Review paper

AI-Enhanced STEM Education: A Bibliometric Study of Research Trends Toward Achieving Sustainable Development Goals

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ABSTRACT

This study aims to explore AI trend studies in STEM education using documents from the Scopus Database. Between 2015 and 2025, 171 documents were selected by researchers using the PRISMA method. The R language, Biblioshiny, and VOSviewer were later used to conduct a comprehensive bibliometric study. This review identifies the dominant and emerging trends in artificial intelligence applications in STEM education. The findings reveal a significant increase in studies on the use of AI in STEM education, with the dominant themes being personalized learning, machine learning, and, more recently, generative AI, such as ChatGPT. The findings revealed that integrating AI into STEM education can significantly contribute to achieving SDG 4 (quality education). It encourages equity, accessibility, and educational excellence. At the same time, it supports SDG 8 (decent work and economic growth) by means of workforce development initiatives. The initiatives prepare students for high-quality jobs in AI economies where demand for AI skills has grown exponentially. Different countries, such as the USA, China, and Singapore, lead the research landscape but have unbalanced collaboration networks. SDG 10 (reduced inequalities) is a point of concern raised by the limited extent of research on a few nations. This is due to the possibility that economically and educationally diverse international settings might not be helped by AI-driven solutions and research agendas from rich contexts, potentially triggering increasing economic and educational inequalities. This research informs the strategic planning of AI-based applications in STEM education worldwide and provides insights into policymakers, scientists, and educators, while remaining aligned with the Sustainable Development Goals.

Keywords: STEM education, artificial intelligence, thematic analysis, trends analysis, sustainability

The exponential growth and convergence of artificial intelligence (AI) technologies, exemplified by applications such as ChatGPT, are reshaping fields in a revolutionary way, with education leading the revolution (Ajayi et al., 2022; Song et al., 2025; Vieriu & Petrea, 2025). Convergence has opened up new avenues for individual learning and creative pedagogies. It has presented unparalleled challenges and opportunities to the education system, particularly in the science, technology, engineering, and mathematics (STEM) education process (Song et al., 2025; Vieriu & Petrea, 2025). STEM education is described as an integrated educational

approach that encompasses teaching, learning, curriculum, and assessment within the Science, Technology, Engineering, and Mathematics disciplines. This includes both the depth of knowledge in a specific STEM field and the integration of knowledge among multiple fields to address real-world problems that cut across disciplines (Bybee, 2013). The description includes all levels of education and acknowledges the dual purpose of STEM education in developing both technical knowledge and essential other skills, such as critical thinking, problem-solving, and collaboration, that are necessary for a technology-driven profession and citizenship (National Academies of Sciences, Engineering, and Medicine, 2018). Growing curiosity about AI within STEM education is a "hot topic" of enormous promise for redesigning how teachers teach, and students learn, in pursuit of more personalized, interactive, and effective learning experiences (Kanyike, 2024; Kohnke & Zaugg, 2025).

The issue of accessibility, engagement, and personalization has been a major challenge for STEM education. The use of AI technologies presents unprecedented opportunities for the development of personalized learning experiences, the provision of immediate feedback, and the support of learners and educators with the aid of smart tutoring systems, the presentation of content, and the provision of tests (Kanyike, 2024).

STEM education is essential in equipping students with the ability to thrive in a rapidly changing world economy driven by technological innovations and advancements, thereby fostering skills in critical thinking, problem-solving, creativity, communication, and analytical capabilities (Barkoczi et al., 2024). AI has come to be strongly considered as a central point in STEM education, as a supplement to teachers' function as guides and examiners of learning by offering individualized learning experiences, instant response, and access to unlimited knowledge and simulations that can be used alongside classical pedagogical methods (Al Darayseh & Mersin, 2025; Zhang et al., 2025). Specific AI tools, including intelligent tutoring systems, adaptive learning systems, chatbots, and educational robots, have been shown to have a positive impact on students' academic performance, participation, and motivation in STEM subjects (Ajayi et al., 2022; Zhang et al., 2025).

These technological advances strongly support universal imperatives of sustainable development, outlined by the United Nations SDGs. In particular, AI incorporation into education aligns directly with SDG4, Quality Education, in providing inclusive and equitable quality education, and lifelong opportunities for everyone. AI offers highly underrecognized potential in promoting the development of equity and access to STEM learning, especially among students with disabilities, by directly addressing existing barriers and adhering to UDL principles. AI-powered tools can support education in which all students have an opportunity to succeed with STEM education and empower a diverse, inclusive workforce able to address new challenges.

Furthermore, AI in education plays a vital role in attaining SDG8: Decent Work and Economic Growth, whose objective is to promote inclusive and sustainable economic growth, full and productive employment, and decent work for all (Gupta et al., 2024; Singh et al., 2024). STEM literacy is rapidly becoming a necessity in order to find one's way through today's society and attain tomorrow's employability, in the aftermath of accelerated technological development and more complex challenges in the world at large (Ajayi et al., 2022). 50% The demand continues to increase among expert STEM specialists in areas like data science and artificial intelligence, and education, therefore, must shift focus from preparing learners to compete with, as opposed to working in effective collaboration with, and as a guide and supervisor in partnership with, AI systems (Song et al., 2025). This necessitates wide-reaching education reforms, as curricula are rewritten and focus is placed on the development of basic human strengths, including creative problem solving, literacy in working with AI, critical thought, communication, and creativity ("4Cs"), irreplaceable by AI (Barkoczi et al., 2024; Song et al., 2025).

The deliberate use of AI in education not only ensures high-quality education for all but also makes a substantial contribution to SDG10: Reduced Inequalities, which attempts to lessen inequality both within and between countries. AI is capable of democratizing high-quality STEM access, particularly among the underserved, through personalized assistance that can close the achievement gap in the conventional classroom environment (Ajayi et al., 2022; Kanyike, 2024). Recent educational research has revealed that learning style theories based on preferences for visual, auditory, or kinesthetic learning are not supported empirically and should not inform learning design. Indeed, an extensive review by the National Academies of Sciences, Engineering, and Medicine (2018) revealed no support for learning style theories as a basis for improving learning outcomes. In fact, educational research has focused more on the need to recognize the value of AI personalization systems in learning outcomes based on empirically supported dimensions of learner variability in prior knowledge, cognitive ability, metacognitive ability, and motivation, rather than learning style theories. Indeed, AI personalization systems are more effective in addressing empirically supported learner variability in learning outcomes through adaptive learning pathways, formative assessment, and interventions based on student knowledge states and developmental levels rather than typological classifications based on learning style theories. Such typological classifications are overly simplistic in addressing the complex nature of human learning. For example, AI-based assistive technology and adaptive learning spaces can significantly reduce access barriers among students with disabilities through tailored content, improved communication, and adaptation in response to personal learning styles (Kohnke & Zaugg, 2025). A tailored strategy can remove obstacles such as

gender imbalances, socioeconomic inequalities, and underrepresentation of minorities in the fields of science, technology, engineering, and mathematics, thus enabling equal opportunities (Ajayi et al., 2022; Kohnke & Zaugg, 2025). That is only possible through a critical examination of obstacles like the digital divide (Almarashdi & Saleh, 2024), in which the poor are unable to pay for the required technology and Internet connectivity, hence increasing the existing learning inequalities. Institutions and policymakers have the obligation to give more emphasis to activities that promote equitable access to technology and infrastructures as a way of not increasing inequalities and making the benefits of using AI filter through all learners regardless of learners' disability or background status (Kohnke & Zaugg, 2025; Zhang et al., 2025).

However, the effective incorporation of artificial intelligence is associated with numerous challenges, including ethical considerations like algorithmic bias, data privacy concerns, and the potential for academic dishonesty through the misuse of artificial intelligence-generated content (Kohnke & Zaugg, 2025). Concerns have also emerged about the potential for artificial intelligence applications to replace human teachers and exacerbate the already existing gaps in education, including inequalities in accessing modern technologies (Ajayi et al., 2022; Kanyike, 2024). Challenges like differences in representation have also led to biased decisions and potential unauthorized access to confidential student data (Kohnke & Zaugg, 2025; Magash & Saaida, 2024). Additionally, there are concerns about the potential for artificial intelligence overdependence by students, which might compromise their critical thinking and problem-solving skills (Vieriu & Petrea, 2025). Apart from the imperativeness of proper teachers' training and support for effective implementation of artificial intelligence in the classroom, has made some educators hesitant about the application of artificial intelligence in the classroom (Ajayi et al., 2022). The importance of sharp pedagogical framework studies, technological infrastructures, and teacher training in addressing the complex interplay between AI and social, pedagogical, and environmental aspects of STEM education has been highlighted by Ajayi et al. (2022), Alhosani et al. (2025), and Zhang et al. (2025).

Although research studies have been witnesses to the effectiveness of particular applications of AI, research into the overall research landscape to interpret the meanings of patterns, trends, and directions in this dynamic field is an urgent requirement. For example, Pradana et al. (2023) have carried out a systematic review and bibliometric study on the application of ChatGPT in education. The research was based on 74 studies retrieved from Google Scholar. It found an increasing trend, known as key contributors, and explored research topics. It also found avenues for further research. It does not have an in-depth framework, but further research on the applications and trends of ChatGPT in education can be suggested. Therefore, this study attempts to add to the knowledge in this regard through the carrying out of a bibliometric study. This study aims to detect and examine the evolving thematic structure, main areas of research, and significant contributions in this new field. Through the blending of information from diverse STEM disciplines, this study intends to offer an in-depth synopsis of the current status of the integration of AI in STEM learning, highlighting established patterns as well as new directions of research interest.

Study objectives and research questions

While several bibliometric studies have looked at shorter time periods, we need a long-term analysis that shows how the field has changed over the past decade (2015-2025). This time frame covers the rise of modern AI technologies and their adoption in education. Systematic reviews have explored AI applications in STEM education (Misra et al., 2023). AI in education, but this new area is still developing with various AI methods and complicated educational aspects, and more specifically, after the advent of ChatGPT and other LLMs. Therefore, this study is to give a detailed bibliometric analysis of the research landscape related to the integration of AI in STEM education by addressing the five primary research questions:
1. What are the main descriptive features of research on AI in STEM education?
2. What is the influential research regarding AI in STEM education?
3. What are the key research words of STEM education for AI?
4. How well do current themes influence the future of AI in STEM education?
5. How do these trends align with the Sustainable Development Goals?

THEORETICAL FOUNDATIONS OF AI IN STEM EDUCATION

Several theoretical frameworks form the basis for integrating AI into STEM education, focusing on constructivist teaching, personalized learning, and adaptive instruction. The conceptual framework for understanding how AI can improve learning in STEM education is presented in the following theories.

AI and STEM education in constructivist learning theory and social development

Vygotsky's social constructivist theory (1978) is the basis for understanding how AI technologies can enhance STEM learning by supporting collaborative learning environments and providing scaffolding instruction at students' zones of proximal development (ZPD). Vygotsky's ZPD is the gap between what a learner can do independently and what can be achieved with the assistance of others. The best learning is in this space through support from more knowledgeable others (Vygotsky, 1978). Based on this theory, learning is achieved through cultural mediation and social interaction. In STEM education, AI systems are able to personalize these findings to create adaptive learning spaces based on students' requirements, while fostering peer interaction and collaboration (Hwang & Tu, 2021).

Though Vygotsky himself did not coin the term "scaffolding," it has since come to play a central role in describing how AI supports learning within the ZPD. Scaffolding is most effective when it most closely aligns with what the learner needs to thrive, to master a task he was previously unable to accomplish (Wood et al., 1976). In addition, cognitive load theory (Sweller, 2011) helps in crafting AI systems that present information such a way that it does not overburden the student but maintains them at an optimal level of difficulty. AI-enabled intelligent tutoring systems are the best manifestation of this concept, providing just-in-time instruction, gradually reducing the level of time and resources spent by traditional instruction (Pea, 2004).

AI and STEM education in personalized learning theory and adaptive educational systems

With reference to AI-based education, the theory of personalized learning is particularly noteworthy. for understanding the role and potential of intelligent technology in personalizing the learning of mathematics, scientific inquiry, and engineering activities. As per Anderson and Dron (2011), and Walkington and Bernacki (2020), this theory has significant alignment with the potential of AI technology in analyzing the learning patterns of individual students and modifying their training programs accordingly. This theory focuses on the need for personalization in education, considering the needs, interests, and abilities of individual students. AI technology has a unique potential in this context.

According to Peng et al. (2019), the theory covers several aspects of personalization, such as differentiated assessment methods (using multiple methods to assess understanding), differentiated teaching methods (adapting to different learning styles and preferences), adaptive pacing (allowing students to progress at their own pace), and personalized content selection (providing materials tailored to individual interests and abilities). Using machine learning algorithms, AI systems can determine the best learning paths for each student based on their learning preferences, performance trends, and engagement levels.

Recent research has revealed several critical components of effective personalised learning systems. Adaptive algorithms can scan massive volumes of student interaction data to uncover patterns that predict learning achievement, detect early warning signals of academic problems, and offer intervention measures that are tailored to individual needs (Reich & Mehta, 2020). These systems go beyond conventional branching algorithms, using sophisticated prediction models that take into account a variety of characteristics such as prior knowledge, learning preferences, motivation levels, and environmental considerations.

RESEARCH METHODOLOGY

Research design

This study employed a bibliometric analysis method to examine the patterns and trends in the use of artificial intelligence in STEM education. Pradana et al. (2023) defined bibliometric analysis as a technique for measuring, monitoring, and evaluating scholarly publications. Bibliometric analysis is a research method that uses statistics and computational techniques to measure and analyze information in published scientific works like journals and conferences (Zafrullah & Ramadhani, 2024). This quantitative technique is crucial for drawing relationships between themes within a specific field, highlighting significant authors and publications, and reflecting the current status of research. This approach helps in identifying the top journals, authors, the methodology employed, and trends (Susanty et al., 2022; Zou et al., 2022). It enables scholars to assess a topic's strengths, limitations, and gaps.

This performance analysis evaluates the contributions of research parts, and science mapping looks at the relationships between them (Donthu et al., 2021). Journals, authors, institutions, and nations are just a few of the study components that are frequently included in review studies and are included in performance analysis. The scope of performance analysis encompasses several key elements common to review studies, including authors, institutions, nations, and publications. However, science mapping techniques include co-authorship analysis, bibliographic coupling, co-word analysis, citation, and co-citation analysis.

Dataset

A substantial amount of bibliographic data is needed for bibliometric techniques, which have been used to examine different themes, journals, and nations (Palos-Sánchez et al., 2022). The majority of the databases, such as Web of Science and Scopus, provide bibliometric data. It is very important to choose the right database when one uses bibliometric analysis because this will generate similar results depending on the database used (Singh et al., 2021). The study used the dataset provided by the Scopus database because it is one of the sources of scientific journal influence and control in the majority of the disciplines. Scopus is a complete database that is dense with high-quality scientific articles. Moreover, Scopus was also selected because it is widely recognized as an extensive bibliographic database in academia (Zhu & Liu, 2020).

On the 18th of August 2025, the Scopus database was searched using title, abstract, and keywords to find the dataset for using AI in STEM education. According to Wardhana et al. (2022), metadata can be used to summarize any subject of study. Therefore, the search terms "Artificial Intelligence" and "STEM education" were used to find accurate and reliable results in the literature. Documents were selected using the PRISMA method to finalize the number of documents needed for analysis. The inclusion and exclusion criteria are thoroughly examined in the PRISMA framework shown in **Figure 1**.

Figure 1

PRISMA diagram describing the collection of documents from the Scopus database
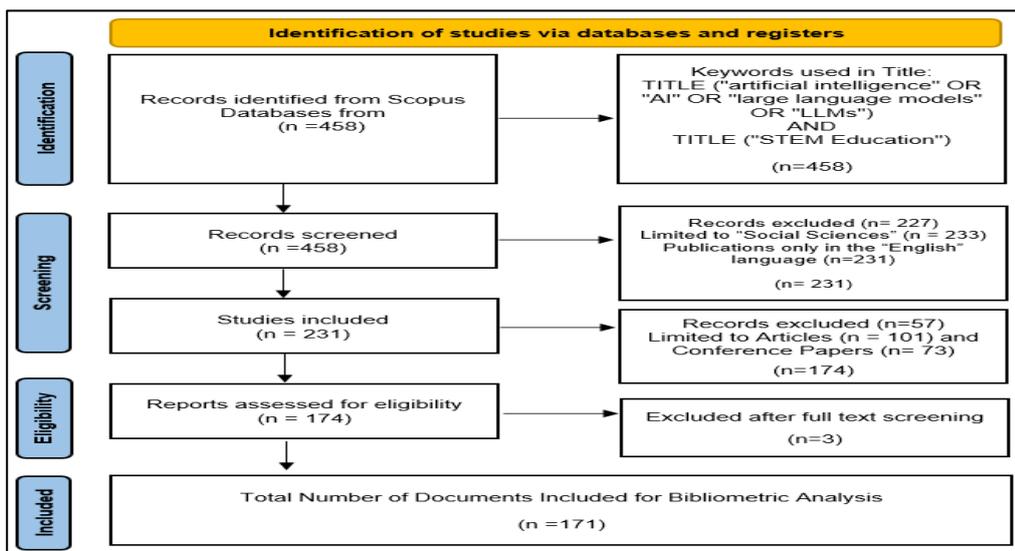
Figure 1 reveals that in the identification phase, 458 documents were collected from Scopus, identifying topics and keywords. The authors restricted the screening phase to English-language "social sciences" articles, then limited it to "articles" and "conference papers", resulting in 174 documents. The inclusion of articles and conference papers ensures that research findings are actively disseminated through publications in peer-reviewed journals and presentations at academic conferences. Three additional documents were subsequently excluded after full-text screening. As a result, 287 documents were excluded, leaving 171 documents included. After determining the number of articles, the authors used the R Biblioshiny software and VOSviewer applications to analyze them and explain the results of the bibliometric analysis. Document selection followed systematic inclusion and exclusion criteria to ensure relevance and quality (**Table 1**).

Table 1

Inclusion and exclusion criteria applied in document selection

| Criterion	Inclusion	Exclusion
AI and STEM Integration	Research examining AI applications in teaching, learning, assessment, or curriculum design in STEM subjects	AI research without educational application; educational research without STEM focus
Subject Area	Articles classified under "Social Sciences" in Scopus	Articles outside the Social Sciences classification
Document Type	Articles and conference papers	Books, book chapters, reviews, editorials, notes, letters, short surveys
Timeframe	Publications from 2015 to 2025	Publications before 2015
Language	English-language publications	Non-English publications
Quality Control	Original research with complete information and metadata	Duplicate publications or studies with insufficient information

RESULTS

To map bibliometric results in the area of AI in STEM education, researchers performed several analyses, including descriptive features, influential research on AI in STEM education, and thematic clusters and topic trends.

Main descriptive features of research on AI in STEM education

The main information in **Figure 2** provides an overview of the characteristics of the documents examined using Biblioshiny.

Figure 2

Descriptive characteristics of the bibliometric dataset (Source: Generated by authors using R *Program Biblioshiny)*
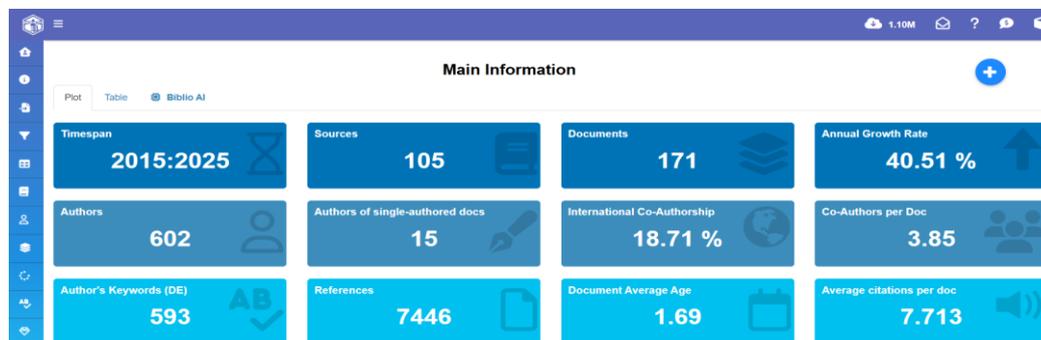

Figure 2 presents the bibliometric analysis, based on data extracted from SCOPUS, paints a picture of a relatively recent and rapidly growing field of research. The time frame 2015-2025 indicates an interest in fresh research. The Scopus collection contains 171 documents from 105 sources, with a high rate of annual growth (40.51%), indicating an interest field that is increasing in activity and interest. The low average document age (1.69 years) and the mean of 7.713 citations per document are expected because the research is comparatively new, reflecting the novelty of the subject. It also means that many studies may not have made the maximum impact or perhaps may not have been cited so far. Evidence of collaboration can be seen in the number of authors (602) with an average ratio of 3.85 co-authors per document. Out of these documents, 18.71% have international co-authorship. The documents consist of articles (99) and conference papers (72). Although the number of documents (171) is not high, the growth rate indicates a snowballing effect.

Annual Scientific Production

From the bibliometric analysis, it is evident that there are temporal patterns in research productivity over the last decade. **Figure 2** illustrates the scientific production from 2015 to 2025, showing the progression of research from its infancy to its establishment as a research domain.

Figure 3

Descriptive characteristics of the bibliometric dataset (Source: Generated by authors using R *Program Biblioshiny)*
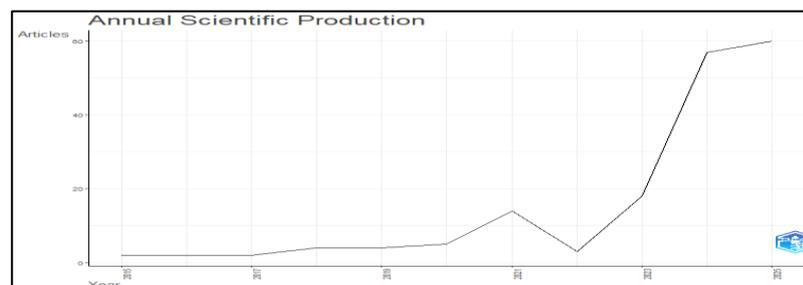
Figure 3 indicates a lack of scientific effort or attention throughout these years, showing a steady but small level of academic productivity in published publications between 2015 and 2020. Notable acceleration observed post-2020, coinciding with the COVID-19 pandemic and increased adoption of digital learning technologies. The number of documents decreased to three in 2022 after increasing to fourteen items in 2021. However, the number of publications has been steadily increasing since 2023, indicating a growing interest in the use of AI in STEM education. Furthermore, publications have increased eightfold since 2020 (from 19 total papers in 2015–2020 to 152 total articles in 2021–2025, with a dip in 2022). Interestingly, publications in 2025 alone, from

January to mid-August, account for approximately 35% of the total publications. This reflects a significant and growing interest in the use of AI in STEM education.

Influential research on AI in STEM education

Influential sources and most cited documents

Bradford's Law, which was introduced in 1934 and further discussed in 1985, is a theory that explains the distribution of publications within a certain domain of knowledge by showing that a small number of publications are contributed by a small group of journals, while the majority of journals contribute a small number of publications each (Brookes, 1985). Bradford's Law categorized sources into three productivity zones: the core zone, the intermediate zone, and the peripheral zone, based on the sources' publication frequency within a certain domain of knowledge. This theory states that a small number of journals contribute a significant number of the most important publications within a certain domain of knowledge, while the majority of journals contribute a significantly small number of publications within the same domain of knowledge. It was further stated that the number of publications within this theory increases geometrically (Hossein-Mohand et al., 2025). This theory helps identify the journals that are most central within a certain domain of knowledge by showing which journals contribute the majority of publications within the same domain (Nicolaisen & Hjørland, 2007)

The Bradford's Law analysis of 171 publications of AI integration in STEM education shows a highly concentrated publication distribution among 105 unique sources, indicating a strong core-periphery structure, typical of a well-established research field. Zone 1, including 9 core sources of journals and conference proceedings (8.6% of all sources), contains 62 publications, or 36.3% of total output, indicating that a third of all output is contained in less than 10% of sources. The most pertinent sources, as measured by the quantity of papers published on AI and STEM education throughout the study period, based on Zone 1 according to Bradford's Law, are shown in the analysis that follows in **Table 2**.

Table 2

Sources categorized in zone 1 according to Bradford's law

Sources	Rank	F	CF
Proceedings - Frontiers in Education Conference, FIE	1	14	14
IEEE Global Engineering Education Conference, Educon	2	13	27
Frontiers In Education	3	9	36
Education And Information Technologies	4	7	43
Computer Applications in Engineering Education	5	4	47
Computers And Education: Artificial Intelligence	6	3	50
Education Sciences	7	3	53
Eurasia Journal of Mathematics, Science, and Technology Education	8	3	56
IEEE Transactions on Learning Technologies	9	3	59

*Note: F = frequency of published documents, CF = cumulative citation frequency.*

As shown in **Table 2**, the "Proceedings - Frontiers in Education Conference" and "IEEE Global Engineering Education Conference" emerge as the top contributors, with 14 (8.2%) and 13 (7.6%) documents, respectively, for the total production per journal or conference. Next in line were "Frontiers in Education" with 9 documents (5.3%), "Education and Information Technologies with 7 documents (4.1%), and Computer Applications in Engineering Education with 4 documents (2.3%). What is more interesting is that 5 sources had 3 documents each, whereas 14 sources had only 2 articles each (1.17%). On the other hand, the rest of the 81 sources, which accounted for 47.4% of the total documents, had only 1 document each, which accounted for only 0.58% for the total production per journal or conference. Zone 2 has 40 sources (38.1% of total sources) contributing 28 publications, while Zone 3 has 56 sources (53.3% of total sources) contributing 81 publications. This is the classic Bradford distribution, whereby the bulk of the sources contribute minimally to the research corpus. This suggests that the research area of AI in STEM education has developed a stable body of specialized journals and conferences in the areas of educational technology and engineering education, with key journals such as Education and Information Technologies and Computer Applications in Engineering Education, along with conference papers, being the main channels for the rapid dissemination of new research.

In addition, the most globally cited documents of AI research in STEM education are reported in **Figure 4**. **Figure 4** shows that the work by Kim NJ. (2022), published in Frontiers in Education, is definitely at the top of the list with a total of 143 global citations, establishing the author as a reference in terms of scientific importance. Ding L. (2023), published in the International Journal of Educational Technology in Higher Education, ranked second with 89 citations, followed by How M-L. (2019), published in Education Sciences, with 87 citations. This high citation count may indicate that fresh or emergent topics have quickly and widely piqued the scientific

community's interest. The publications with the most citations appeared in a variety of scientific journals. This collection of publications demonstrates that educational technology research is applied in a variety of technological and pedagogical situations, emphasizing the field's multidisciplinary nature.

Figure 4

Most globally cited publications in AI-enhanced STEM education research (Source: Authors' elaboration using R Program Biblioshiny)
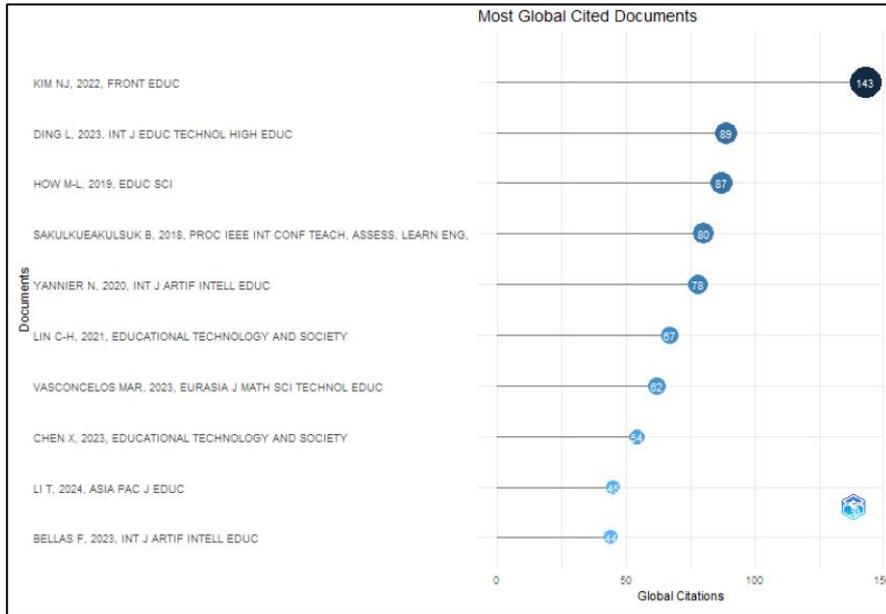
The most relevant authors and their production over time

The authors with the largest number of relevant documents were Li T. with six documents, Huang Y-M., Kim J., Lee H-Y., Lin C-J., and Wu T-T. with five documents each, Chen X., Wang W-S., and Zhan Z. with four documents, and Ali M. with three documents. The following **Figure 5** shows the author's production over time, where the bubble size indicates the number of articles published in a given year, while the color intensity corresponds to the Total Citations per Year (TCpY). Many bubbles are appearing in 2023-2025, demonstrating a growing trend towards the topics of AI and STEM.

Figure 5

Temporal evolution of author productivity in AI-enhanced STEM education research (2015-2025) (Source: Authors' elaboration using R Program Biblioshiny)
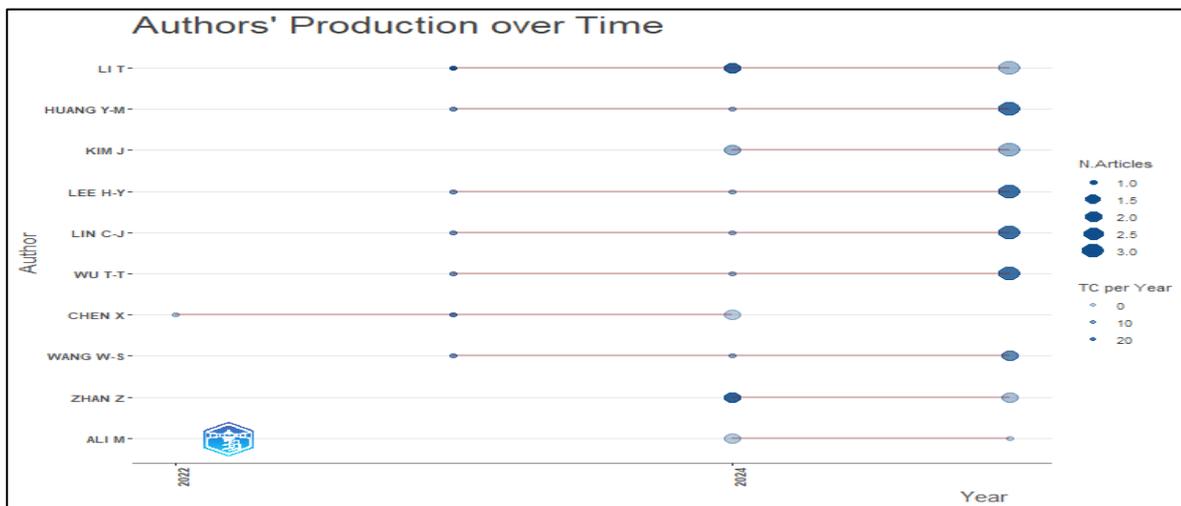

Figure 5 indicates that most authors have a relatively short publication history within the scope of this bibliometric analysis, primarily spanning from 2022 to 2025. This suggests a recent emergence or growing interest in the specific research area captured by the analyzed publications (AI and STEM). Lee T has a good

number of publications (six articles), and his citations are good, with a focus on the integration of artificial intelligence in education and virtual teachers. Kim J follows, with five articles published in this field, with a focus on inclusive STEM education. Huang Y-M, Lee H-Y, Lin C-J, and Wu T-T have some common publications. They have five publications in 2023 and 2025, with a relatively high annual growth rate (TCpY), with a focus on enhancing reflective thinking and adaptive learning with the help of AI. Chen X, Wang W-S, Zhang Z, and Ali M have some publications, with a focus on relatively recent publications (in 2022), with some publications having few citations. Kim J has a surge in publications, with a focus on AI applications.

The most relevant affiliations and their production over time

Analysis of institutional contributions reveals a concentration of research productivity among specific universities with established programs in educational technology and STEM education. **Table 3** presents the most productive institutions ranked by publication output, identifying key research centres driving innovation in AI-enhanced STEM education.

Table 3

Most productive institutions in AI-enhanced STEM education research

Affiliation	Articles	Percentage	country
National Cheng Kung University	20	11.70%	Taiwan
South China Normal University	16	9.40%	China
Singapore University of Technology and Design	10	5.80%	Singapore
Lingnan Normal University	8	4.70%	China
Mindanao State University-Sulu	8	4.70%	Philippines
Monash University	8	4.70%	Australia
Total (Top 6)	70	40.90%	

As indicated in **Table 3**, the top-of-the-world producer is National Cheng Kung University, with 20 publications (11.7% of total output). The second-best competitor in the world, following the same trend but not so strong, is South China Normal University, with 16 publications (9.4%). The third best is the Singapore University of Technology and Design, with 10 publications (5.8%), while Lingnan Normal University, Mindanao State University-Sulu, and Monash University each produced 8 publications (4.7% each). The top six institutions collectively account for 70 publications, representing 40.9% of the total research output. This shows the competitive environment in which these institutions operate. Their strategic focus on digitalization in education and the significant investments they have made in the infrastructure of AI can be considered the main reasons for the concentration of research efforts in technologically advanced Asian economies. The beginning of an in-depth analysis of the application of AI in STEM education can be seen in the relative increase in publications, with these institutions taking the lead globally in the introduction of best practices and methodology.

This moderate concentration suggests that while several institutions have established strong research programs, the field is not dominated by a small number of elite universities, allowing for diverse perspectives and approaches. Notably, five of the six most productive institutions are located in Asia (Taiwan, China, Singapore, and the Philippines), with only Monash University representing Australia, indicating strong regional research capacity and investment in AI-enhanced STEM education within the Asia-Pacific region. This geographical pattern aligns with broader trends in educational technology research and national priorities emphasizing STEM education and technological innovation in Asian countries."

Besides total institutional productivity in terms of institutions (**Table 3**), temporal analysis of publication patterns helps in ascertaining the time of entry of each institution into the research field and the trajectory of its contribution to date. **Figure 6** shows the temporal evolution of institutional productivity from 2015 to 2025, which represents the trajectory of each institution's contribution based on its strategic goals and development, as well as its adoption of technological innovations in AI.

From **Figure 6**, it is evident that three different stages of engagement are evident in AI-assisted STEM education research. The emergence stage is evident from 2015-2019, with pioneering institutions such as National Cheng Kung University and South China Normal University having a modest number of 1-2 publications per annum. The expansion stage is evident from 2020-2021, with a gradual increase in productivity and new institutions entering the domain of AI-assisted STEM education research, such as the Singapore University of Technology and Design. However, a major acceleration is observed from 2022-2023, wherein institutions are observed to have exponential growth curves with sharply increasing trajectories that perfectly coincide with the emergence of ChatGPT in November 2022 and the availability of AI tools within the field of education. The leading institutions are observed to have accelerated their research output exponentially from 2-3 publications per annum in 2021 to 6-8 publications per annum in 2023, signifying substantial investments in research programs and recruitment of human resources for such purposes. The sharply increasing trajectories are

observed even up to 2024-2025, signifying that this is not a surge but a fundamental expansion of institutional engagement in AI-assisted STEM education research. The steeply rising lines indicate how promising this field is still considered to be.

Figure 6

Institutional productivity over time in AI-enhanced STEM education research (Source: Authors' elaboration using R Program Biblioshiny)
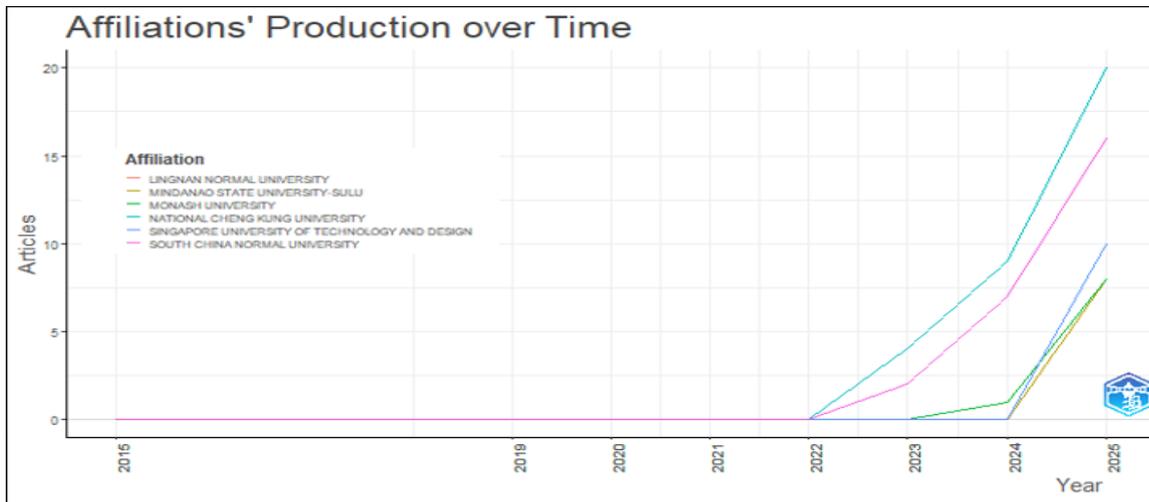
Most cited countries

Although the number of publications reflects research productivity, citation analysis measures the countries that have the most impactful research in AI-enhanced STEM education discourse. **Figure 7** displays the total number of citations per country, showing which countries have had the most impactful research in terms of shaping the discourse in terms of its theoretical underpinnings, methodology, and applications.

Figure 7

Total citation counts by country for AI-enhanced STEM education research (Source: Authors' elaboration using R Program Biblioshiny)
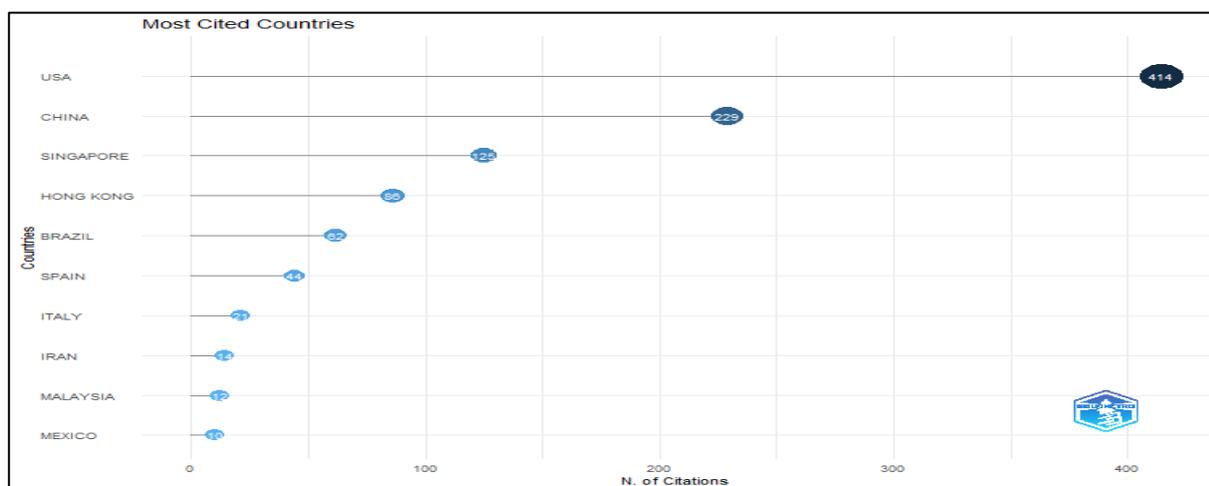

Figure 7 shows that the USA is the most referenced country, with 414 citations overall, making it the most prominent country in terms of the scientific influence of AI in STEM education. China comes in second place with 339 citations (82% of U.S. impact), demonstrating significant influence despite fewer publications. Singapore ranks third with 125 citations, indicating a strong impact relative to its publication volume and suggesting high average citation rates. Following with 86, 62, and 44 citations each are Hong Kong, Brazil, and Spain. Though citations are lower in the other nations.

Such a high citation disparity between the top two countries and the rest may indicate the dominance of a few research powerhouses in disseminating scholarly knowledge. Such findings may lead to an understanding of the

possible citation biases that may be in favor of well-established research institutions in developed countries, as highly cited research from the dominant countries may shape the international research directions in AI-based STEM education.

Corresponding author's countries

While publication volume and citation impact reveal research productivity and influence, collaboration patterns provide insights into the international versus local character of research programs. **Figure 8** presents corresponding author country data and international collaboration rates, distinguishing between single country publications (SCP) and multiple country publications (MCP).

Figure 8

International collaboration patterns by corresponding author's country (Source: Authors' elaboration using R Program Biblioshiny)

SCP: Single Country Publications, MCP: Multiple Country Publications
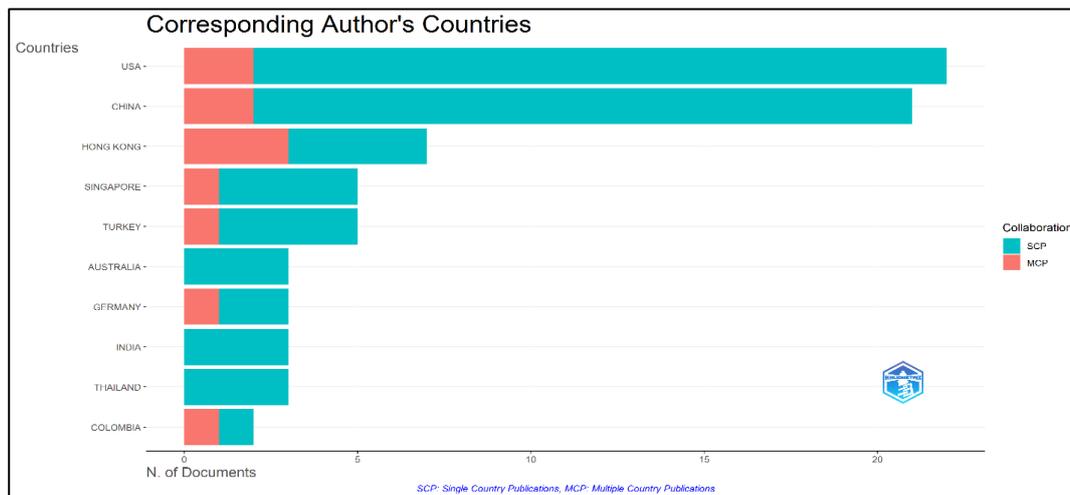
Figure 8 reveals that the leading producers are the United States (22 articles) and China (21 articles), which predominantly use single-country periodicals. However, the low percentages of multiple-country publications (MCP) (9.1% and 9.5%, respectively) indicate a concentration on domestic research within these countries, which potentially limiting incorporation of international perspectives and cross-cultural insights. In contrast, Hong Kong has a higher international collaboration rate (MCP: 42.9%) of its total research. Followed by Colombia (MCP%50). Overall, the data reveal a mismatch between research production and international collaboration, with certain countries prioritising local research.

This large discrepancy illustrates the inherent contradiction between productivity and collaboration, as the United States and China prioritize their domestic programs to achieve high publication rates through their existing national networks, while Hong Kong and Colombia prioritize international partnerships to improve research capabilities and cultural understandings. In terms of the SDGs, this phenomenon prompts important concerns about whether research that prioritizes large domestic programs effectively considers the varied international contexts necessary to achieve quality education (SDG 4), workforce development (SDG 8), and reduced inequalities (SDG 10) or whether international collaboration can improve research relevance to achieve the SDGs in sustainable development contexts internationally.

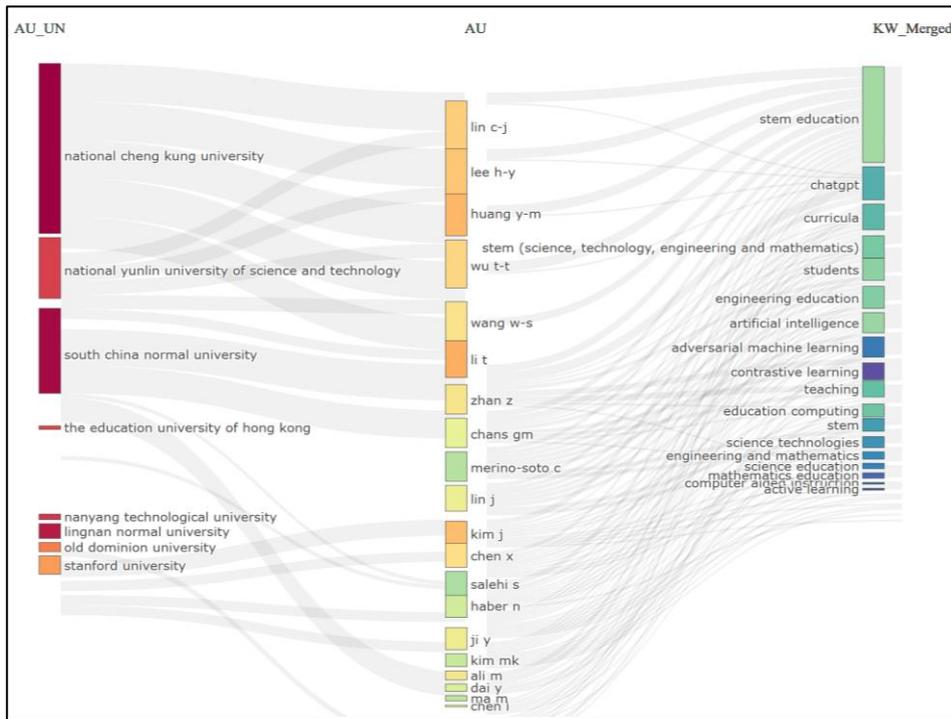### Interconnections among authors, institutional affiliations, and research keywords

In addition to examining authors, institutions, and keywords separately, analyzing their interrelationships shows how research capabilities and subject-matter expertise are distributed within the field. **Figure 9** presents a three-part diagram illustrating the relationships between the most prolific authors (AU), their institutions (AU_UN), and keywords (KW_Merged), The line thickness (flows) graphically expresses the strength or frequency between the items of each category. Providing a comprehensive view of the network structure that organizes knowledge production in AI-enhanced STEM education.

The network structure represented in **Figure 9** illustrates that knowledge production in AI-enhanced STEM education is organized in terms of clusters, rather than as a uniformly distributed field. The high flows between National Cheng Kung University and the keywords 'stem education' and 'chatgpt' reveal the presence of institutional research programs in which multiple scholars investigate a theme, which may potentially create a positive environment in terms of shared resources and collaborative synergies. The weaker flows between other institutions and more specific keywords such as 'adversarial machine learning' may reveal areas of research expertise by individual scholars or small research groups. This is characteristic of a maturing interdisciplinary

field in which core themes are addressed by multiple institutions, while more specialized topics are addressed by specific research groups.

Thematic clusters and trend topics

Co-occurring keywords and thematic clusters

To understand the thematic structure and conceptual organization of AI-enhanced STEM education research, keyword co-occurrence analysis was conducted using VOSviewer. **Figure 10** illustrates the network of major research topics, revealing how different concepts and themes are interconnected within the field.
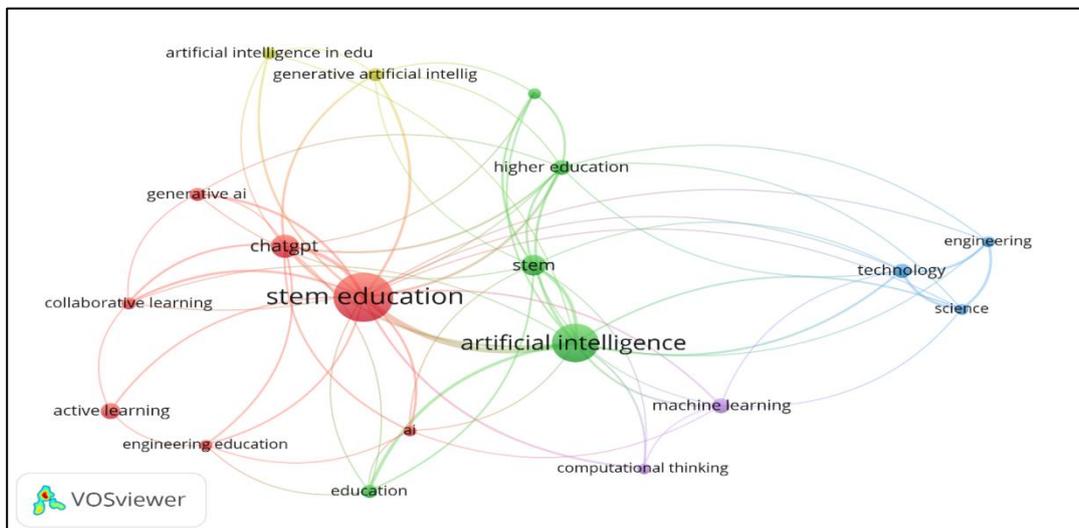
As depicted in **Figure 10**, the keyword network indicates the presence of five distinct thematic clusters, which signify distinct research domains in AI-enhanced STEM education. These thematic clusters are distinguished from each other using color-coding and signify the complex nature of this field, which varies from

emerging technologies and pedagogical tools to foundational disciplines and computational tools. The five thematic clusters identified in this study are presented in **Table 4**, which indicates the labels and keywords.

Table 4

Inclusion and exclusion criteria applied in document selection

| Cluster Color	Cluster Label	Representative Keywords
Red	Generative AI & Pedagogical Integration	STEM education, ChatGPT, generative ai, collaborative learning, active learning, engineering education.
Green	Core AI & Educational Systems	Artificial intelligence, stem, higher education, educational innovation, education, ai.
Blue	Foundational STEM Fields	Technology, science, engineering.
Yellow	AI Specializations & Applications	Artificial intelligence in edu, generative artificial intellig.
Purple	Computational Analysis	Machine learning, computational thinking.

As illustrated in **Figure 10** and shown in **Table 4**, the keyword network reveals five distinct thematic clusters, each representing a coherent research domain within AI-enhanced STEM education. These five thematic clusters show different degrees of alignment with the SDGs 4, 8, and 10, though the issue of equity is still not adequately represented. Cluster 1: "Generative AI & Pedagogical Integration" is aligned with SDG 4 in terms of the "quality education" strategy that incorporates "collaborative learning" and "active learning" pedagogies, as well as SDG 8 in the development of competencies in technology-intensive professions, especially in the field of engineering education that prepares students to enter the workforce (Huang et al., 2019). Cluster 2: "Core AI & Educational Systems" is aligned with the issue of equity represented in SDG 10 in the field of "educational innovation" that expands access to education at the higher education level, though it might overlook the issue at the K-12 and vocational education levels (Garcia et al., 2023). Cluster 5: "Computational Analysis & Thinking" is aligned with SDG 8 in the development of competencies in "computational thinking" and "machine learning" that are essential in the AI-driven job market (Peng et al., 2019). However, the lack of the use of key equity-related words such as "accessibility," "inclusion," "gender," "diversity," and "disadvantaged populations" in the clusters may imply that although the research is relevant to the achievement of the fourth SDG, which is the provision of quality education, and the eighth SDG, which is the development of the workforce, not enough attention is paid to the achievement of the tenth SDG, which is the reduction of inequalities in education and the economy, and this is an area that needs to be explored in the future to ensure that AI is used to promote equity in STEM and not to widen the gaps that exist

Trend topics

While **Figure 10** and **Table 4** identified current thematic clusters, temporal analysis reveals how research priorities have evolved over the study period, reflecting technological advancements, societal changes, and shifting educational needs. **Figure 11** presents the temporal evolution of research terms from 2015 to 2025, illustrating distinct phases of thematic development.

Figure 11

Temporal evolution of research terms in AI-enhanced STEM education (2015-2025). (Source: Authors' elaboration using R Program Biblioshiny)
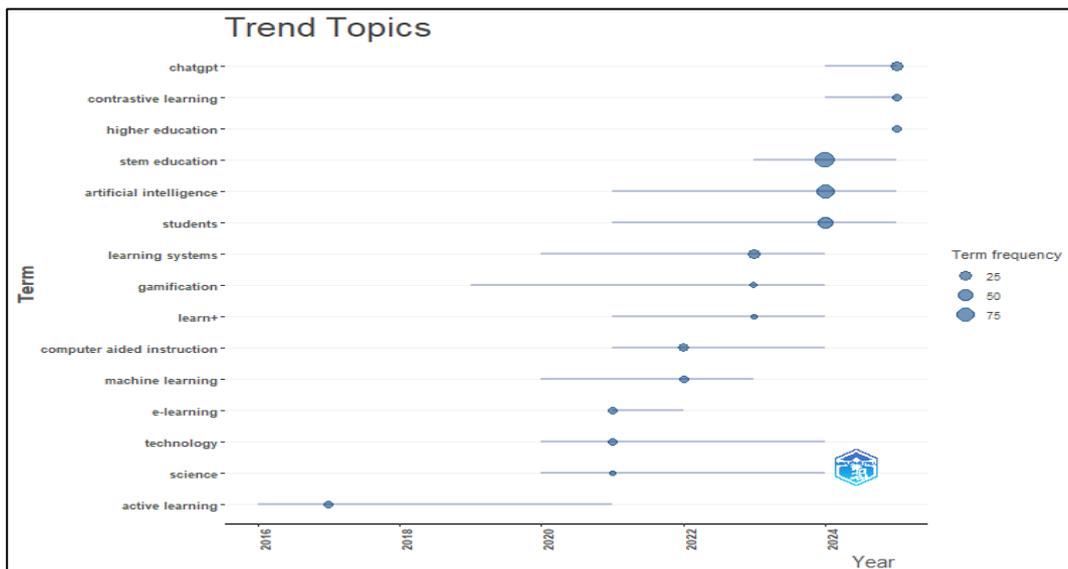
The temporal evolution of the research themes in **Figure 11** shows a clear trend in research priorities that align with the Sustainable Development Goals 4, 8, and 10. The research priorities in the early period (2016) were "active learning" pedagogies that aligned with the focus on "quality education" in SDG 4. In the second period (2020-2022), the priorities of the research were "e-learning," "machine learning," "learning systems," "gamification," which may reflect the impact of the COVID-19 pandemic and the "digital transformation" in education, as well as the "potential of AI in education to support the objectives of quality education in SDG 10 and workforce development in SDG 8" (Peng et al., 2019; Garcia et al., 2023). In the most recent period (2024), the research priorities were "ChatGPT," "contrastive learning," "higher education," "STEM education," which likely reflect the rapid development in generative AI technologies and the recognition of the importance of AI literacy in the education sector. However, the progression from pedagogical foundations through technological implementation to the latest AI applications illustrates the dynamism of the field in addressing the issue of quality education (SDG 4) and workforce preparation (SDG 8), while the lack of substantial attention to issues of equity (SDG 10) in the past may necessitate future studies to focus on how the latest AI applications may help to reduce rather than increase educational and economic inequalities among diverse populations of learners.

DISCUSSION

The bibliometric summary of AI trends in STEM instruction based on Scopus information indicates a changing and increasingly dynamic research landscape with major geographic trends, thematic emphasis, and exponential increases that all suggest the transformational potential of AI in the classroom. The steep rise in publications since 2015 is consistent with wider technological developments in computational processing power, natural language processing, and machine learning that have enabled AI uses to be more realistic and sophisticated (Chen et al., 2022; Zawacki-Richter & Latchem, 2018; Webb, 2026). The transition of AI technology from experimental prototype to effective pedagogic tool responsive to genuine pedagogical issues is a testament to the trend of growth. As institutions around the world sought technological solutions to ensure educational continuity during periods of remote learning, the COVID-19 pandemic likely accelerated the adoption of AI. This created opportunities for AI technologies to show their worth in supporting a variety of learning modalities (Almarashdi, 2024; Southgate et al., 2019; Bakir & Banikhalaf, 2025). Findings from recent systematic reviews that show how AI applications in education have developed from basic rule-based systems to complex adaptive learning platforms driven by deep learning algorithms are supported by the temporal trends found (Hwang & Tu, 2021; Xu & Ouyang, 2022). Recent research also demonstrates the transformative potential of AI to advance SDG 4 by promoting equality, access, and quality of education, while supporting SDG 8 through workforce development initiatives that prepare students for decent work in AI-driven economies, where employer demand for AI skills has grown significantly since 2010 (Gajjala et al., 2026).

The field of AI-enhanced solutions for STEM learning focuses on adaptive algorithms, immersive technologies, and individualized learning that aligns with SDG 4's promotion of inclusive and equitable quality education, as well as bordering on SDG 8's interest in the acquisition of technical and vocational skills for employment, decent work, and entrepreneurship in technology-based businesses. These technologies are an answer to the constraints of catering to diverse learning needs in traditional classrooms. Yet, there may be gaps in research, with less research addressing critical problems of implementation such as teacher professional learning, infrastructure requirements, issues of equity, and sociotechnical considerations (Susanto et al., 2020). The geographical distribution of research output, wherein the United States and China are among the leading producers, replicates global trends for AI research and development. Carnegie Mellon University and the Education University of Hong Kong are among the leading sources of innovation for AI-facilitated STEM education. Geospatial focus, however, raises concern for SDG 10 (reduced inequalities) in terms of research agendas, methodological bias, and relevance to diverse school environments (Garcia et al., 2023; Muciaccia & Macchia, 2025; Hahn et al., 2025). Emerging publications from developing nations could diversify the body of research and promise that AI applications pay regard to issues relevant in a broader range of school environments (Smith & Jones, 2020).

CONCLUSION

The inspiration for this research is derived from the works of Donthu et al. (2021), and Zawacki-Richter & Latchem (2018). The types of insights gained from this type of bibliometric research are helpful in providing guidance in terms of how to best navigate this complex landscape, but also require the heterogeneity of approaches, knowledge, and critical reflection in terms of the goals, values, and outcomes of AI in education. Continuous dialogue by researchers, educators, policy thinkers, learners, and communities should guide the path to AI-facilitated STEM education for the universal benefit of all students, coupling technological advance with

learning values in support of an enhanced human flourishing, with frequent systematic reviews of research trends remaining essential to keep pace with developments, feel out evolving priorities, and ensure that the research activity is mapped into the highest priority needs and opportunities in AI-facilitated STEM education. The transformative potential of artificial intelligence (AI) in STEM education will grow as its technologies continue to develop and mature, presenting both opportunities and challenges for education systems worldwide. Realizing this transformative potential of AI in STEM education requires sustained investment in scientific research, evidence-based policymaking, international collaboration, and a firm commitment to equity and quality education.

RESEARCH LIMITATIONS

The methodological limitations of this bibliometric study should be taken into consideration while interpreting its results. The study's reliance on the Scopus database and English publications may create biases, which can result in the exclusion of important publications from regional publications, non-English publications, and emerging publications not indexed in Scopus (Mongeon & Paul-Hus, 2016). The publications addressing regional educational challenges in non-English-speaking regions, where important innovations in AI and STEM education are likely to take place, are not adequately represented in this study. The study's focus on publications from the "Social Sciences" category in the Scopus database may result in the exclusion of important publications from publications in computer sciences, engineering, or pure sciences that deal with educational applications from different categories, which are not included in this study. The exclusion of publications like books, book chapters, reviews, and grey publications, which are not peer-reviewed publications, while important for maintaining the quality and consistency of publications, means that important syntheses, frameworks, and policy publications are not included in this study (Zawacki-Richter & Latchem, 2018).

Moreover, it is important to note that there are limitations to the use of bibliometric indicators, where the number of citations reflects various biases, including the publication's age, the authors' prestige, and the prestige of the organization, while publications that were recently made have not had the adequate time to be cited, possibly diminishing the value of the latest research on the latest technologies in artificial intelligence (Donthu et al., 2021). In addition, the thematic analysis, using the method of keyword co-occurrence, may not accurately represent the complexity of the concepts, where the research does not specifically focus on research that aligns with the SDG, possibly diminishing the value of research that focuses on educational equity, workforce, and economic growth. Most importantly, the quality of the research, the effectiveness of the research, and the application of the research cannot be determined using the bibliometric method, where the number of publications does not necessarily equate to the effectiveness of the research, the application of the research, and the successful educational outcomes (Zupic & Čater, 2015).

FUTURE RESEARCH

Subsequent studies must be implementation-focused, longitudinal in design, comparative in methods, sociotechnical and equity-oriented in their goals, so that AI benefits are distributed to different student groups. Moreover, caution should be exercised concerning the manner in which AI assimilation can accelerate or turn back momentum towards the achievement of Sustainable Development Goals 4, 8, and 10, and towards keeping technological advancement in line with the values of quality learning, decent work, economic prosperity, and reduction of inequalities on which the 2030 Agenda for Sustainable Development is based. Policymakers must acknowledge that effective AI integration involves coordinated investment in various areas like infrastructure technology, teacher professional development, curriculum adjustment, and quality mechanisms, while trading off stimulating innovation against reasonable protections for students' privacy, algorithmic explainability, and ongoing human control over essential educational choices (Huang et al., 2019).

Ethical statement

This bibliometric study utilized publicly available published literature from the Scopus database and did not involve human participants, primary data collection, or experimental interventions. Therefore, formal ethical approval from an institutional review board was not required.

Competing interests

The authors declare no conflicts of interst, financial or otherwise, that could have influenced this research.

Author contributions

Hanan Shaher Almarashdi: Research concept and design, Collection and/or assembly of data, Data analysis and interpretation, Writing the article, Critical revision of the article, and Final approval of the article. Othman Abu Khurma: Collection and/or assembly of data, Writing the article. Khaleel AlArabi: Collection and/or assembly of data, Writing the article. Enas Abulibdeh: Collection and/or assembly of data, Writing the article. Jihan Yousef: Collection and/or assembly of data, Writing the article. All authors contributed to the Final approval of the article.

Data availability

The data supporting the findings of this study were retrieved from the Scopus database.

AI disclosure

AI-assisted writing tools were used solely for language editing, grammar checking, and improving text clarity and readability. All subtantive research contents represent the orginal work of the authors. The authors assume complete responsibility for the accuracy, integrity, and final content of this manuscript.

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