

A Bibliometric Analysis of Trends in Artificial Intelligence and STEM Education

Amaira Utami* and Nanang Winarno

Department of Science Education, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Indonesia

Abstract

The application of artificial intelligence (AI) to pedagogical frameworks is rapidly evolving, particularly in STEM education. This study investigated research trends in the literature on AI and STEM education from the earliest to the most recent. A bibliometric analysis was conducted to answer seven research questions. The Scopus database was used to collect data, yielding 354 documents from 2008 to 2025. The findings revealed that publication trends in AI and STEM education increased gradually, whereas the annual citation rate fluctuated. According to the keyword co-occurrence analysis, STEM education, AI, and robotics were the most commonly used terms. Research trends in AI and STEM education are evolving from the integration of simple computer systems in early publications to the practical use of AI platforms, such as ChatGPT, in STEM teaching. These findings provide comprehensive information and insights into the dynamics of AI and STEM education, informing future research.

Keywords: Artificial intelligence, bibliometric analysis, robotics interventions, STEM education, technology-enhanced learning

Introduction

In this fast-paced world, where science and technology advance rapidly, Artificial Intelligence (AI) makes significant contributions to human life, including in education. The emergence of AI in education has attracted considerable attention in recent years (Chen et al., 2020; Hwang et al., 2020). AI is recognized as a supercomputer with advanced capabilities that integrate adaptive behaviour, human-like cognition, and two-way communication between humans and computers (Chen et al., 2020; Kohnke & Zaugg, 2025). Artificial Intelligence is a broad concept encompassing computational technologies that replicate human thought, enabling machines to tackle tasks that would previously have required human intelligence (Jantakun et al., 2021). The presence of AI aims to facilitate idea generation in addressing cognitive challenges by mimicking human intelligence, including pattern and speech recog-

niton, learning adaptation, and decision-making (Chassignol et al., 2018; Sharma et al., 2019; Wartman & Combs, 2018).

Artificial Intelligence in Education (AIEd) has emerged as an interdisciplinary field that integrates advanced technologies such as machine learning, data analytics, and algorithms (Kavitha & Joshith, 2024) within educational paradigms, particularly in the context of teaching practices, research pursuits, assessments, and academic administration (Chassignol et al., 2018; Falebita & Kok, 2024; Hwang et al., 2020; Jebli et al., 2021). The main aim is to promote educational reform (Ouyang & Jiao, 2021) and create engaging learning environments (Xu & Ouyang, 2022a). This is aligned with interdisciplinary STEM learning, which is not just outlining the connection across science, technology, engineering, and mathematics disciplines but, more importantly, the implementation of interdisciplinary learning practices, curriculum, and

assessment (Gao et al., 2020), and deep interdisciplinary knowledge integration (Liao et al., 2021). The presence of AI may help students to understand STEM concepts better (Carlos et al., 2023). In reality, implementing STEM teaching is challenging. It is not as simple as integrating several disciplines, but the “intentional” and “specific” factors need to be considered in the curriculum (Bryan et al., 2015). Integrating AI into STEM education requires tactical considerations (Xu & Ouyang, 2022b) that go beyond technological aspects to address the social and psychological factors influencing students’ attitudes (Ateş & Gündüzalp, 2025).

The integration of Artificial Intelligence (AI) within STEM (Science, Technology, Engineering, and Mathematics) education is a subject of academic interest, particularly in identifying best practices for STEM teaching and fostering students’ skills. This study aimed to investigate the evolution of research on the use of AI in STEM education by analyzing publications from the Scopus database, spanning from the earliest studies to the most recent contributions. The outcomes of this study are expected to provide a solid foundation for future investigations in AI and STEM education. While several bibliometric studies have addressed various aspects of AI in education, such as its application in science education (Akhmadijeva et al., 2023), AI integration in STEM/STEAM education based on publications from 2014 to 2024 from the Web of Science (WoS) database (Sun & Saleh, 2024), and insights, opportunities, and patterns of AI-enhanced STEM education of 186 documents published in 2013 to 2023 from Web of Science (WoS) database (Yang et al., 2024), a comprehensive bibliometric study that systematically traces the evolution of AI research in STEM education, from the initial to the most recent publications from Scopus database remains absent. This gap in the literature highlights the need for an in-depth examination of the full trajectory of AI research in STEM education from its inception to the present publication. This study not only presents insights into emerging trends and research directions but also provides a foundational roadmap to guide future

scholars in advancing AI-driven innovation in STEM education.

Methodology

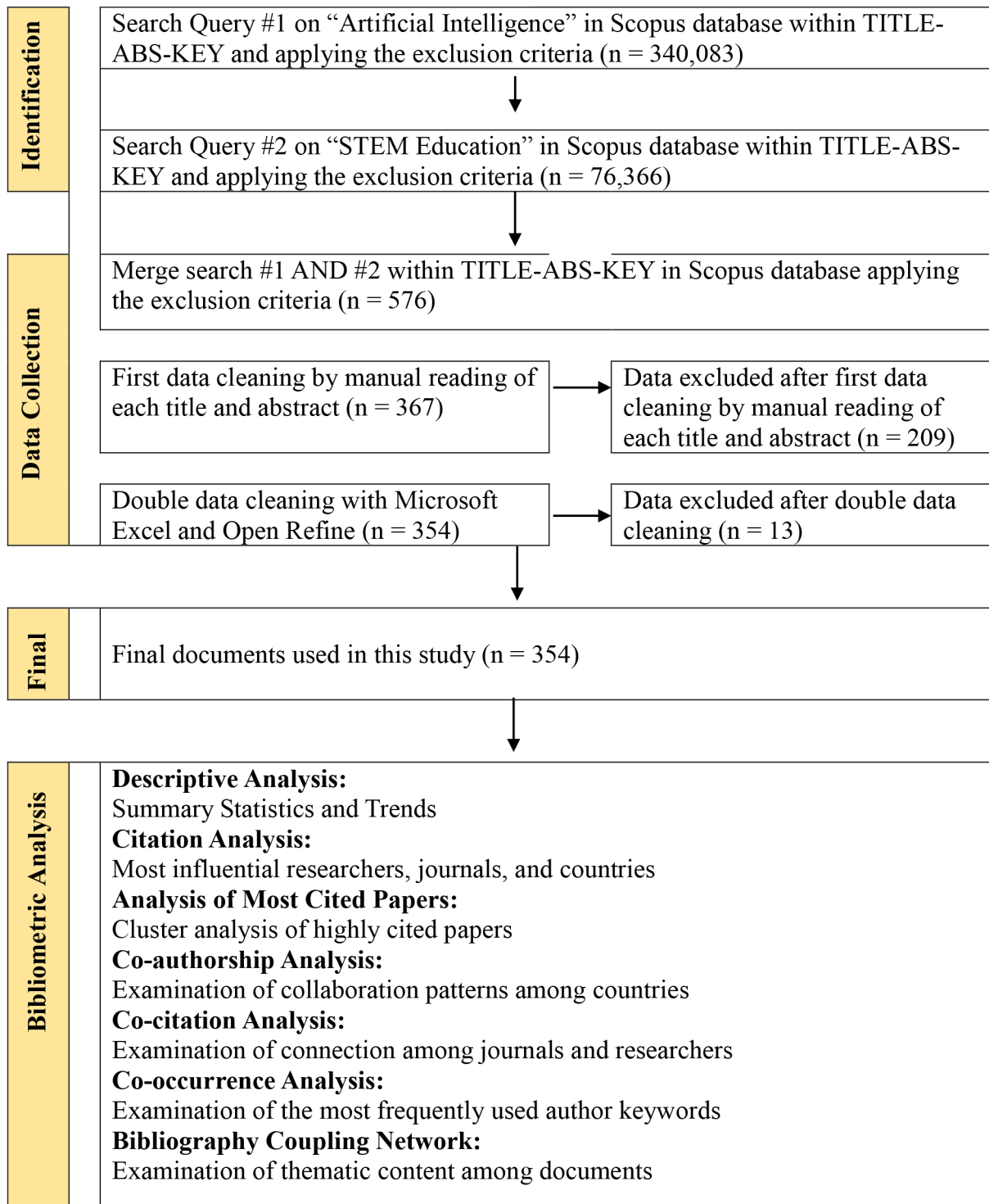
Research Design

This study employs bibliometric analysis to generate quantitative data and determine the current state of research on Artificial Intelligence and STEM education. The bibliometric study analyses the connections among publications, authors, countries, affiliations, etc., using visual data (Zupic & Čater, 2015), which is gaining substantial popularity within the academic community when combined with content analysis (Koskinen et al., 2008). This study comprises two primary stages Jamali et al. (2023): dynamic and structural analyses. Dynamic research examines publication patterns and distributions, including authors’ data, keywords, citations, and bibliometric indices such as the h-index. Meanwhile, structural studies include analyses of co-occurrence, collaboration, and co-citation networks, as well as thematic maps.

Data Collection

Data were collected from the Scopus database on March 06, 2025. Scopus by Elsevier is a prominent publisher, renowned for its high-quality studies and an extensively used database for rigorous scientific research (Alshater et al., 2022). According to Chadegani et al. (2013) the Scopus database, it has extensive coverage in the social sciences compared to the Web of Science (WoS). Alshater et al. (2022) and Falagas et al. (2008) revealed that for citation analysis purposes, Scopus provides approximately 20% better coverage than Web of Science (WoS), while Google Scholar was criticized for its inconsistent accuracy, coverage, and poor quality. Therefore, this study used the Scopus database as the source of document collection. This study examined past and current research trends in AI and STEM education. The timespan covered 17 years of publication, from the first published article on Artificial Intelligence (AI) in STEM Education in 2008 to the last review on March 06, 2025.

Figure 1: Document Collection Flow



Data Processing and Tools

The bibliometric analysis tools used in this study included Microsoft Excel, OpenRefine, RStudio, and VOSviewer. Data were collected from the Scopus database following specific search queries and inclusion and exclusion criteria, as shown in Table 1. The data were exported as Comma-Separated Values (CSV) files. Microsoft Excel and OpenRefine were used to clean the data, eliminating incomplete and inappropriate data used in this study. Double data cleaning was conducted to obtain specific and clean data for the study. Moreover, the OpenRefine software merged the terms that were meant and defined similarly. Subsequently,

RStudio and the Bibliometrix package were used to analyze the quantitative data from the documents (Aria & Cuccurullo, 2017). Because the data in RStudio was not easily editable, Microsoft Excel was used to redesign and restructure the quantitative data into graphs and tables. Finally, VOSviewer was used to visualize bibliometric networks (Van Eck & Waltman, 2010) and conduct network and content analyses of the documents used in this study. Detailed information on the document collection flow is presented in Figure 1.

Table 1: *Inclusion and Exclusion Criteria*

Inclusion Criteria	Exclusion Criteria
Empirical studies related to the field of Artificial Intelligence in Science Education Publications written in English	Not empirical studies
Article published in peer-reviewed journal	Publications written in other languages aside from English
Publications or journal issues related to the topic of the utilization of Artificial Intelligence in STEM Education	Book chapters, magazines, conference proceedings, news, posters The studies or journals' issues which does not align with the research's main topic

Result and Discussion

Table 2 summarizes the descriptive statistics for the dataset on “Artificial Intelligence” and “STEM Education” from the Scopus database (2008-2025). The data were divided into two sections according to the research design: dynamics and structure. First, in the dynamic analysis, 354 articles were published in 119 journals during the given timespan. It can be seen that the average citation per document was 24.13, which is regarded as exceptionally high compared to the social sciences fields (2.1) (Mumu et al., 2021) and the field of engineering study (6.92) (Ebrahim et al., 2020). Moreover, the dataset covered 1,125 author keywords.

On the other hand, Table 2 also presents the data from the structural study. A total of 1,167 authors published articles on Artificial Intelligence and STEM education, including 31 single-authored and 323 collaborative publications. The number of co-authors per document is 3.7, which indicates the average number of authors who collaborated on a single document. The last criterion of the bibliometric structure study is the number of references (18,461). The average number of references per document was 52.15 (18,461/354), suggesting that future studies on “Artificial Intelligence” and “STEM education” should include at least 52 references per article.

Table 2: Dataset Summary

Dynamics Study		Structure Study	
Criteria	Results	Criteria	Results
Timespan	2008-2025	Authors	1,167
Sources (number of journals)	119	Single-authored Documents	31
Documents	354	Co-Authors per Documents	3.7
Average Citation per Doc	24.13	References	18,461
Author’s Keywords (DE)	1,125		

Publication Trends by Years and Average Annual Citation

Figure 2(A) shows that the number of publications on “Artificial Intelligence” and “STEM Education” is gradually increasing. Artificial intelligence has evolved rapidly in the last few years, becoming a current research hotspot (Zhang & Lu, 2021) since the end of the 20th century (Xu, 2013). The steady increase in annual scientific publications indicates that more researchers are studying the topic, leading to advances in knowledge and the emergence of new research areas (Liu et al., 2020). The number of AI and STEM education research publications published in 2025 decreased significantly to

only 13, as the data were collected on March 06, 2025. Some documents related to AI and STEM education are likely to be produced in 2025. The graph indicates that research on “Artificial Intelligence” and “STEM education” will remain trending in the coming years. Xu and Ouyang (2022a) agree that considering AI to improve the quality of STEM learning is a fertile ground for further studies. Song and Wang (2020) revealed that further research on Artificial Intelligence is emerging. Taken together, these findings indicate that research on the integration of AI in STEM education is an emerging area with significant potential for further scholarly development.

Figure 2. (A): Annual Publication Trends

Figure 2. (B): Average Annual Citations

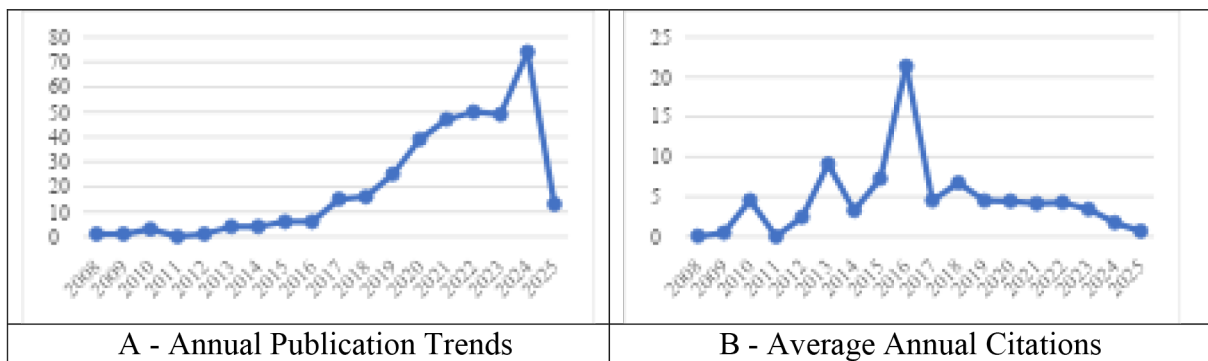


Figure 2 (B) depicts the average citations per year for research on “Artificial Intelligence” and “STEM education.” In the initial period, the average annual citation rate was 0.06, and it fluctuated in the following years, peaking in 2016 at 21.32. The average yearly citation sharply declined to 4.51 in 2017 and remained

depressed at 1.73 in 2024. Citation is sometimes referred to as the “measurement” of scientific quality (Abramo & D’Angelo, 2011; Durieux & Gevenois, 2010), encompassing aspects of scientific impact and relevance (Aksnes et al., 2019), and it can be affected by several factors.

Citation Analysis

The citation analysis of journal sources was conducted according to the h-index, number of published articles, total citations, first publication year, and link strength. Table 3 presents the top 10 journal distributions ranked by total citations. The most cited journal was Computers and Education. This open-access journal with an impact factor of 4.1 is in Quartile 1 (Q1), published by Elsevier Ltd., United Kingdom. There are 9 articles on “Artificial Intelligence” and “STEM education” published since 2015, with a total of 1,180 citations and an average citation per document (NCpR) of 131.1. The second-most-cited journal was the Journal of Science Education and Technology (TC = 667). This journal is in Quartile 1 (Q1) by Springer, Netherlands, with an impact factor of 3.3. There are 13 documents published in this journal, making it the second most productive journal. It is essential to highlight that the Journal of Science Education and Technology (JOST) not only

ranked highly based on total citations and number of publications but also achieved the highest total link strength (TLS = 52), indicating it is the most influential and impactful journal. Moreover, two journals published the most documents: IEEE Transactions on Education (NCpR = 24.7; TLS = 8) and Education Sciences (NCpR = 21.6; TLS = 14), with 15 articles published. However, these journals have low citation rates (NCpR) and total link strengths (TLS), indicating that they are less influential. The higher the TLS score, the stronger the connection between nodes (Kwon, 2023). Several researchers have also highlighted similar results: Computers & Education (Moreno-Guerrero et al., 2020; Talan, 2021), IEEE Transactions on Education (Chen et al., 2020), and the Journal of Science Education and Technology (Jamali et al., 2023) are among the standout publishers of articles related to AI and STEM education.

Table 3: Journal Distribution Rank

Journal Source	h_index	NP	TC	NCpR	PY_start	TLS
Computers and Education	8	9	1180	131.1	2015	27
Journal of Science Education and Technology	9	13	667	51.3	2015	52
International Journal of Technology and Design Education	7	8	560	70.0	2014	31
IEEE Transactions on Education	10	15	370	24.7	2010	8
Education Sciences	7	15	324	21.6	2019	14

*NP (number of publications), TC (total citations), NCpR (number of citations per research), PY_start (start of publication year), TLS (total link strength)

Citation analysis of the corresponding authors' countries was performed using the Bibliometrix package in RStudio and VOSviewer. The top 10 countries by total citations, based on the two criteria, are presented in Table 4. Firstly, the country should have at least two published articles on “Artificial Intelligence” and “STEM education” followed by the second criterion with a minimum of two citations. Initially, the authors were from 68 countries, but only 48 met the publication threshold and were included in this study. It is clear that the USA is the most

influential country, with the most publications (133), the most total citations (4,185), and the highest total link strength (123), followed by the UK in second position with 1,106 total citations from 19 publications. Some relevant studies also revealed similar results, with the US being the top country with the most published articles on Artificial Intelligence (Akhmadiyeva et al., 2023; Guo et al., 2024; N. Sun & Saleh, 2024) and STEM education (Jamali et al., 2023; Su & Yang, 2024; Zhan et al., 2022).

Table 4: *Countries Distribution Rank*

Ran k	Countr y	NP	TC	NCp R	TL S	Ran k	Countr y	N P	TC	NCp R	TL S
1	USA	13	4,18	31.5	123	6	Taiwan	16	48	30.4	23
2	UK	19	1,10	52.2	18	7	Spain	21	47	22.5	15
3	Australi a	16	872	54.5	6	8	Cyprus	4	43	108.0	26
4	Finland	4	766	191.5	13	9	Canada	15	33	22.1	31
5	Austria	3	720	240.0	5	10	Hong Kong	11	32	29.6	7

Document Citation Analysis

A citation analysis of articles with the highest citation counts on the subject in the Scopus database was conducted. The pertinent data is shown in Table 5.

Table 5: *Most Cited Documents*

Author	Title	Journal Source	Yea r	T C
Potkonjak, V., et al.	Virtual Laboratories for Education in Science, Technology, and Engineering: A Review	Computers and Education	2016	668
Kazakoff, E. R., et al.	The Effect of a Classroom-based Intensive Robotics and Programming Workshop on Sequencing Ability in Early Childhood	Early Childhood Education Journal	2013	297
Sullivan, A., & Bers, M. U.	Robotics in the Early Childhood Classroom: Learning Outcomes from an 8-week Robotics Curriculum in Pre-kindergarten through Second Grade	International Journal of Technology and Design Education	2016	265

Table 5 presents information about the top ten authors based on the most frequently cited documents in the Scopus database from 2008 to 2025. As can be seen, Potkonjak et al. (2016) received the most citations (668). They reviewed articles on virtual laboratories in STEM fields published in the journal *Computers & Education*. The second to fourth most-cited papers mainly

discussed the integration and implementation of robotics in the classroom environment. Kazakoff et al. (2013), as the second most-cited paper, received 297 total citations, followed by Sullivan and Bers (2016) 265 in the third place. Their articles discuss the design of robotics programs for preschool students.

Table 6: *Earliest Published Documents*

Author	Title	Journal Source	Year	T C
Schneider, D. R., et al.	Active Learning and Assessment within the NASA Robotics Alliance Cadets Program	International Journal of Engineering Education	2008	1
Zapata-Rivera, D., et al.	Combining Learning and Assessment in Assessment-based Gaming Environments: A Case Study from A New York City School	Interactive Technology and Smart Education	2009	8
Nugent G., et al.	Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes	Journal of Research on Technology in Education	2010	190

The three earliest publications on AI and STEM education are listed in Table 6. Schneider et al. (2008) A paper was written investigating the NASA Robotics Alliance Cadets Program to design an interactive, integrative undergraduate STEM education curriculum and assessment. The results show that the instruments meet the criteria for accessibility and sustainability and satisfy the program validation standards. This article has only received one citation since it was first published. Following this, Zapata-

Rivera et al. (2009) the focus was on fostering students' vocabulary and mathematics comprehension using BELLA, an integrated assessment and educational gaming system. These results support the idea that BELLA illustrates the advancement of artificial intelligence in the academic context, reflecting its validity as an instructional resource. Interestingly, one of the first published articles Nugent et al. (2010) had numerous citations (190) discussing the practical implications of robotics in the learning context.

Table 7: *Latest Published Documents*

Author	Title	Journal Source	Year	T C
Valeri, F., et al.	Exploring Students' Experience of ChatGPT in STEM Education	Computers and Education: Artificial Intelligence	2025	0
Li, T., et al.	Exploring Human and AI Collaboration in Inclusive STEM Teacher Training: A Synergistic Approach based on Self-determination Theory	The Internet and Higher Education	2025	0
Chan, K. W., et al.	Automatic Item Generation in Various STEM Subjects Using Large Language Model Prompting	Computers and Education: Artificial Intelligence	2025	1

The three latest publications on Artificial Intelligence and STEM Education are presented in Table 7. The total number of citations for the latest documents remains very limited; therefore, the discussion will mainly focus on the research topic. Valeri et al. (2025) In a paper titled “Exploring Students’ Experience of ChatGPT in STEM Education,” the authors aimed to investigate how upper-secondary students use ChatGPT in STEM education. A mixed-methods approach was used to gather qualitative and quantitative data through surveys and semi-structured interviews. The finding highlights students’ use of ChatGPT specifically to learn biological concepts. The results also showed that although students had a limited understanding of AI, they could perform a compelling prompting approach. Li et al. (2025) intended to explore human (interpersonal) and human-machine (generative AI) to foster STEM teaching in collaborative learning. Three collaborative methods were employed: in-service Teacher-Student Teacher Pair Learning (TSPL), ChatGPT-Student Teacher Pair Learning (CSPL), and integrated Human-Machine Collaborative Learning (iHMCL). These results suggest that the collaborative learning approach is effective across all three methods. Chan et al. (2025) systematically investigated the large language models (LLMs), such as ChatGPT’s ability to generate assessments on STEM fields. Their findings suggest that chat-of-thought prompting, particularly with GPT-4.0, produces well-formed questions, supporting the potential of LLMs as valuable tools for teachers in generating STEM-related assessments.

In summary, after discussing the most cited, earliest, and latest documents, it can be concluded that research trends in AI and STEM education are evolving. The earliest publications in the Scopus database on AI and STEM education found that research mainly focused on integrating simple computer systems. It is a contrast to notice that the research topic on AI and STEM education evolved from the use of robotics, technological devices, and game-based learning to the practical use of AI-based platforms such as large language models (Latif et al., 2023), predictive analysis

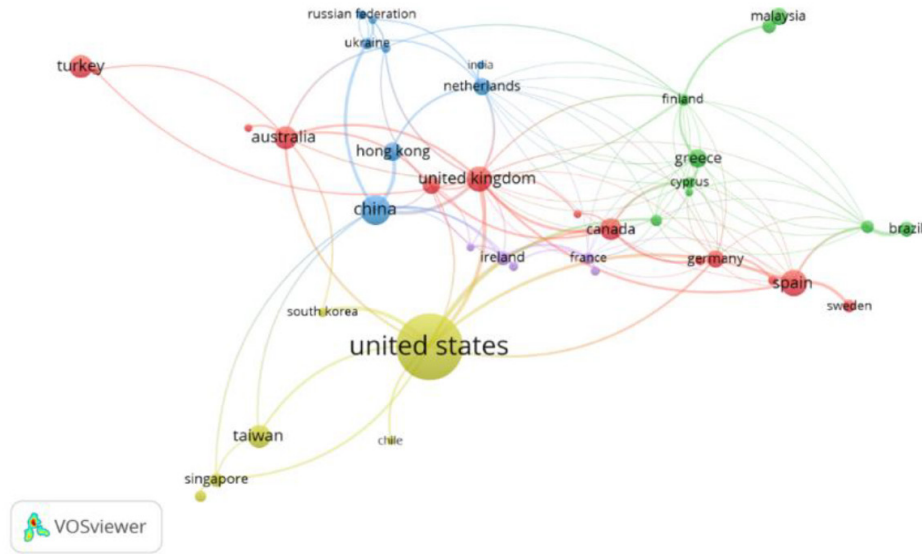
(Jia et al., 2024), deep learning (Hwang et al., 2020), and natural language processing (Chng et al., 2023). The field of AI has experienced rapid advancement and transitioned from the use of simple computer systems to embedded systems (Chassignol et al., 2018), pushing the limits of achievable capabilities with intelligent machines (Marengo et al., 2024), big data technologies (Duan et al., 2019), artificial neural networks, and deep learning (Haenlein & Kaplan, 2019).

Co-authorship Analysis

Co-authorship analysis was conducted to investigate international author collaboration. In this study, 68 countries were included; 42 met the minimum two-publication threshold for AI and STEM education. Fractional counting was performed to mitigate the impact of multiple-author documents (Alshater et al., 2022). Figure 3 shows the five clusters, each in a different color, representing how countries are connected within the research network. The UK, Canada, Colombia, and Germany were in the same cluster, presenting internal collaboration within a similar field. The size of the circle indicates the dominance of total publications, while the line indicates the connection or cooperation between countries. Moreover, a closer position between the two countries indicates a strong and broad collaboration. For instance, the United States produced the most documents co-authored with authors from 11 countries.

In contrast, the Netherlands and Germany cooperated with 14 countries (link = 14) to produce nine papers. Surprisingly, the United Kingdom has the most links (20), indicating that, in producing 19 documents, UK authors collaborated with foreign authors from 20 countries. Overall, while the US has the highest number of publications, its collaboration was limited to authors from only 11 countries. In comparison, the UK, despite producing fewer documents (19), has a significantly higher collaboration rate, involving authors from 20 countries. This suggests that both the number of publications and international co-authorship are important indicators of research impact and collaboration.

Figure 3: *Co-Authorship Analysis in the Authors' Country*

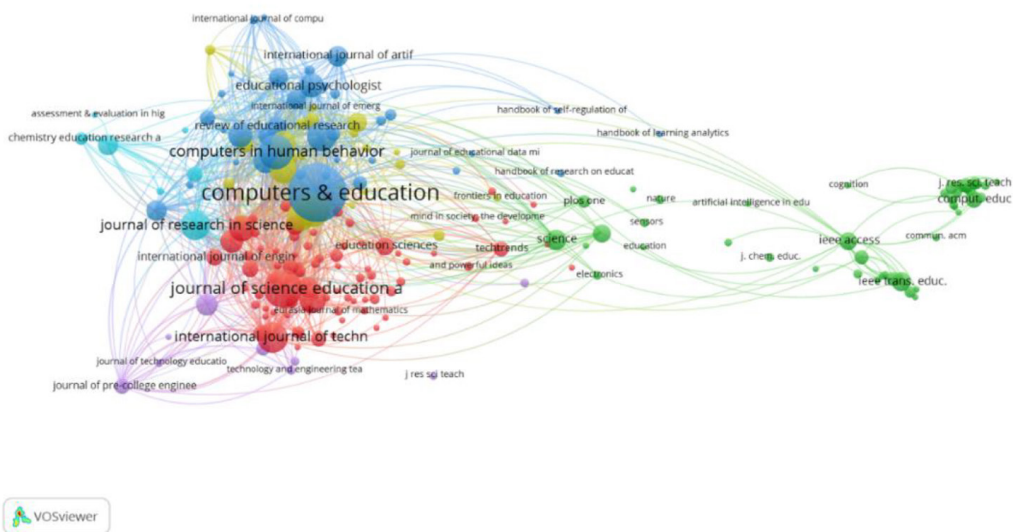


Co-citation Analysis

Co-citation analysis was conducted to visualize connections among published articles in the Scopus database on AI and STEM education. Co-citation analysis investigates the associations and interrelations among scholarly articles and research fields (Kim & McMillan, 2008). The citation count was limited to at least 10, resulting in 211 journals meeting the threshold out of 8,932. As shown in Figure 4, six clusters indicate a similar field of study, and they are often cited together. For instance, the

blue node represents computer-science-related journals such as “Computers and Education” and “Computers in Human Behaviour.” Moreover, the larger circles indicate citations that are more frequently cited within the respective clusters. The spatial distribution of the nodes indicates the connections; the closer their positions, the more often they have been co-cited. For instance, “Computers and Education” appears to overlap significantly with other journals, reflecting its centrality in the network.

Figure 4: *Co-citation Analysis on Journal Sources*

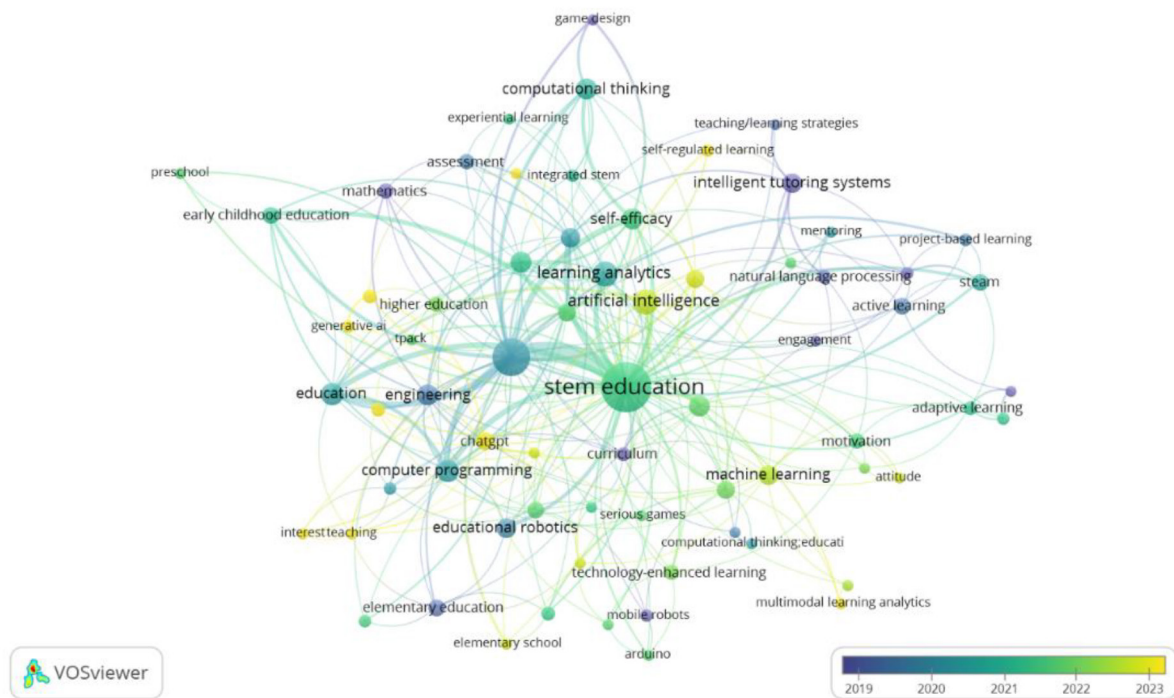


Keywords Co-occurrence Analysis

Keyword co-occurrence analysis was conducted on author keywords to determine and explore the network structure of connections among them, as shown in Figure 5. Studies on

keyword co-occurrence within scholarly publications can yield valuable insights into research trends (Liu et al., 2020).

Figure 5: *Co-occurrence Analysis on Authors' Keywords*



The occurrence threshold was set to at least 3, yielding 69 terms used in this study from an initial 1,163 keywords. STEM education is the most widely discussed term, as indicated by the larger circle relative to the other nodes. In addition to size, the location of the nodes also reflects their frequency and their strong connections to different terms. For instance, STEM education, artificial intelligence, and robotics are positioned at the center of the map, indicating their co-occurrence and the frequency with which they are studied alongside other keywords within clusters. The results also revealed that ChatGPT, artificial intelligence, generative AI, STEM integration, and machine learning are the leading, emerging, and most discussed terms, as indicated by the yellow circles.

Bibliographic Coupling Network

Bibliographic coupling analysis yields insights into the alignment of scholarly articles in terms of their thematic content or additional attributes. Bibliographic coupling analysis was conducted using VOSviewer, following Van Eck and Waltman (2010), and the unit of analysis was set to documents. Three criteria were used to define and analyze the data. First, the minimum number of citations was set at 10. Of the 354 papers, 165 met the threshold, resulting in 158 interconnected datasets. Second, fractional analysis was performed instead of full counting. Fractional counting facilitates a degree of control to minimize the effect of documents written by a larger number of authors (Alshater et al., 2022). Third, the cluster size was set to at least 10, yielding 8 clusters.

Figure 6: *Bibliometric Coupling Network Analysis*

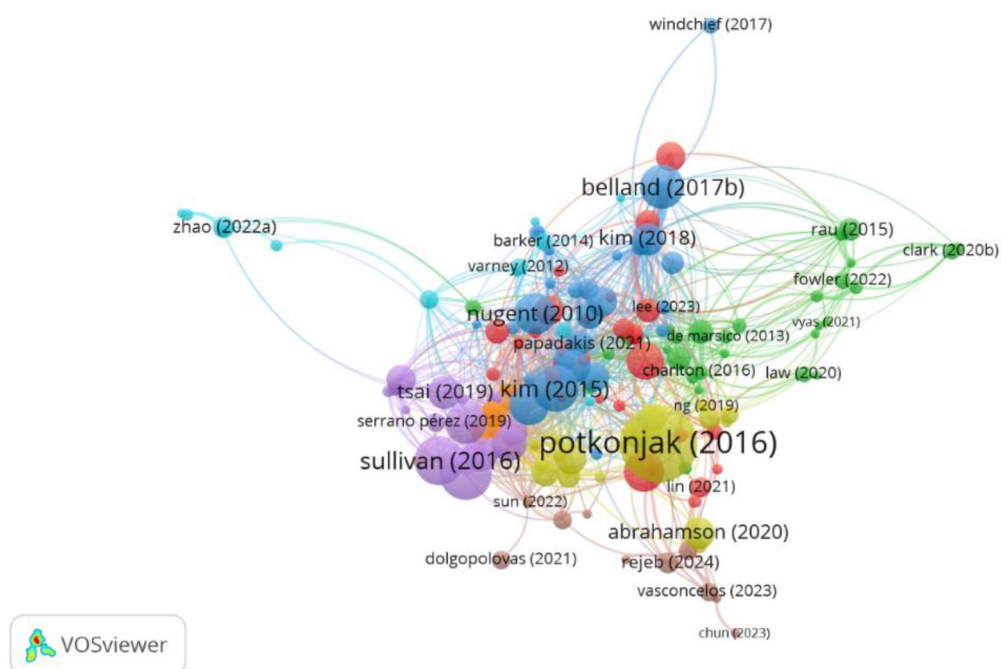


Figure 6 presents the results of the analysis of each cluster generated by VOSviewer bibliographic coupling network analysis. Furthermore, a comprehensive review and identifying its categorization, as shown in Table 8.

Table 8: *Thematic Topic of Research on AI and STEM Education*

Number	Colour	Documents	Thematic Topic
Cluster 1	Red	31 items	AI in Education and Learning Technologies
Cluster 2	Green	29 items	Technology-enhanced Learning Environments and STEM Teaching
Cluster 3	Dark blue	28 items	Robotics Interventions in STEM Learning
Cluster 4	Yellow	20 items	STEM Virtual Laboratories
Cluster 5	Purple	17 items	Robotics in Early Childhood Education
Cluster 6	Light blue	13 items	Engineering Design Process and Game Integration
Cluster 7	Orange	10 items	Robotics and STEM Perceptions
Cluster 8	Brown	10 items	Emerging Technologies and AI in Education

Cluster 1: Artificial Intelligence in Education and Learning Technologies

Cluster 1 represents the most substantial entity within the group, encompassing 31 publications that mainly focus on the broader applications of AI and various learning technologies in education. The key themes discussed in this cluster included intelligent tutoring systems, AI-driven personalized learning, and educational technologies. Lin et al. (2021) Conducted a three-week STEM learning integrated with AI for 328 students and found a strong correlation between students' AI literacy and AI ethical issues awareness. Dzikovska et al. (2014) developed a circuit simulator, "Basic Electricity and Electronics Tutorial Learning Environment (BEETLE II)" to address students' challenges in studying electricity and electronics topics through guided experimentation and reflective discussion. The results show that the system is highly effective in fostering students' self-explanation ability, with an effect size of 1.72 relative to the pre- and post-test results. Graesser et al. (2018) designed the "ElectronixTutor" to investigate intelligent tutoring systems (ITSs) to address STEM challenges, particularly on the electronic circuits topic, by gathering several types of well-tested and valid intelligent tutoring systems like BEETLE II (Dzikovska et al., 2014), AutoTutor, LearnForm, ASSISTments, narrative instruments, and videos into a single integrated system. Chng et al. (2023) identified 82 documents through a systematic literature search on how AI and technology facilitate STEM education. The results highlight that augmented reality (AR) and natural language processing are two technologies commonly used in STEM learning. Alabdulhadi and Faisal (2021) Conducted a systematic literature review of 47 publications from four databases investigating self-study simulator-based intelligent tutoring systems (ITSs) in STEM education. The study revealed that most ITSs are implemented in computer science and engineering subjects, particularly in tertiary education settings. Although they are also found in elementary and middle/high school education, their numbers are limited. Following this, Paladines and Ramirez

(2020) a systematic review of intelligent tutoring systems using natural language was conducted across 33 documents published over the last two decades. This result aligns with Alabdulhadi and Faisal (2021), who found the finding that ITSs are often used by tertiary (university) students in STEM subjects, with the majority agreeing to use them to solve scientific problems by applying laws, theories, and rules.

Cluster 2: Technology-enhanced Learning Environments and STEM Teaching

The second largest cluster, comprising 29 items, is Cluster 2. This cluster primarily focuses on designing, implementing, and evaluating technology-enhanced learning environments in STEM education, including virtual or e-learning environments, flipped-classroom models, and active-learning approaches. Fowler et al. (2022) Conducted a one-week technology-enhanced STEM program for 107 7th-grade students. The results showed that the program positively impacted students' spatial skills and attitudes towards STEM. Battaglia and Kaya (2015) Conducted experimental research on two groups of students, following a traditional lecture (23 students) and a flipped digital circuit engineering class (29 students) on a similar topic. The research revealed that students in the flipped classroom design comprehended theoretical concepts more deeply than those in the traditional lecture class. Furthermore, Yannier et al. (2020) integrated AI into the design of intelligent science station technology using a discovery model to enable active learning on specific science topics. This led to the finding that students had better comprehension of scientific principles, as indicated by a fourfold increase in post-test scores compared to pre-test scores.

Cluster 3: Robotics Interventions in STEM Learning

28 publications in Cluster 3 focused on robotics as an educational intervention in STEM learning. Nugent et al. (2010) examined two robotics and geospatial technologies interventions for middle school students. The first intervention was a 40-hour robotics program,

and the second was a 3-hour program similar to it. The results showed that the intervention period impacted students' conditions differently. Students who followed the 40-hour program had a more profound understanding, while the short-term intervention program influenced students' attitudes and motivation but did not improve their learning performance. Konijn and Hoorn (2020) designed an autonomous tutoring robot for 86 students (8-10 years) and revealed that students benefited from a robot tutor, particularly in multiplication tables. Moreover, Kim et al. (2015) aimed to facilitate pre-service teachers' design and application of STEM-based learning using robotics. Quantitative and qualitative analyses were conducted, and the results indicated that the robotics program influenced teachers' STEM engagement and attitude toward STEM. Jaipal-Jamani and Angeli (2017) also investigated robotics programs in preparing STEM teaching. The findings revealed that robotics activities enhanced pre-service teachers' self-efficacy, computational thinking, understanding of scientific concepts, and interest in integrating robotics into STEM instruction.

Cluster 4: STEM Virtual Laboratories

Cluster 4, comprising 20 documents, focuses on the use of AI and technological devices in developing and implementing STEM virtual laboratories. Potkonjak et al. (2016), as the largest node in Figure 5, is the most-cited document (TC = 668) aimed at summarizing research on virtual laboratories within STEM fields, including computer graphics, augmented reality (AR), and virtual worlds that are replicated as fully software-based virtual labs. De Jong et al. (2021) developed the "Go-Lab", an online platform that enables teachers to design Inquiry Learning Spaces (ILSs) in STEM-related online laboratories. "Go-Lab" has been translated into 30 languages, with 614 laboratory activities, including 54 remote labs, 543 virtual labs, and 17 data sets on STEM fields, benefiting 99,321 students. Hossain et al. (2018) designed an open online course and interactive biology cloud laboratories comprising 2300+ inquiry-based experiments run by over 300 students. The

study revealed that millions of users worldwide could utilize integrated open online courses and biology labs.

Cluster 5: Robotics and Programming in Early Childhood STEM Education

Cluster 5 comprised 17 documents that mainly discussed the utilization of robotics and programming in early childhood education. Kazakoff et al. (2013) investigated a one-week robotics programming program for 27 early childhood students in a STEM magnet school in the US. Paired-sample t-tests revealed that the program significantly enhanced preschool students' sequencing abilities. Sullivan and Bers (2016) conducted a two-month robotics program utilizing the "KIWI robotics kit" integrated with a programming language for 60 early childhood STEM curricula students. After the program, the children were assessed on their understanding of robotics and basic programming concepts. A significant influence on their understanding was observed, and Bers discussed "Coding as Another Language" (CAL) as a pedagogical approach for a preschool computer science program aimed at nurturing early childhood students to use a new language (symbolic or character representation) to express or communicate a function.

Cluster 6: Engineering Design Process and Game Integration

A total of 13 publications were included in Cluster 6, mainly related to the engineering design process and game-enhanced learning in STEM. Bampasidis et al. (2021) initiated a Hydrobots project involving >300 teams of students in designing remotely operated underwater vehicles applying the engineering design process (EDP) in STEM fields. The study reported that the project contributed to students' science performance, transversal ability, and positive attitude toward science and technology. Sen et al. (2021) investigated the computational thinking of gifted and talented students in a ten-week STEM program based on EDP. The program involves robotics and 3D modeling, utilizing Lego bricks, and seeks to enhance the computational thinking abilities of both gifted and talented students.

Zhao et al. (2022) investigated game-based programming courses (Newton Project and Educational Games for Programming Course) for undergraduate and postgraduate students. Four data types were collected: content understanding, students' learning confidence, interest in STEM, and learning engagement. The findings presented the positive benefits of implementing serious games in programming classes. Ferro et al. (2021) designed *Gea 2: A New Earth*, a digital serious game, as virtual 3D learning media. The serious game integrates educational resources, content-based learning materials, a communicative interface, and an intelligent tutoring system. The study focused on the game's validation and evaluation by hundreds of participants. This indicates that the game is attractive to students for learning environmental topics.

Cluster 7: Robotics and Computational Thinking

In Cluster 7, 10 documents discussed the impact of robotics programs on students' computational thinking skills. Naya-Varela et al. (2023) presented "Robobo SmartCity" as a learning resource designed to teach students the basic principles of Artificial Intelligence (AI) and nurture their computational intelligence (CI). "Robobo SmartCity" has been tested on high school students and has presented outstanding results in student learning outcomes. Shang et al. (2023) aimed to investigate third and fourth-grade students' self-efficacy and computational thinking skills by conducting a "Robotics STEM Camp" program in three consecutive days. 153 students from three rural schools in China participated in this program. The three-day robotics STEM camp significantly impacted students' self-efficacy and computational thinking. In particular, those who pursued engineering programs had stronger computational thinking skills. They explored factors influencing primary students' computational thinking (CT) skills by conducting collaborative robotics activities for fourth and fifth-grade students. The results discussed three main factors influencing CT: learning motivation, enjoyment, and intrinsic motivation.

Cluster 8: Emerging Technologies and AI in Education

Cluster 8 comprised 10 documents focused on emerging technologies, particularly Artificial Intelligence (AI) and ChatGPT, and their ethical implications for education. Ding et al. (2023) purportedly investigated undergraduate students' perceptions of using ChatGPT as a virtual educational resource in STEM education. Interestingly, the findings show that although ChatGPT is often inaccurate in its answers, students mostly believe it can answer questions correctly. Following this, Wang et al. (2024) analyzed ChatGPT's ability to answer 40 college-level engineering physics questions. Surprisingly, although ChatGPT may provide correct answers to 62.5% of questions, its answers are inaccurate (8.3%).

Conclusion

This bibliometric study has several implications, especially for future studies on the evolving trends in Artificial Intelligence and STEM education. The analysis examined publication trends, citation analysis, research hotspots and topic shifts, co-authorship, co-citation, co-occurrence, and topic diversity of past and most recent articles on AI and STEM education from 2008 to 2025. The results of this study provide comprehensive information for future researchers interested in AI and STEM education, highlighting the most popular topics and future research trends. This study also presents comprehensive information on the most established authors in AI-STEM education, offering guidance for future collaboration and partnership opportunities, access to essential resources, and staying informed about the latest advancements in the field. Information about the top journal publishers might provide insights into identifying relevant articles and ideas for choosing publishers for future research. Overall, the research findings contribute to the theoretical understanding of the dynamics of Artificial Intelligence and STEM education.

However, this study might have several limitations, ranging from the database used being limited to Scopus to the combination of

multiple databases such as Web of Science (WoS) and Google Scholar, which might yield different results and trends. Secondly, the number of publications in 2025 was limited since this study was conducted in March 2025. Moreover, this study manually read each article's abstract as a selection criterion. This stage may have had both positive and negative impacts on the study. The positive side might be ensuring that all documents used in this study align with the research topic, as collecting documents based on the research title does not guarantee that the discussion within the articles aligns with the topic. However, the author's personal interest may have influenced the selection criteria.

Conflict of Interest Disclosure

The authors declare that there are no conflicts of interest regarding the publication of this article. The authors have no financial or personal relationships that could inappropriately influence the content of this manuscript. All research and work presented in this article were conducted independently and without any external influence or bias.

Declaration of AI Assistance

The authors declare that the AI writing tool Grammarly was used to improve the clarity, grammar, punctuation, and overall readability of this manuscript. The tool was used solely for language refinement. All content, ideas, analysis, and conclusions presented in this work are entirely constructed manually by the authors.

Table 11: *Most Cited Documents' Research Hotspot*

Article	TC	Robotics	Assessment	Gaming	Early Childhood	Attitude	Virtual Laboratory	Programming	Intelligent Tutoring System	Self-Efficacy	Computational Thinking Skill	Curriculum
Potkonjak et al. (2016)	668		X				X					
Kazakoff et al. (2013)	297	X			X			X				
Sullivan & Bers (2016)	265	X			X			X				X
Kim et al. (2015)	239	X			X	X						
Belland et al. (2017)	213								X			
Nugent et al. (2010)	190	X				X						
Leonard et al. (2016)	190	X		X		X				X		
Yang (2022)	179				X							X
Jaipal-Jamani & Angeli (2017)	178	X								X	X	
Bers (2019)	131				X			X				X

References

- Abramo, G., & D'Angelo, C. A. (2011). Evaluating Research: From Informed Peer Review to Bibliometrics. *Scientometrics*, 87(3), 499–514. <https://doi.org/10.1007/s11192-011-0352-7>
- Akhmadieva, R. S., Udina, N. N., Kosheleva, Y. P., Zhdanov, S. P., Timofeeva, M. O., & Budkevich, R. L. (2023). Artificial Intelligence in Science Education: A Bibliometric Review. *Contemporary Educational Technology*, 15(4). Retrieved from <https://eric.ed.gov/?id=EJ1406974>
- Aksnes, D. W., Langfeldt, L., & Wouters, P. (2019). Citations, Citation Indicators, and Research Quality: An Overview of Basic Concepts and Theories. *Sage Open*, 9(1). <https://doi.org/10.1177/2158244019829575>
- Alabdulhadi, A., & Faisal, M. (2021). Systematic Literature Review of STEM Self-Study Related ITs. *Education and Information Technologies*, 26(2), 1549–1588. <https://doi.org/10.1007/s10639-020-10315-z>
- Alshater, M. M., Hassan, M. K., Rashid, M., & Hasan, R. (2022). A Bibliometric Review of the Waqf Literature. *Eurasian Economic Review*, 12(2), 213–239. <https://doi.org/10.1007/s40822-021-00183-4>
- Aria, M., & Cuccurullo, C. (2017). Bibliometrix : An R-tool for Comprehensive Science Mapping Analysis. *Journal of Informetrics*, 11(4), 959–975. <https://doi.org/10.1016/j.joi.2017.08.007>
- Ateş, H., & Gündüzalp, C. (2025). Proposing a Conceptual Model for the Adoption of Artificial Intelligence by Teachers in STEM Education. *Interactive Learning Environments*, 1–27. <https://doi.org/10.1080/10494820.2025.2457350>
- Bampasidis, G., Piperidis, D., Papakonstantinou, V. C., Stathopoulos, D., Troumpetari, C., & Poutos, P. (2021). Hydrobots, an Underwater Robotics STEM Project: Introduction of Engineering Design Process in Secondary Education. *Advances in Engineering Education*. Retrieved from <https://eric.ed.gov/?id=EJ1309105>
- Battaglia, D. M., & Kaya, T. (2015). How Flipping Your First-year Digital Circuits Course Positively Affects Student Perceptions and Learning. *International Journal of Engineering Education*, 31(4), 1126–1138. Retrieved from <https://sacredheart.elsevierpure.com/ws/portalfiles/portal/40000585/B.1.1.9%20IJEE15.pdf>
- Belland, B. R., Walker, A. E., Kim, N. J., & Lefler, M. (2017). Synthesizing Results From Empirical Research on Computer-Based Scaffolding in STEM Education. *Review of Educational Research*, 87(2), 309–344. <https://doi.org/10.3102/0034654316670999>
- Bers, M. U. (2019). Coding as Another Language: A Pedagogical Approach for Teaching Computer Science in Early Childhood. *Journal of Computers in Education*, 6(4), 499–528. <https://doi.org/10.1007/s40692-019-00147-3>
- Bryan, L. A., Moore, T. J., Johnson, C. C., & Roehrig, G. H. (2015). Integrated STEM Education. In C. C. Johnson, E. E. Peters-Burton, & T. J. Moore (Eds.), *STEM Road Map* (p. 16). Routledge. <https://doi.org/10.4324/9781315753157>
- Carlos, C. M. L., Maggiore, N. M., Dini, V., & Caspari-Gnann, I. (2023). Characterizing Facilitation Practices of Learning Assistants: An Authoritative-to-Dialogic Spectrum. *International Journal of STEM Education*, 10(1), 38. <https://doi.org/10.1186/s40594-023-00429-4>

- Chadegani, A. A., Salehi, H., Yunus, M. M., Farhadi, H., Fooladi, M., Farhadi, M., & Ebrahim, N. A. (2013). A Comparison between Two Main Academic Literature Collections: Web of Science and Scopus Databases. *Asian Social Science*, 9(5), 18–26. <https://doi.org/10.48550/arXiv.1305.0377>
- Chan, K. W., Ali, F., Park, J., Sham, K. S. B., Tan, E. Y. T., Chong, F. W. C., Qian, K., & Sze, G. K. (2025). Automatic Item Generation in Various STEM Subjects Using Large Language Model Prompting. *Computers and Education: Artificial Intelligence*, 8, 100344. <https://doi.org/10.1016/j.caeai.2024.100344>
- Chassignol, M., Khoroshavin, A., Klimova, A., & Bilyatdinova, A. (2018). Artificial Intelligence trends in education: a narrative overview. *Procedia Computer Science*, 136, 16–24. <https://doi.org/10.1016/j.procs.2018.08.233>
- Chen, L., Chen, P., & Lin, Z. (2020). Artificial Intelligence in Education: A Review. *IEEE Access*, 8, 75264–75278. <https://doi.org/10.1109/ACCESS.2020.2988510>
- Chen, X., Xie, H., & Hwang, G.-J. (2020). A Multi-perspective Study on Artificial Intelligence in Education: Grants, Conferences, Journals, Software Tools, Institutions, and Researchers. *Computers and Education: Artificial Intelligence*, 1, 100005. <https://doi.org/10.1016/j.caeai.2020.100005>
- Chng, E., Tan, A. L., & Tan, S. C. (2023). Examining the Use of Emerging Technologies in Schools: a Review of Artificial Intelligence and Immersive Technologies in STEM Education. *Journal for STEM Education Research*, 6(3), 385–407. <https://doi.org/10.1007/s41979-023-00092-y>
- Damar, S., & Koksalmis, G. H. (2024). A Bibliometric Analysis of Metaverse Technologies in Healthcare Services. *Service Business*, 18(2), 223–254. <https://doi.org/10.1007/s11628-024-00553-3>
- De Jong, T., Gillet, D., Rodríguez-Triana, M. J., Hovardas, T., Dikke, D., Doran, R., Dziabenko, O., Koslowsky, J., Korventausta, M., Law, E., Pedaste, M., Tasiopoulou, E., Vidal, G., & Zacharia, Z. C. (2021). Understanding Teacher Design Practices for Digital Inquiry-based Science Learning: The Case of Go-Lab. *Educational Technology Research and Development*, 69(2), 417–444. <https://doi.org/10.1007/s11423-020-09904-z>
- Ding, L., Li, T., Jiang, S., & Gapud, A. (2023). Students' Perceptions of Using ChatGPT in A Physics Class As A Virtual Tutor. *International Journal of Educational Technology in Higher Education*, 20(1), 63. <https://doi.org/10.1186/s41239-023-00434-1>
- Duan, Y., Edwards, J. S., & Dwivedi, Y. K. (2019). Artificial Intelligence for Decision Making in the era of Big Data – Evolution, Challenges and Research Agenda. *International Journal of Information Management*, 48, 63–71. <https://doi.org/10.1016/j.ijinfomgt.2019.01.021>
- Durieux, V., & Gevenois, P. A. (2010). Bibliometric Indicators: Quality Measurements of Scientific Publication. *Radiology*, 255(2), 342–351. <https://doi.org/10.1148/radiol.09090626>
- Dzikovska, M., Steinhauer, N., Farrow, E., Moore, J., & Campbell, G. (2014). BEETLE II: Deep Natural Language Understanding and Automatic Feedback Generation for Intelligent Tutoring in Basic Electricity and Electronics. *International Journal of Artificial Intelligence in Education*, 24(3), 284–

332. <https://doi.org/10.1007/s40593-014-0017-9>
- Ebrahim, S. A., Poshtan, J., Jamali, S. M., & Ebrahim, N. A. (2020). Quantitative and Qualitative Analysis of Time-Series Classification Using Deep Learning. *IEEE Access*, 8, 90202–90215. <https://doi.org/10.1109/ACCESS.2020.2993538>
- Falagas, M. E., Pitsouni, E. I., Malietzis, G. A., & Pappas, G. (2008). Comparison of PubMed, Scopus, Web of Science, and Google Scholar: Strengths and Weaknesses. *The FASEB Journal*, 22(2), 338–342. <https://doi.org/10.1096/fj.07-9492LSF>
- Falebita, O. S., & Kok, P. J. (2024). Strategic Goals for Artificial Intelligence Integration among STEM Academics and Undergraduates in African Higher Education: A Systematic Review. *Discover Education*, 3(1), 151. <https://doi.org/10.1007/s44217-024-00252-1>
- Ferro, L. S., Sapio, F., Mecella, M., Temperini, M., & Terracina, A. (2021). *Intelligent Pedagogic Agents (IPAs) in GEA2, an Educational Game to Teach STEM Topics* (pp. 226–236). https://doi.org/10.1007/978-3-030-52287-2_23
- Fowler, S., Cutting, C., Kennedy, J., Leonard, S. N., Gabriel, F., & Jaeschke, W. (2022). Technology Enhanced Learning Environments and the Potential for Enhancing Spatial Reasoning: A Mixed Methods Study. *Mathematics Education Research Journal*, 34(4), 887–910. <https://doi.org/10.1007/s13394-021-00368-9>
- Gao, X., Li, P., Shen, J., & Sun, H. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. *International Journal of STEM Education*, 7, 1–14. <https://doi.org/10.1186/s40594-020-00225-4>
- Graesser, A. C., Hu, X., Nye, B. D., VanLehn, K., Kumar, R., Heffernan, C., Heffernan, N., Woolf, B., Olney, A. M., Rus, V., Andrasik, F., Pavlik, P., Cai, Z., Wetzel, J., Morgan, B., Hampton, A. J., Lippert, A. M., Wang, L., Cheng, Q., ... Baer, W. (2018). ElectronixTutor: An Intelligent Tutoring System with Multiple Learning Resources for Electronics. *International Journal of STEM Education*, 5(1), 15. <https://doi.org/10.1186/s40594-018-0110-y>
- Guo, S., Zheng, Y., & Zhai, X. (2024). Artificial Intelligence in Education Research during 2013–2023: A Review based on Bibliometric Analysis. *Education and Information Technologies*, 29(13), 16387–16409. <https://doi.org/10.1007/s10639-024-12491-8>
- Haenlein, M., & Kaplan, A. (2019). A Brief History of Artificial Intelligence: On the Past, Present, and Future of Artificial Intelligence. *California Management Review*, 61(4), 5–14. <https://doi.org/10.1177/0008125619864925>
- Hossain, Z., Bumbacher, E., Brauneis, A., Diaz, M., Saltarelli, A., Blikstein, P., & Riedel-Kruse, I. H. (2018). Design Guidelines and Empirical Case Study for Scaling Authentic Inquiry-based Science Learning via Open Online Courses and Interactive Biology Cloud Labs. *International Journal of Artificial Intelligence in Education*, 28(4), 478–507. <https://doi.org/10.1007/s40593-017-0150-3>
- Hwang, G.-J., Xie, H., Wah, B. W., & Gašević, D. (2020). Vision, Challenges, Roles and Research Issues of Artificial Intelligence in Education. *Computers and Education: Artificial Intelligence*, 1, 100001. <https://doi.org/10.1016/j.caeai.2020.100001>

- Jaipal-Jamani, K., & Angeli, C. (2017). Effect of Robotics on Elementary Preservice Teachers' Self-Efficacy, Science Learning, and Computational Thinking. *Journal of Science Education and Technology*, 26(2), 175–192. <https://doi.org/10.1007/s10956-016-9663-z>
- Jamali, S. M., Ale Ebrahim, N., & Jamali, F. (2023). The Role of STEM Education in Improving the Quality of Education: A Bibliometric Study. *International Journal of Technology and Design Education*, 33(3), 819–840. <https://doi.org/10.1007/s10798-022-09762-1>
- Jantakun, T., Jantakun, K., & Jantakoon, T. (2021). A Common Framework for Artificial Intelligence in Higher Education (AAIHE Model). *International Education Studies*, 14(11), 94. <https://doi.org/10.5539/ies.v14n11p94>
- Jebli, R., ElBouhdidi, J., & Chkouri, M. Y. (2021). A Proposed Architecture of an Intelligent System for Assessing the Student's UML Class Diagram. *International Journal of Emerging Technologies in Learning (IJET)*, 16(21), 4. <https://doi.org/10.3991/ijet.v16i21.25105>
- Jia, F., Sun, D., & Looi, C. (2024). Artificial Intelligence in Science Education (2013–2023): Research Trends in Ten Years. *Journal of Science Education and Technology*, 33(1), 94–117. <https://doi.org/10.1007/s10956-023-10077-6>
- Kavitha, K., & Joshith, V. P. (2024). The Transformative Trajectory of Artificial Intelligence in Education: The Two Decades of Bibliometric Retrospect. *Journal of Educational Technology Systems*, 52(3), 376–405. <https://doi.org/10.1177/00472395241231815>
- Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The Effect of a Classroom-Based Intensive Robotics and Programming Workshop on Sequencing Ability in Early Childhood. *Early Childhood Education Journal*, 41(4), 245–255. <https://doi.org/10.1007/s10643-012-0554-5>
- Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to Promote Elementary Education Pre-service Teachers' STEM Engagement, Learning, and Teaching. *Computers & Education*, 91, 14–31. <https://doi.org/10.1016/j.compedu.2015.08.005>
- Kim, J., & McMillan, S. J. (2008). Evaluation of Internet Advertising Research: A Bibliometric Analysis of Citations from Key Sources. *Journal of Advertising*, 37(1), 99–112. <https://doi.org/10.2753/JOA0091-3367370108>
- Kohnke, S., & Zaugg, T. (2025). Artificial Intelligence: An Untapped Opportunity for Equity and Access in STEM Education. *Education Sciences*, 15(1), 68. <https://doi.org/10.3390/educsci15010068>
- Konijn, E. A., & Hoorn, J. F. (2020). Robot Tutor and Pupils' Educational Ability: Teaching the Times Tables. *Computers & Education*, 157, 103970. <https://doi.org/10.1016/j.compedu.2020.103970>
- Koskinen, J., Isohanni, M., Paajala, H., Jääskeläinen, E., Nieminen, P., Koponen, H., Tienari, P., & Miettunen, J. (2008). How to Use Bibliometric Methods in Evaluation of Scientific Research? An Example from Finnish Schizophrenia Research. *Nordic Journal of Psychiatry*, 62(2), 136–143. <https://doi.org/10.1080/08039480801961667>

- Kwon, C.-Y. (2023). Research Trends of Pharmacopuncture: a Bibliometric Analysis Using VOSviewer (2007-2023). *Journal of Pharmacopuncture*, 26(3), 227–237. <https://doi.org/10.3831/KPI.2023.26.3.227>
- Latif, E., Mai, G., Nyaaba, M., Wu, X., Liu, N., Lu, G., Li, S., Liu, T., & Zhai, X. (2023). *AGI: Artificial General Intelligence for Education*. <http://arxiv.org/abs/2304.12479>
- Leonard, J., Buss, A., Gamboa, R., Mitchell, M., Fashola, O. S., Hubert, T., & Almughyrah, S. (2016). Using Robotics and Game Design to Enhance Children’s Self-Efficacy, STEM Attitudes, and Computational Thinking Skills. *Journal of Science Education and Technology*, 25(6), 860–876. <https://doi.org/10.1007/s10956-016-9628-2>
- Li, T., Zhan, Z., Ji, Y., & Li, T. (2025). Exploring Human and AI Collaboration in Inclusive STEM Teacher Training: A Synergistic Approach based on Self-determination Theory. *The Internet and Higher Education*, 65, 101003. <https://doi.org/10.1016/j.iheduc.2025.101003>
- Liao, J., Yang, J., & Zhang, W. (2021). The Student-centered STEM Learning Model Based on Artificial Intelligence Project: A Case Study on Intelligent Car. *International Journal of Emerging Technologies in Learning (IJET)*, 16(21), 100–120. Retrieved from <https://www.learntechlib.org/p/220523/>
- Lin, C.-H., Yu, C.-C., Shih, P.-K., & Wu, L. Y. (2021). STEM based Artificial Intelligence Learning in General Education for Non-Engineering Undergraduate Students. *Educational Technology & Society*, 24(3), 224–237. Retrieved from <https://www.jstor.org/stable/27032867>
- Liu, J., Li, J., & Fan, C. (2020). A Bibliometric Study of Pool Fire Related Publications. *Journal of Loss Prevention in the Process Industries*, 63, 104030. <https://doi.org/10.1016/j.jlp.2019.104030>
- Marengo, A., Pagano, A., Pange, J., & Soomro, K. A. (2024). The Educational Value of Artificial Intelligence in Higher Education: A 10-year Systematic Literature Review. *Interactive Technology and Smart Education*, 21(4), 625–644. <https://doi.org/10.1108/ITSE-11-2023-0218>
- Moreno-Guerrero, A.-J., López-Belmonte, J., Marín-Marín, J.-A., & Soler-Costa, R. (2020). Scientific Development of Educational Artificial Intelligence in Web of Science. *Future Internet*, 12(8), 124. <https://doi.org/10.3390/fi12080124>
- Mumu, J. R., Tahmid, T., & Azad, M. A. K. (2021). Job Satisfaction and Intention to Quit: A Bibliometric Review of Work-family Conflict and Research Agenda. *Applied Nursing Research*, 59, 151334. <https://doi.org/10.1016/j.apnr.2020.151334>
- Naya-Varela, M., Guerreiro-Santalla, S., Baamonde, T., & Bellas, F. (2023). Robobo SmartCity: An Autonomous Driving Model for Computational Intelligence Learning Through Educational Robotics. *IEEE Transactions on Learning Technologies*, 16(4), 543–559. <https://doi.org/10.1109/TLT.2023.3244604>
- Nugent, G., Barker, B., Grandgenett, N., & Adamchuk, V. I. (2010). Impact of Robotics and Geospatial Technology Interventions on Youth STEM Learning and Attitudes. *Journal of Research on Technology in Education*, 42(4), 391–408. <https://doi.org/10.1080/15391523.2010.10782557>

- Ouyang, F., & Jiao, P. (2021). Artificial Intelligence in Education: The Three Paradigms. *Computers and Education: Artificial Intelligence*, 2, 100020. <https://doi.org/10.1016/j.caeai.2021.100020>
- Paladines, J., & Ramirez, J. (2020). A Systematic Literature Review of Intelligent Tutoring Systems With Dialogue in Natural Language. *IEEE Access*, 8, 164246–164267. <https://doi.org/10.1109/ACCESS.2020.3021383>
- Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., & Jovanović, K. (2016). Virtual Laboratories for Education in Science, Technology, and Engineering: A Review. *Computers & Education*, 95, 309–327. <https://doi.org/10.1016/j.compedu.2016.02.002>
- Schneider, D. R., Leon, M., Van Der Blink, C., Ahmed, N., Shah, D., & Li, K. (2008). Active Learning and Assessment within the NASA Robotics Alliance Cadets Program. *International Journal of Engineering Education*, 24(6), 1091. Retrieved from https://www.ijee.ie/articles/Vol24-6/s8_ijee2049.pdf
- Sen, C., Ay, Z. S., & Kiray, S. A. (2021). Computational Thinking Skills of Gifted and Talented Students in Integrated STEM Activities based on the Engineering Design Process: The Case of Robotics and 3D Robot Modeling. *Thinking Skills and Creativity*, 42, 100931. <https://doi.org/10.1016/j.tsc.2021.100931>
- Shang, X., Jiang, Z., Chiang, F.-K., Zhang, Y., & Zhu, D. (2023). Effects of Robotics STEM Camps on Rural Elementary Students' Self-efficacy and Computational Thinking. *Educational Technology Research and Development*, 71(3), 1135–1160. <https://doi.org/10.1007/s11423-023-10191-7>
- Shankar, S. K., Pothancheri, G., Sasi, D., & Mishra, S. (2025). Bringing Teachers in the Loop: Exploring Perspectives on Integrating Generative AI in Technology-Enhanced Learning. *International Journal of Artificial Intelligence in Education*, 35(1), 155–180. <https://doi.org/10.1007/s40593-024-00428-8>
- Sharma, R. C., Kawachi, P., & Bozkurt, A. (2019). The Landscape of Artificial Intelligence in Open, Online and Distance Education: Promises and Concerns. *Asian Journal of Distance Education*, 14(2), 1–2. Retrieved from <http://asianjde.com/ojs/index.php/AsianJDE/article/download/432/292>
- Song, P., & Wang, X. (2020). A Bibliometric Analysis of Worldwide Educational Artificial Intelligence Research Development in Recent Twenty Years. *Asia Pacific Education Review*, 21(3), 473–486. <https://doi.org/10.1007/s12564-020-09640-2>
- Stewart, W. H., Baek, Y., Kwid, G., & Taylor, K. (2021). Exploring Factors That Influence Computational Thinking Skills in Elementary Students' Collaborative Robotics. *Journal of Educational Computing Research*, 59(6), 1208–1239. <https://doi.org/10.1177/0735633121992479>
- Su, J., & Yang, W. (2024). STEM in Early Childhood Education: A Bibliometric Analysis. *Research in Science & Technological Education*, 42(4), 1020–1041. <https://doi.org/10.1080/02635143.2023.2201673>
- Sullivan, A., & Bers, M. U. (2016). Robotics in the Early Childhood Classroom: Learning Outcomes from An 8-week Robotics Curriculum in Pre-Kindergarten through Second Grade. *International Journal of Technology and Design Education*, 26(1), 3–20. <https://doi.org/10.1007/s10798-015-9304-5>

- Sun, N., & Saleh, S. (2024). *Mapping the Landscape of AI Implementation in STEM and STEAM Education: A Bibliometric Analysis* (pp. 99–111). https://doi.org/10.1007/978-981-96-0205-6_7
- Talan, T. (2021). Artificial Intelligence in Education: A Bibliometric Study. *International Journal of Research in Education and Science*, 7(3), 822–837. <https://doi.org/10.46328/ijres.2409>
- Valeri, F., Nilsson, P., & Cederqvist, A.-M. (2025). Exploring students' experience of ChatGPT in STEM education. *Computers and Education: Artificial Intelligence*, 8, 100360. <https://doi.org/10.1016/j.caeai.2024.100360>
- Van Eck, N. J., & Waltman, L. (2010). Software Survey: VOSviewer, A Computer Program for Bibliometric Mapping. *Scientometrics*, 84(2), 523–538. <https://doi.org/10.1007/s11192-009-0146-3>
- Wang, K. D., Burkholder, E., Wieman, C., Salehi, S., & Haber, N. (2024). Examining the potential and pitfalls of ChatGPT in science and engineering problem-solving. *Frontiers in Education*, 8. <https://doi.org/10.3389/educ.2023.1330486>
- Wartman, S. A., & Combs, C. D. (2018). Medical Education Must Move From the Information Age to the Age of Artificial Intelligence. *Academic Medicine*, 93(8), 1107–1109. <https://doi.org/10.1097/ACM.0000000000002044>
- Xu, L. Da. (2013). Introduction: Systems Science in Industrial Sectors. *Systems Research and Behavioral Science*, 30(3), 211–213. <https://doi.org/10.1002/sres.2186>
- Xu, W., & Ouyang, F. (2022a). A Systematic Review of AI Role in the Educational System based on a Proposed Conceptual Framework. *Education and Information Technologies*, 27(3), 4195–4223. <https://doi.org/10.1007/s10639-021-10774-y>
- Xu, W., & Ouyang, F. (2022b). The application of AI technologies in STEM education: a systematic review from 2011 to 2021. *International Journal of STEM Education*, 9(1), 59. <https://doi.org/10.1186/s40594-022-00377-5>
- Yang, W. (2022). Artificial Intelligence Education for Young Children: Why, What, and How in Curriculum Design and Implementation. *Computers and Education: Artificial Intelligence*, 3, 100061. <https://doi.org/10.1016/j.caeai.2022.100061>
- Yang, Y., Sun, W., Sun, D., & Salas-Pilco, S. Z. (2024). Navigating the AI-Enhanced STEM Education Landscape: A Decade of Insights, Trends, and Opportunities. *Research in Science & Technological Education*, 1–25. <https://doi.org/10.1080/02635143.2024.2370764>
- Yannier, N., Hudson, S. E., & Koedinger, K. R. (2020). Active Learning is About More Than Hands-On: A Mixed-Reality AI System to Support STEM Education. *International Journal of Artificial Intelligence in Education*, 30(1), 74–96. <https://doi.org/10.1007/s40593-020-00194-3>
- Zapata-Rivera, D., VanWinkle, W., Doyle, B., Buteux, A., & Bauer, M. (2009). Combining Learning and Assessment in Assessment-based Gaming Environments. *Interactive Technology and Smart Education*, 6(3), 173–188. <https://doi.org/10.1108/17415650911005384>

- Zhan, Z., Shen, W., Xu, Z., Niu, S., & You, G. (2022). A Bibliometric Analysis of the Global Landscape on STEM Education (2004-2021): towards Global Distribution, Subject Integration, and Research Trends. *Asia Pacific Journal of Innovation and Entrepreneurship*, 16(2), 171–203. <https://doi.org/10.1108/APJIE-08-2022-0090>
- Zhang, C., & Lu, Y. (2021). Study on Artificial Intelligence: The State of the Art and Future Prospects. *Journal of Industrial Information Integration*, 23, 100224. <https://doi.org/10.1016/j.jii.2021.100224>
- Zhao, D., Muntean, C. H., Chis, A. E., Rozinaj, G., & Muntean, G.-M. (2022). Game-Based Learning: Enhancing Student Experience, Knowledge Gain, and Usability in Higher Education Programming Courses. *IEEE Transactions on Education*, 65(4), 502–513. <https://doi.org/10.1109/TE.2021.3136914>
- Zupic, I., & Čater, T. (2015). Bibliometric Methods in Management and Organization. *Organizational Research Methods*, 18(3), 429–472. <https://doi.org/10.1177/1094428114562629>