confronting practical problems, students must learn to use STEM comprehensively and effectively (Kuo et al., 2019). To improve students' international competitiveness, it is necessary to shift away from the traditional approach to education, in which students simply learn and practice by taking individual courses. Instead, students should be encouraged to develop their higher-level thinking skills through multidisciplinary learning experiences. This includes fostering creative thinking, critical thinking, and problem-solving abilities (Fajrina et al., 2020). Hwang et al. (2020) pointed out that STEM activities can be conducted in formal and informal learning environments and target learners across different grades. STEM education enables teachers to help students acquire knowledge and skills from multiple subjects. Teachers can guide students in completing projects through teamwork and show them how to identify and solve problems. Research has revealed that STEM activities that encourage students to explore, communicate, think, and interact can enhance their problem-solving and creative thinking abilities (Kuo et al., 2019).

Teaching different subjects individually can only cultivate students' ability in that subject (Tang & Williams, 2019). Although this subject-based learning can facilitate teachers' teaching and students' learning and allow students to understand the relationship between subjects, knowledge integration is an invisible obstacle to developing students' thinking abilities (Hwang et al., 2020). The ultimate goal of teaching is to foster students' ability to solve problems, which coincides with STEM's interdisciplinary integration (Yahya & Hashim, 2021). Therefore, future courses will focus on the interdisciplinary integration of teaching between different courses. Although researchers have praised STEM research, practical STEM instructional design, implementation, and related explanatory documents and articles are not very common. Designing a multidisciplinary experimental study that incorporates learning strategies to improve student achievement and educational goals in STEM activities is challenging for most educational technology researchers (Siregar et al., 2019). Therefore, by analyzing interdisciplinary STEM-related research in this paper, researchers can explore the potential learning strategies of new topics and interdisciplinary fields. Additionally, this analysis will serve as a reference for subsequent educational researchers for inquiry design.

This literature review has found that past findings are disparate and have made it difficult for educators to decide whether to attempt interdisciplinary STEM education. In addition, an integrative review has been conducted to explore the trends of STEM education. If we can analyze and draw conclusions regarding the global trends in STEM education, it will be easier for researchers to understand the cross-disciplinary international research directions, the research interests, and how the evolution of information technology has impacted STEM education. Hence, evaluating whether interdisciplinary learning strategies have a positive impact on STEM education is necessary. To make this determination, this study conducted an integrative review of the trends in published papers in SSCI/SCI international journals on STEM education in the fields of educational research and educational scientific disciplines from 1999 to 2023 to investigate the following research questions:

RQ1: Which journals publish the most STEM education research?
RQ2: Which articles are the top 10 most frequently cited STEM education research?
RQ3: Which countries are the top 10 publishers for STEM education research?
RQ4: Who are the most published STEM education research authors?
RQ5: Which institutions made the most publications on STEM education research?
RQ6: What are the learning strategies for STEM education research distribution?
RQ7: What are the main keyword clusters from STEM education research?

Method

Data Collection

This study investigated publications from the PubMed, Scopus, Web of Science (WoS), Embase, CINAHL, and Medline databases from 1999 to 2023 with the keywords: "STEM," "Science," "Technology," "Engineering," and/or

"Mathematics," and in the "education" category. A total of 1565 research papers were collected. Of these, 1378 were published in journals, 510 of which were published via the educational research and educational scientific disciplines fields and were, therefore, eligible for this study (Fig. 1). Two researchers manually filtered and confirmed each article to determine their eligibility for this study. In the event of inconsistent codes, the researchers discussed the matter until they reached a mutual agreement. The 510 research papers were imported into VOSviewer to build and visualize word cloud networks. VOSviewer is a widely used software tool for constructing and visualizing word cloud networks based on the articles retrieved from academic databases. It can analyze various types of relationships between articles and generate graphic results in the form of semantic networks accordingly, such as co-authorship networks, co-citation networks, and keyword co-occurrence networks. The primary function of VOSviewer is to provide a graphical representation, enabling users to discern patterns, clusters, and relationships in large sets of visualized data (Oladinrin et al., 2023). Through visual graphs, researchers can quickly identify documents and meaningful graphs in the databases for authors, institutions, countries, and keyword co-occurrence analysis (Chu et al., 2022). According to previous integrative review, if published articles are frequently cited, it can be inferred that the authors and research directions of these articles are essential indicators of the development of a specific professional field (Tosun, 2022). In addition, researchers can clearly understand the development trends and historical background of STEM education through the citation rate of published articles and the frequency of keywords, thus inspiring new researchers to trace and explore potential research issues in STEM education research.

Learning Strategy Coding Schemes

This study aimed to address the gap in learning strategies by conducting a content analysis. The analysis categories were determined by referring to the mobile technology–supported STEM education model recommended by Hwang et al. (2020), which highlighted a set of learning strategies tailored for mobile-assisted STEM instruction, including "Issue-quest learning," "Knowledge construction tools," "Inquiry-based learning," "Peer competition or gaming," "Individual project-based learning," "Collaborative project-based learning and knowledge sharing," and "Peer assessment" (see Fig. 2). The definition of individual strategies is described as follows: (1) Issue-quest learning: Using mobile technologies as a mean to extend the scope of learning content, such as searching for data or downloading applications for practicing. (2) Knowledge construction tools: Using graphical mobile applications, such as concept mapping or mind mapping tools, to organize the knowledge learned from the textbooks and online resources as well as what have observed and experienced in the field. (3) Inquiry-based learning: Designing activities to engage students in raising questions, proposing

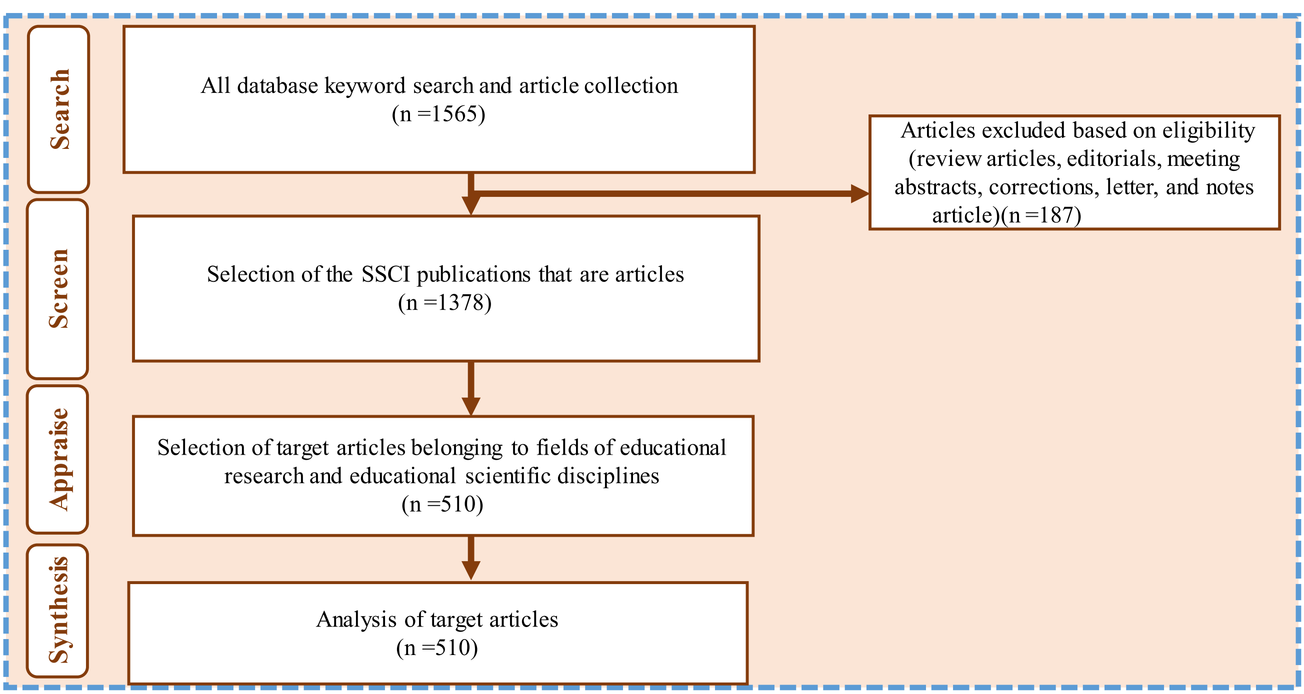


Fig. 1 Database searching process

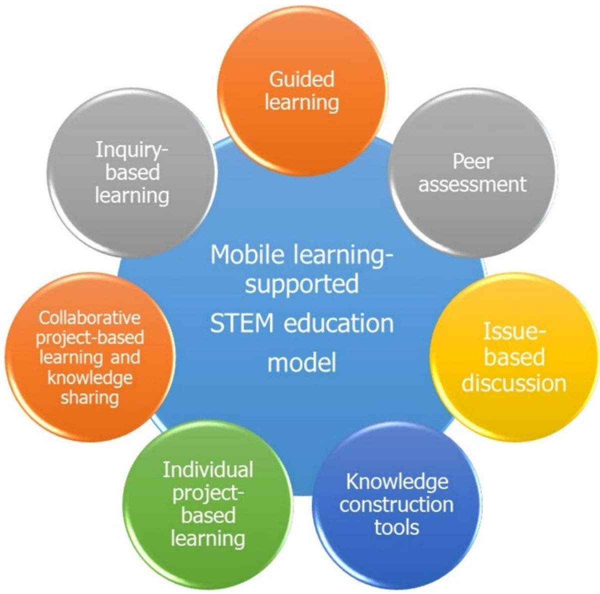


Fig. 2 STEM education model (Hwang et al., 2020)

hypothesis, collecting data, or designing experiments to have deeper understandings in a specified issue. (4) Peer competition or gaming: Engaging students in competitive and gamified activities to motivate their learning. (5) Individual project-based learning: Engaging individual students to complete a project. (6) Collaborative project-based learning and knowledge sharing: Engaging students in completing projects in small teams and sharing their idea during the learning process. (7) Peer assessment: Engaging students in assessing peers' work based on the rubrics provided by the teacher. Hence, seven coding items (i.e., the seven strategies) were included in the coding scheme of the present study.

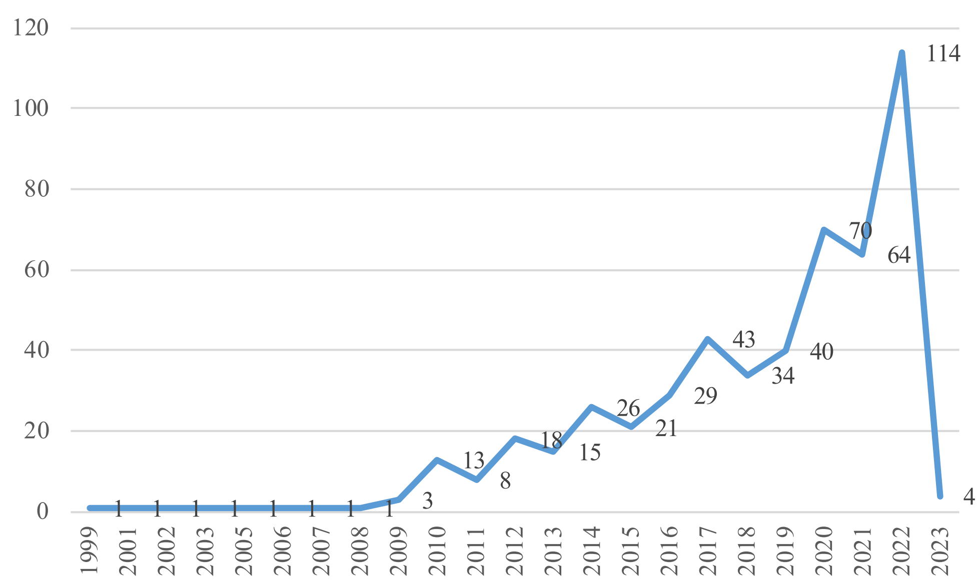
Results

Data Distribution

Figure 3 shows the number of STEM education publications per year from 1999 to 2023 that met our criteria. From 1999 to 2010, fewer than five STEM education articles were published per year. Charlton and Birkett (1999) published the first journal article on STEM, where they applied an integrative model of factors to a computing course to explore students' learning performance. This was published in the *Journal of Educational Computing Research*. Figure 3 shows, with the advancement of global information technology, an exponential increase in the publication of STEM education and technology application articles after 2015. This means that more and more education research scholars are conducting research in the STEM fields of educational research and educational scientific disciplines.

From the studies collected that met our research criteria, most STEM education research focused on factors that affected students or teachers who learned or taught STEM-related subjects. For example, in order to retain and graduate more STEM majors on campus, Perera et al. (2019) implemented a peer-focused, active-learning recitation program with large enrollment chemistry courses to enhance student success in general chemistry; Century et al. (2020) used a quasi-experimental study to verify the transdisciplinary problem-based learning approach that explored the impact of computer science on elementary school students. Cohen and Gilead (2022) applied a practice-based education introduced complexity theory for democratic citizenship. In addition, past research has explored the effects of using instructional tools in STEM lessons rather than using effective strategies for designing STEM activities. For example, Luo et al. (2019) developed and applied a scale to measure students'

Fig. 3 STEM education publications per year from 1999 to 2023



continuing motivation in learning STEM; Ko et al. (2023) developed and validated a scale to measure scientists' and engineers' views of social responsibility and STEM education. We found few studies reporting the use of learning strategies to improve students' STEM outcomes, such as "issue-quest learning," "knowledge construction tools," and "inquiry-based learning." In the future, STEM education research needs to be accompanied by effective learning strategies and appropriate research question design.

Distribution of Word Cloud Analysis in Journals

Figure 4 shows that from 1999 to 2023, STEM-related SSCI or SCI journals published more than six articles. The *International Journal of Science Education* published the most articles ($N=30$), followed by the *International Journal of STEM Education* ($N=26$). Mainstream STEM articles published from 1999 to 2023 focused on STEM interdisciplinary learning to investigate learners' learning outcomes. For example, Jiang et al. (2019) proposed discipline-specific roles for interdisciplinary learning for STEM + L program applications. In addition, according to the InCites JCR report, the *International Journal of Science Education* is regarded as a SSCI journal as it is an influential journal in the fields of educational research and educational scientific disciplines.

Top Highly Cited STEM-Related Articles

Table 1 shows the most cited STEM-related articles from 1999 to 2023. The most cited article, "Societal issues and their importance for contemporary science education: A pedagogical justification and the state-of-the-art in Israel, Germany, and the USA" by Hofstein et al. (2011), had 140 citations. "Before and after third grade: Longitudinal evidence for the shifting role of socioeconomic status in reading growth" by Kieffer (2012) was published in the *Reading and Writing Journal* and had 119 citations. The third most cited article was that of Carnes et al. (2012), which promoted institutional change through biased education and was published in the *Journal of Diversity in Higher Education*; it had 109 citations. These STEM-related articles explained the potential impact that cross-domain learning and collaboration can have on the transformation of STEM education for IT educators and learners.

Distribution of Word Cloud Analysis by Country

Figure 5 shows the distribution of STEM-related education articles based on the nationality of the first author. The top five countries with the most published articles were the USA ($N=331$), Australia ($N=45$), Canada ($N=22$), England ($N=22$), and China ($N=22$).

Distribution of Word Cloud Analysis by Author Efficiency

Figure 6 shows the most prolific STEM education authors from 1999 to 2023. The top three authors were Tang, K. S., from Australia ($N=7$); Schunn, C. D., from the USA ($N=6$); and Castek, J., from the USA ($N=5$).

The Affiliations Produced with STEM via Education Research

Figure 7 illustrates the distribution of STEM research by institution from 1999 to 2023: Michigan State University with 22 published papers, respectively, followed by the University of Wisconsin System with 15 papers. The results of the analysis were visualized using VOSviewer, showing global institutional collaboration trends. Michigan State University, University Arizona, Purdue University, and

Fig. 4 STEM education article distribution in journals from 1999 to 2023

Table 1 Top 10 most cited STEM education articles from 1999 to 2023

Ranking	Publication source	Authors	Title	Technical subject	Number of citations
1	International Journal of Science and Mathematics Education	Hofstein et al. (2011)	Societal issues and their importance for contemporary science education-a pedagogical justification and the state-of-the-art in Israel, Germany, and the USA	Science and mathematics education	140
2	Reading and Writing	Kieffer (2012)	Before and after third grade: longitudinal evidence for the shifting role of socioeconomic status in reading growth	Reading and writing	119
3	Journal of Diversity in Higher Education	Carnes et al. (2012)	Promoting institutional change through bias literacy	Higher education	109
4	Science Education	Allchin et al. (2014)	Complementary approaches to teaching nature of science: integrating student inquiry, historical cases, and contemporary cases in classroom practice	Science education	95
5	Journal of Research in Science Teaching	Gunckel et al. (2012)	A learning progression for water in socio-ecological systems	Science teaching	93
6	Journal of Science Education and Technology	Jang (2016)	Identifying twenty-first-century stem competencies using workplace data	Science education and technology	92
7	ACM Transactions on Computing Education	Repenning et al. (2015)	Scalable game design: a strategy to bring systemic computer science education to schools through game design and simulation creation	Computing education	86
8	Early Education and Development	DeFlorio and Beliakoff (2015)	Socioeconomic status and preschoolers' mathematical knowledge: the contribution of home activities and parent beliefs	Early education and development	83
9	Reading Research Quarterly	Chandler-Olcott and Mahar (2003)	Tech-savviness meets multiliteracies: exploring adolescent girls' technology-mediated literacy practices	Reading research quarterly	82
10	Studies in Science Education	Bevan (2017)	The promise and the promises of making in science education	Science education	80

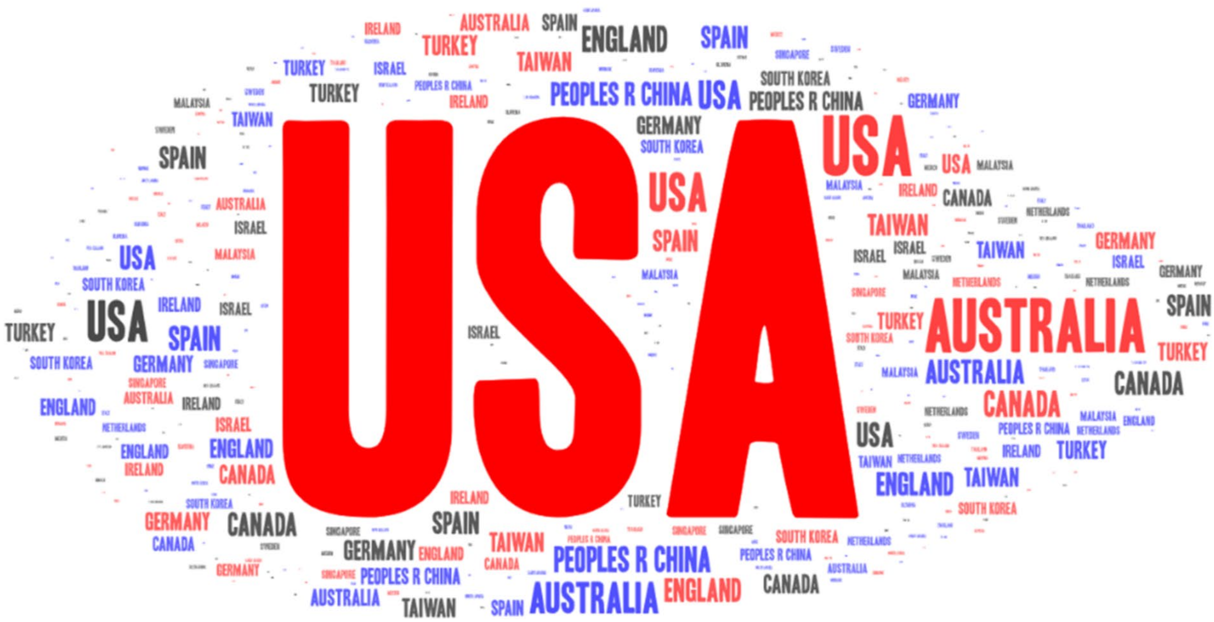


Fig. 5 STEM education publications are distributed by the nationality of the first author

University Wisconsin came in as the four major cooperative institutions. Figure 7 shows Michigan State University as the largest collaborator in purple. The analysis showed the trends in STEM education fields and multinational collaborative research institutions.

Figure 8 shows the STEM education affiliation citation analysis from 1999 to 2023. Michigan State University grew as a mainstream research institution for STEM education, with a total of 384 citations over the past 10 years. For instance, Schultheis et al. (2022) surveyed the effects that data nuggets had on student interest in STEM careers, determined self-efficacy in data tasks, and determined one's ability to construct scientific explanations. This article had 80 citation counts in the search system. This indicated that Michigan State University inspired new scholars to engage with STEM education.

Application Learning Strategies via Content Analysis

Figure 9, derived from a full-text content analysis, illustrates the distribution of the application of learning strategies in STEM education from 1999 to 2023. It can be seen that knowledge construction tools were the most applied STEM application strategy ($N = 135$), followed by inquiry-based learning ($N = 70$) and peer competition or gaming ($N = 67$). Peer assessment was the least commonly applied STEM

Fig. 6 Most STEM education articles published by author

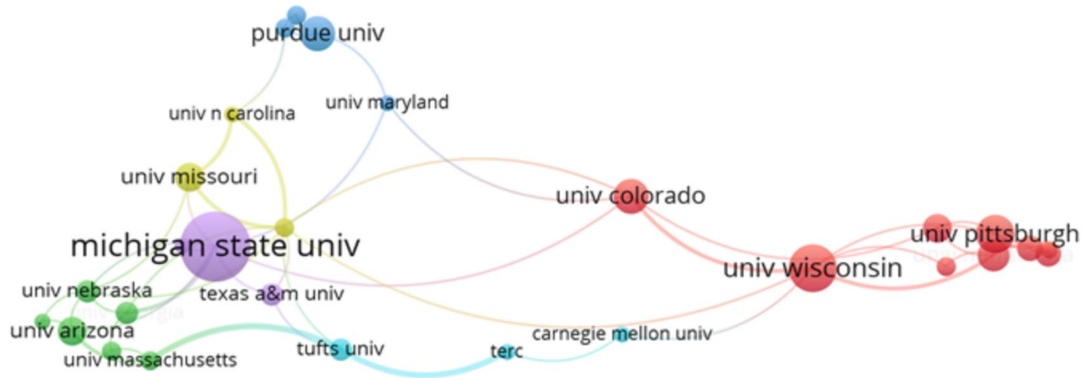


Fig. 7 STEM education publications distributed by collaborative affiliations

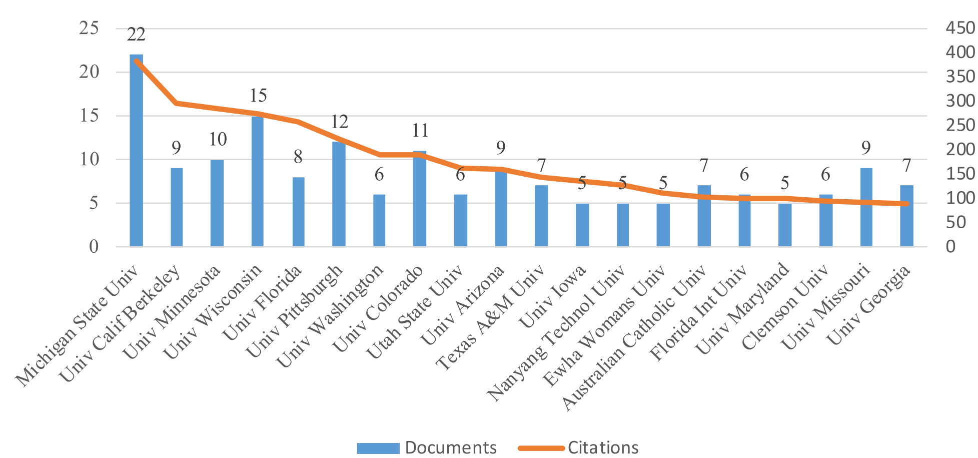
application strategy. One research paper by Chang et al. (2021) used a peer assessment-facilitated STEM approach in a mathematics course to promote students' cross-disciplinary performance and higher-order thinking. We found that prior publications showed that STEM education utilized learning strategies in various fields, including diversity disciplinary education and conduct issue-quest learning, knowledge construction tools, inquiry-based learning, peer competition or gaming, individual project-based learning, collaborative project-based learning and knowledge sharing, and peer assessment. These fields may influence future investigations via class design learning strategies.

Popular Author Keywords

To understand the global trends in STEM education, the most frequently used keywords by co-occurrence were analyzed and visualized through VOSviewer (Fig. 10). The VOSviewer settings are as follows: the number of occurrences of keywords (10), items (59), links (1029), and total link strength (2985). Figure 10 shows that the most frequently used keywords are science ($N=114$), literacy ($N=100$), education ($N=96$), students ($N=87$), STEM ($N=61$), and knowledge ($N=57$). This finding shows that most researchers have paid attention to STEM education in the fields of educational research and educational scientific disciplines.

Table 2 groups the keywords used in Fig. 10 into four clusters. The keywords in the first red cluster include Students, Knowledge, Scientific Literacy, Framework, and Argumentation. These keywords are associated with the information environment STEM education type. The keywords of the second purple cluster include Science, STEM, Attitudes, and Achievement. These keywords are associated with the impact of gender on STEM literacy ability. The keywords in the third blue cluster include Literacy, Education, STEM Education, Teachers, and Inquiry. These keywords are associated with STEM literacy to educate learners to cultivate problem-solving. The keywords in the fourth yellow-green cluster include Performance, Impact, Curriculum, Model, and Design in the information environment. These keywords are associated with STEM literacy and model design in the curriculum to impact learners' learning performance. VOSviewer's visualizations, combined with a co-occurrence analysis, validated the most frequently used keywords and provided researchers with a clear path and comprehensive understanding of the

Fig. 8 Affiliation citation analysis from 1999 to 2023



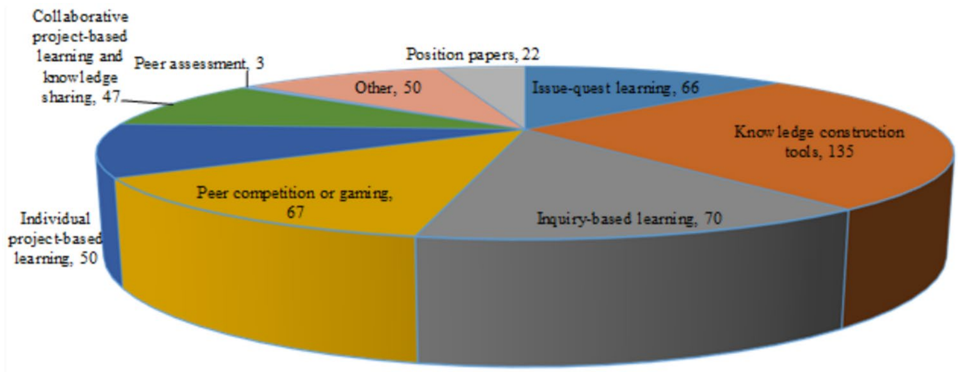


Fig. 9 Distribution of STEM education application strategies

clusters of Students, Science, Literacy, and Performance. Specifically, the four clusters highlighted the majority of research issues and imminent progress in STEM literacy.

Discussion

With the recent growth of globalization, information technology, and the diversification of resources, especially in the fields of educational research and educational scientific disciplines, teachers have integrated STEM education into their course design to improve students' learning, critical thinking, and problem-solving skills (Kuo et al., 2019; Yahya & Hashim, 2021). Through an analysis of the most cited international journal articles on STEM education in the six databases, this study has enabled educational researchers to identify articles, journals, authors, countries, institutions, learning strategies, and keywords that meet their needs. In this article, a bibliographic analysis and VOSviewer exploration analysis were conducted to determine the breadth and depth of STEM education research from 1999 to 2023. Figure 3 shows related articles on the rapid development of interdisciplinary STEM

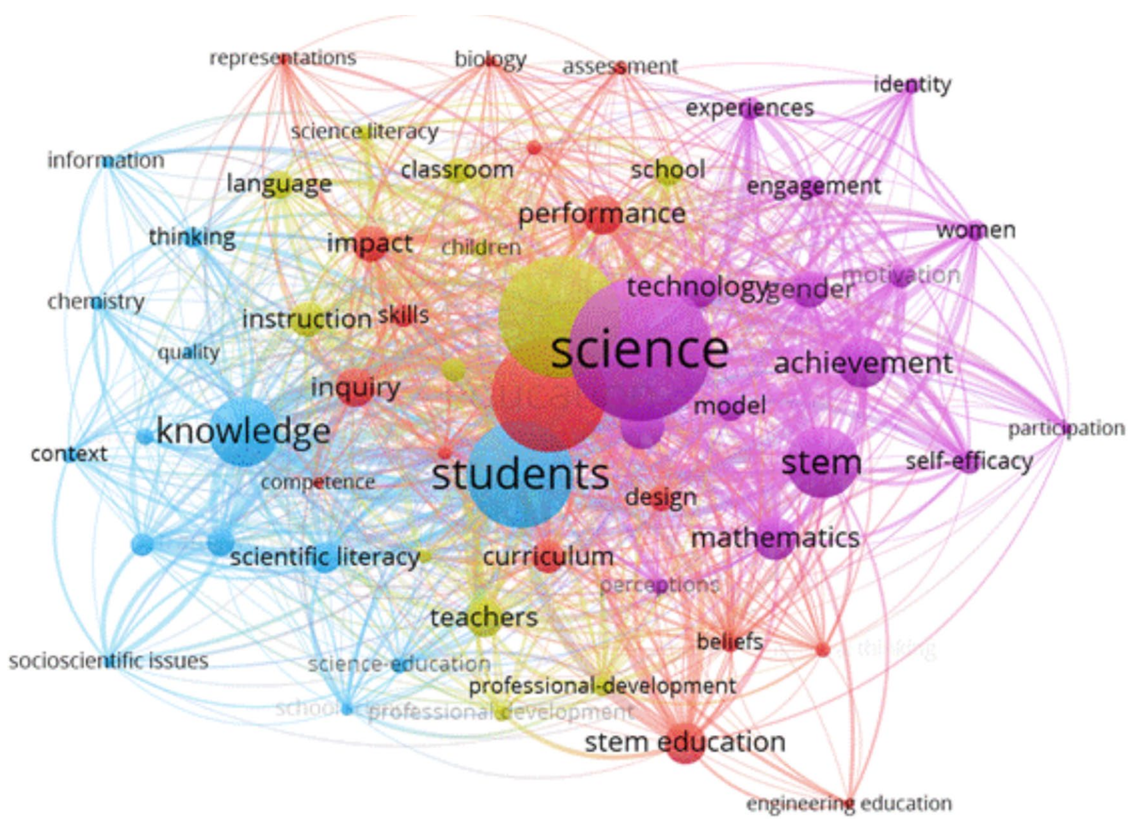


Fig. 10 Distribution of the most frequently used author keywords in STEM education research

Table 2 The co-occurrence analysis with author keywords cluster

Cluster 1	Cluster 2	Cluster 3	Cluster 4
Students	Science	Literacy	Performance
Knowledge	STEM	Education	Impact
Scientific Literacy	Attitudes	Stem Education	Curriculum
Framework	Achievement	Teachers	Model
Argumentation	Mathematics	Inquiry	Design
Thinking	Gender	Instruction	Skills
Conceptions	Technology	School	Beliefs
Context	Self-Efficacy	Language	Professional-Development
Science-Education	Experiences	Classroom	Perceptions
Chemistry	Engagement	Science Education	Computational Thinking
Middle School	Motivation	Professional Development	Implementation
Socioscientific Issues	Women	Children	Assessment
Information	Identity	Science Literacy	Competence
Quality	Participation	Teacher Education	
Representations			
School Science			

education and the increasing educational research in STEM education. This coincides with information technology applications that invest in interdisciplinary research and design to improve students' STEM and problem-solving skills. The visual representations of the selected articles can help new researchers to grasp and understand research trends and collaborations in this field. Finally, we try to answer the research question below.

Response the Most STEM Education Publish Journals

From the research work, we can see that STEM education publication frequency has increased exponentially since 2015. The top three international publications in terms of STEM education article distribution were the *International Journal of Science Education*, the *International Journal of STEM Education*, and the *Journal of Chemical Education*. Notably, the *International Journal of Science Education* was the most STEM education published journal in the fields of educational research and educational scientific disciplines. Additionally, this SSCI/SCI journal had a good impact factor and was frequently cited in educational research and educational scientific disciplines because of its high-quality research. These accomplishments showed that educational researchers are working hard to conduct empirical research related to STEM education (Wang et al., 2022a, b).

Response to the Top 10 STEM Education Research Articles

Hofstein et al. (2011) had the highest number of research citations (140). The research was first proposed in Israel, Germany, and the USA to teach how science is linked to students' life, environment, and citizenship roles and to discuss art, potential, and barriers to effective implementation. Kieffer (2012) had the second-highest number of research citations (119). Kieffer's (2012) longitudinal research analysis found that STEM education can mitigate the impact of low socioeconomic status on reading growth, garnering international attention. Carnes et al. (2012) had the third-highest number of research citations (119). Carnes et al. (2012) posed equal opportunities for the participation and advancement of men and women in academic science, technology, engineering, mathematics, and medicine (STEMM) and collected data from a survey on the bias literacy workshop. Their findings suggested that educational intervention may effectively promote institutional change regarding gender equity, pushing forward equal opportunities in STEM. The high number of citations may be due to this being the first STEM research on gender issues. Table 1 lists the top 10 most cited articles related to STEM education, showing that educational researchers have been able to identify global STEM education research trends and issues for more than 10 years by paying attention to the highly cited research. Frequent citations of academic articles, especially in STEM research, are acknowledgments by scholars of their importance and influence. Such as the top-cited STEM articles from 1999 to 2023. Notably, Hofstein et al. (2011) emphasize societal perspectives in STEM, suggesting a shift toward understanding the broader societal context of science; Kieffer (2012) highlights the interplay between literacy and STEM, emphasizing the importance of foundational literacy and socioeconomic factors in STEM achievement. Additionally, Carnes et al. (2012) focus on enhancing inclusivity, diversity, and equity in STEM by addressing biases. These articles underline the interdisciplinary nature of STEM research, indicating that combining different fields can enrich STEM education. By understanding the core themes of influential works, the STEM community can guide the discipline's growth more effectively. This could help researchers understand what has not been explored or inspire research directions and interests.

Response to the Top STEM Education Published Countries, Authors, and Institutions

The top five countries that published articles related to STEM education were the USA, Australia, Canada, England, and China. The authors who published the most STEM education-related papers were Tang KS ($n=7$), Schunn CD ($n=6$), and Castek J ($n=5$). Tang (2022) posited a social-material theory of argumentation on material inquiry and transformation as a prerequisite process of scientific argumentation. Michigan State University, the University of Arizona, Purdue University, and the University of Wisconsin were the four major cooperative institutions for the publication of STEM education research. For example, Odden et al. (2019) posed an exploratory case study using computational essays on physics computational education; the research team was comprised of researchers from the University of Oslo, Oregon State University, and Michigan State University and explored undergraduate physics computational education. They also identified physics students' computational education in practices, knowledge, and beliefs. This study highlighted the benefits of multi-university collaboration and prepared other researchers for some of the potential challenges, such as which institutions to consider for collaboration, language barriers, and information technology complications.

Response to the STEM Education Learning Strategies Distribution via Content Analysis

Figure 9 reveals an additional finding from this study's content analysis: knowledge construction tools, inquiry-based learning, and issue-quest learning were the most common learning strategies for STEM education research. Regarding the term learning strategies of the knowledge construction tools, for example, Wiesner et al. (2020) expressed that textual feature roles, background knowledge, and disciplinary expertise in reading a calculus textbook offer didactical disciplinary education, and the revision of disciplinary education applied to didactical texts describes and analyzes the ways through which the professor draws on his identity as a teacher to shape his reading practices. Furthermore, Fig. 9 shows that interdisciplinary learning strategies in STEM education are worth promoting in various contexts, such as issue-quest learning, inquiry-based learning, peer competition or gaming, individual project-based learning, collaborative project-based learning, and knowledge sharing, and peer assessment combined with specific disciplines or cross-field research design.

Response to the STEM Education Main Keyword Clusters Distribution

This study compiled a list of the most frequently used keywords in STEM research; supplementary education researchers can easily find relevant research topics in the databases. Through this STEM education research co-occurrence analysis, the keywords defined by the main authors were divided into four categories: students, science, literacy, and performance. Hébert and Jenson (2020) posed that K-12 education conveyed "making" as a means to support computational and design thinking, technology literacy, and success in STEM fields. Therefore, the most used keywords help researchers explore and analyze STEM education research trends and learn about the most common issues in the field. In another example, Century et al. (2020) used a quasi-experimental study of a transdisciplinary problem-based learning approach to show that a computer course combining English language arts, science, and social studies yielded higher student achievement. Their research contributed to STEM educational research and educational scientific disciplines. This study's analysis can serve follow-up education researchers in their understanding of STEM education's global impact and provide them with a proven context.

Conclusion

This study's integrative review via co-occurrence analysis showed STEM education as an area worthy of further exploration in educational research and educational scientific disciplines; STEM educational designs can improve students' learning effectiveness, critical thinking, cross-team cooperation, and problem-solving skills through the combination of different disciplines and learning strategies, that is, the value of competitiveness. In addition, this study highlighted several fresh STEM learning designs that can guide future researchers and educators.

Advancements in mobile technology have enabled students to learn anytime, anywhere. This improved access to learning resources can enhance student performance. Further development of digital STEM learning technologies and further research on these technologies can provide multiple perspectives and opportunities for improving student outcomes. Future research could explore how IT and education researchers can collaborate across cultures to incorporate various digital learning technologies, such as augmented reality (AR), virtual reality (VR), and practical courses, or to propose learning strategies and measuring tools for developing in-depth experimental STEM studies for analyzing user data. By placing students at the center of these study designs, there is an expected improvement in students' core literacy in learning effectiveness, creative thinking, critical thinking, and problem-solving.

Strengths and Limitations

This study presents a detailed bibliographic analysis, enriched by VOSviewer's visualizations, charting the trajectory of STEM education within the arenas of educational research and educational scientific disciplines from 1999 to 2023. The findings provide a reference for those who intend to conduct STEM research or implement STEM activities in school settings.

While it offers a comprehensive perspective on the STEM discourse, highlighting the breadth and depth, there are constraints to consider. First, the research primarily relied on data from the six databases, focusing on the educational research and educational scientific discipline sectors. An expansion to other areas of the databases might have yielded divergent outcomes. Second, a notable limitation is the absence of an exploration into how the proliferation in STEM education has potentially influenced real-world innovations within STEM industries. If a more encompassing keyword strategy were employed, combined with interdisciplinary expert insights, a more holistic view of journals, authors, institutions, learning strategies, and prevailing trends might have been unearthed. This research, while robust in its findings and being the first of its kind in the past decade, underscores the value of future studies that can bridge these identified gaps.

Implications

The rapid evolution of globalization and technological advancements, particularly in information technology, coupled with a surge in diverse resources, has profoundly reshaped the educational paradigm. This has been notably evident in educational research and scientific fields, where STEM education's integration is increasingly viewed as pivotal for enhancing student learning, critical thinking, and problem-solving capabilities, a stance supported by contemporary research. The findings of the present study have profound implications from different angles:

1. For Educators: The results highlight the indispensability of interdisciplinary collaboration in STEM, revealing that a synthesis across disciplines can fortify STEM education. The intersectionality of literacy and STEM and the importance of creating an inclusive and diverse learning environment stand out as crucial takeaways.
2. For Educational Institutions: The potency of STEM educational approaches, which have been shown to enhance learning outcomes, critical thinking, teamwork, and problem-solving skills, is clear. The benefits of collaborations across universities, as showcased by studies like Odden et al. (2019), also emerge as significant.
3. For Policymakers: The surge in STEM research publications since 2015 and the high citation of specific papers signify STEM's escalating prominence. Policies that accentuate interdisciplinary research, tap into emerging digital technologies like AR and VR, and prioritize inclusivity in STEM fields can be game-changers.

By collecting and analyzing specific articles, journals, authors, countries, institutions, learning strategies, and keywords, this study showed that STEM education has advantages in cultivating students in various fields. Different from previous STEM retrospective research, such as that of Ibáñez and Delgado-Kloos (2018) and Wang et al. (2022a, b), which proposed that in the digital age, the introduction of technology and cross-team cooperation curriculum activities are fundamental to education, this article analyzed research from a comprehensive perspective using an integrative review and word cloud analysis. This study suggested that interdisciplinary teachers and R&D personnel work together to plan, design, and develop research outcomes from a learning-centered perspective to educate students in a way that fosters social connection within society. Students could be taught to equip themselves with critical thinking and problem-solving skills to advance STEM education and work to achieve global benefits. These findings encourage increased attention from researchers and educators to fill STEM education gaps through interdisciplinary learning and diversified learning approaches.

Author Contribution Wen-Song Su oversaw the research's framework, gathered and analyzed data, and contributed to the manuscript's composition. Ching-Yi Chang took the lead in forming the concept and analyzing the data and was involved in both the writing and revision processes. The author(s) have reviewed and given their approval to the final version of the manuscript.

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Availability of Data and Materials The data that support the findings of this study are available from the corresponding author upon request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Competing Interests The authors declare no competing interests.

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