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Artificial Intelligence in STEM Education: A Bibliometric Analysis

Siti Fatimah[1]; Sarwi[2]; Sri Haryani[2]

[1] Doctoral Program in Science Education Universitas Negeri Semarang, Indonesia

[2] Faculty of Mathematics and Natural Sciences Universitas Negeri Semarang, Indonesia

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Abstract

Artificial intelligence-oriented STEM Education is a form of innovation in science learning. This research aims to analyze the trend in publications on artificial intelligence-oriented STEM Education from 2013 to 2023, visualization of STEM education and artificial intelligence research trends, and how artificial intelligence-oriented STEM education research contributes to elementary school learning. This study was conducted in September 2023 using bibliometric analysis. Data was extracted from the Scopus database using the keywords "Artificial Intelligence and STEM Education" from 2013 to 2023, resulting in 118 records. After exclusions, 96 documents were retained. Subsequently, data mapping was performed using Biblioshiny and VOSViewer software. The research findings indicate a strong relationship between artificial intelligence and STEM education. In terms of document type, conference papers were the most common source compared to other document types. Additionally, based on the countries, the United States contributes the most to research in STEM education and artificial intelligence, followed by China and Hong Kong. An interesting finding is that the contribution of AI in STEM education is still low in elementary school, so research on this topic can be further developed in elementary education.

Keywords: *Artificial Intelligence; STEM Education; Science Learning; Bibliometric Analysis; Elementary School*

Introduction

The term artificial intelligence was introduced in 1956. Subsequently, artificial intelligence was divided into several branches, such as machine learning, neural networks, and deep learning (see figure 1). Artificial intelligence has been a significant innovation in the world of technology. Artificial intelligence makes it easy for users to access information around the world. In terms of utility, artificial intelligence plays an immensely significant role. However, it is undeniable that the existence of artificial intelligence also presents significant challenges.

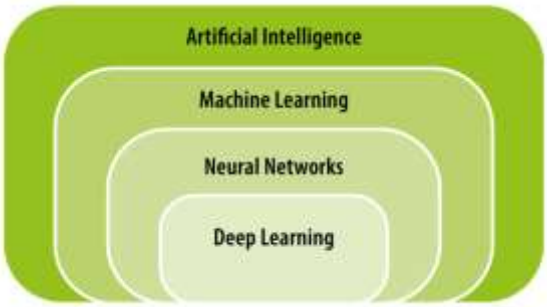

Figure 1. The relationship between artificial intelligence, machine learning, neural networks and deep learning (UNESCO, 2021)

UNESCO defines artificial intelligence as machines capable of emulating specific functions of human intelligence, including features such as perception, learning, reasoning, problem-solving, language interaction, and even generating creative works (UNESCO, 2021, p. 6). Artificial intelligence is also described as an agent, in this case, a computer, capable of understanding its environment and making decisions (Russel & Norvig, 2012). Artificial intelligence is viewed by the general public as the ability of machines or computers to think and act like humans (S.A. & C.D., 2018). Artificial intelligence can perform cognitive functions that operate similarly to humans in terms of learning, understanding, reasoning, and interacting (Tao et al., 2019). To improve process efficiency, artificial intelligence helps in decision-making, simplifies information analysis processes, makes them more agile, and can even provide more comprehensive data (De Souza Zanirato Maia et al., 2023).

Artificial intelligence is divided into three types (see figure 2), Stage 1, Machine learning: In this stage, artificial intelligence is referred to as Artificial Narrow Intelligence (ANI). This is a basic level of artificial intelligence that is programmed to perform a single task intelligently. Simply put, it comprises a collection of simple algorithms used by the system to learn from past experiences. Examples of this type include speech recognition, chatbots, personal assistants, and voice assistant applications. Stage 2, Machine Intelligence: This is an advanced set of algorithms utilized by systems to learn from experiences. This type of AI is known as Artificial General Intelligence (AGI). As its name implies, it is designed for general purposes and continuous learning. For example, self-driving cars, autopilot systems, etc. Stage 3, Machine Consciousness: is the phase in which systems learn from experiences independently, without any external data. This type of AI is referred to as Artificial Super Intelligence (ASI). This particular level of AI is far more intelligent, sophisticated, and powerful than human intelligence. (Hemalatha & Kumari, 2020).

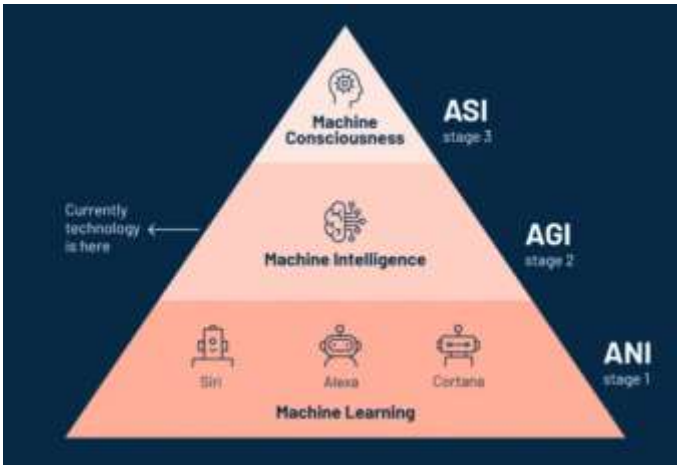

Figure 2. Stages of Artificial Intelligence

Artificial intelligence has proven to provide numerous benefits, particularly in the field of education (Huang & Qiao, 2022; Hwang, 2022). In the field of education, artificial intelligence acts as a tool to help teachers in developing more innovative and effective learning experiences. There are numerous benefits of using artificial intelligence to support educational platforms. Artificial intelligence not only reduces work time but also enhances capacity in ways beyond human capabilities, such as analyzing students' knowledge levels and optimizing teaching and learning activities (Thongprasit & Wannapiroon, 2022, p. 7). In the educational field, the focus of artificial intelligence is primarily on the interaction between humans and artificial intelligence platforms for learning. These platforms improve the efficiency of evaluating students' academic performance. They also serve as tools for assessing and monitoring learning progress and analyzing strengths and weaknesses in the learning process, thereby improving teaching patterns for teachers. Furthermore, the presence of these platforms has the potential to stimulate students' learning interests (Diao, 2020; Gong, 2020).

An artificial intelligence learning platform consists of four main components, namely user, learning platform, intelligent technology, and curriculum. The first component is the user, which consists of students, teachers, and administrators. The second component is the learning platform, consisting of a user management system, supporting system, intelligent tutoring system, and Massive Open Online Course (MOOC). The third component is intelligent technology, such as web services, mobile technology, virtual reality, artificial intelligence, online classrooms, E-learning, and embedded process monitoring. The last component is the curriculum, which consists of advanced learning supplements, data analysis, assessment, evaluation indicators, student quality monitoring, and practices (Thongprasit & Wannapiroon, 2022, p. 79). (see figure 3)

Figure 3. Elements of an intelligence learning platform

Artificial Intelligence in Education (AIEd) is considered the combination of three primary fields such as computer science, statistics, as well as education. Apart from these three things, AIEd is an interdisciplinary field that encompasses various aspects, resulting in the creation of other subfields, such as Educational Data Mining (EDM), Learning Analytics (LA), and Computer-Based Education (CBE) (X. Chen et al., 2020). (see figure 4)

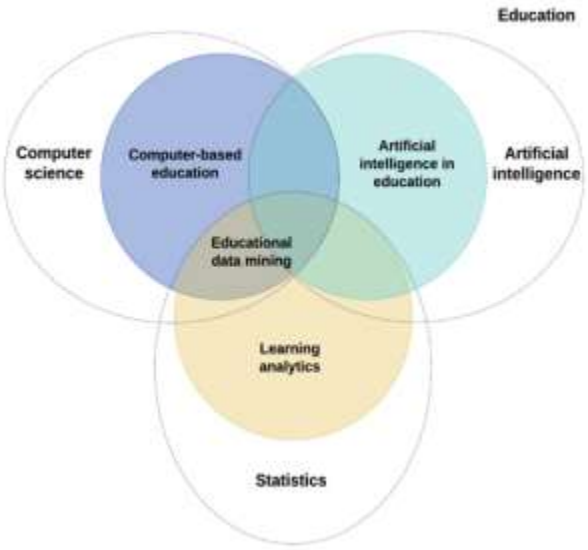

Figure 4. The relationship between AIEd, EDM, CBE, and LA

Educational data mining (EDM) is the analysis of various types of educational data using statistical algorithms, ML, and DM. EDM aims to generate systematic and automated insights from students' responses (L. Chen et al., 2020). The objective of EDM is to develop an approach for examining unique educational data to understand how students learn and how they can achieve higher learning outcomes and deeper insights into understanding a phenomenon. Additionally, EDM functions as a powerful tool to improve the learning processes and mastery of knowledge, thereby leading to enhanced comprehension among students (L. Chen et al., 2020). Numerous applications integrate AIEd and EDM to analyze students' behavior such as identifying students at risk of dropping out of school so as to provide appropriate support through data analysis of class attendance and submission of assignments (Luckin et al., 2016).

Learning Analytics (LA) can also be referred to as the measurement, collection, analysis, and reporting of data about students and their contexts to understand and optimize the learning process. The techniques utilized in LA include statistics, visualization, discourse analysis, and social network analysis. LA primarily focuses on describing data and outcomes. On the other hand, Computer-Based Education (CBE) is defined as the utilization of computers in education to deliver instruction to students. Initially, CBE systems were tools applied solely on standard computers without the utilization of AI. However, with the advent of AI, it has become possible to enhance intelligent adaptive systems for educational purposes (X. Chen et al., 2020).

Artificial Intelligence in STEM Education

Artificial intelligence is highly relevant with STEM education, an education system that emphasizes the utilization of technology (Huang & Qiao, 2022). The presence of both of these components complement each other. Through STEM education, artificial intelligence becomes the right tool for developing technological literacy (artificial intelligence literacy). Technological literacy is an important aspect of STEM, with artificial intelligence further developing students' abilities in technology. Integrating artificial intelligence into STEM education will shape interdisciplinary knowledge. It also affects computational skills, motivation and interest in learning, and self-efficacy (Huang & Qiao, 2022). This type of learning significantly contributes to the improvement of computational thinking (CT). Korkmaz et al. identify five factors in the development of CT: creativity, algorithmic thinking, critical thinking, problem-solving, and cooperation (Korkmaz et al., 2017). Artificial intelligence in education is not only about creating algorithms but also based on knowledge to solve problems, semantics processing, and handling unstructured data.

It is explained that the use of artificial intelligence in STEM education is largely oriented toward project-based learning (Huang & Qiao, 2022) (see table 1). This learning begins by forming small groups and the application of artificial intelligence algorithms in projects as a means of seeking solutions to existing problems. Students develop prototype systems, which are then presented in class, and provide a reflection report on the developed product. Table 1 provides a comparison between traditional courses and courses using STEAM-integrated artificial intelligence.

Table 1. Comparison between the traditional AI courses and AI courses with STEAM

	Traditional AI courses	AI courses with STEAM
Teaching content	AI fundamentals	AI Fundamentals + Art, Science, Mathematics, Technology, Engineering
Pedagogy	Algorithm oriented	Project Oriented
Practical implementation	Individual	Group
Assessment	Prototype	Prototype + Project Presentation & Reflection Report

Table 1 illustrates the distinction between courses that solely employ artificial intelligence and courses that integrate artificial intelligence with STEAM. It is explained that classes incorporating STEAM will integrate artificial intelligence with art, science, mathematics, technology, and engineering. The integration of these two components promotes multidisciplinary knowledge that will broaden students' perspectives. Juškevičienė et al recommend developing CT skills through STEM education (Juškevičienė et al., 2021). Other research findings indicate that students' CT skills, as well as their interests and entrepreneurial attitudes, will develop through STEM education (Hava & Koyunlu Ünlü, 2021). This emphasizes the importance of implementing STEM to develop CT skills. Artificial intelligence education with STEM provides students more opportunities to collaborate and communicate in acquiring diverse knowledge through inquiry. Students will discover solutions to problems through interdisciplinary thinking and utilizing relevant technology to solve problems. Students will become increasingly adept at creatively exploring solutions through the use of reasonable engineering technology and will be able to objectively and fairly evaluate processes. AI education combined with STEM can effectively meet the students' needs according to their talents and interests (Huang & Qiao, 2022).

Several research studies on the importance of integrating Artificial Intelligence with STEM have been conducted by various researchers, such as Zhai et al; Ouyang et al; and Neumann & Waight (Neumann & Waight, 2020; Ouyang et al., 2022; Zhai et al., 2022). AlKanaan explains that artificial intelligence has been used in STEM education, with countries such as Saudi Arabia starting to adopt this form of education. In this case, artificial intelligence, especially robots, has been believed by teachers to improve students' interpersonal skills. This evidence supports that the use of robots has a positive impact on the development of students' competency (AlKanaan, 2022). Huang and Qiao explained that learning that integrates artificial intelligence with STEM can develop students' competency better than learning that is not integrated with STEM (Huang & Qiao, 2022). Lin et al. found that STEM education that uses artificial intelligence is effective in improving students' artificial intelligence literacy. The studies also reveal that students become more aware of ethical issues related to the use of artificial intelligence (Lin et al., 2021).

Research Questions

This research focuses on the trends in artificial intelligence in STEM education research from 2013 to 2023, with five research questions:

a. To what extent is the publication profile of artificial intelligence in STEM education from 2013 to 2023?
b. To what extent is the distribution of publications on artificial intelligence in STEM education among countries and affiliations worldwide?
c. Who are the primary authors in artificial intelligence in STEM education research worldwide?
d. What is the visualization of the trends in artificial intelligence in STEM education?
e. To what extent does artificial intelligence-oriented STEM education research contribute to elementary education?

Method

1.1. Research Design

This research conducts a systematic review of published empirical studies to identify research on artificial intelligence in STEM education (Yue et al., 2022). This systematic review uses a bibliometric analysis adapted from Kulakli & Osmanaj; Yang et al; Bonilla-Chaves & Palos-Sánchez (Bonilla-Chaves & Palos-Sánchez, 2023; Kulakli & Osmanaj, 2020; Yang et al., 2017).

Figure 5. Five steps in conducting bibliometric analysis (Ari Masitoh et al., 2021; Suprapto et al., 2021)

1.2. Material

The literature search was conducted in September 2023 using the Scopus database. Scopus is one of the quality data sources, which is considered in document selection (Wei et al., 2023). This research used three search terms in titles, abstracts, and keywords: “Artificial Intelligence” and “STEM education”. The researcher only looked at scientific articles published between 2013 and 2023 and didn't limit the source of the publication. The literature search yielded a total of 118 records. Of the 118 documents, 96 met the search criteria. The data were documented in a (.csv) format.

1.3. Data Analysis

The analysis data was processed and analyzed using VOSViewer and Biblioshiny applications to examine research trends in artificial intelligence in STEM education.

Result and Discussion

Result

The Publication Profile of Artificial Intelligence in STEM Education from 2013 to 2023

The results of the search for relevant scientific articles on artificial intelligence in STEM education in the Scopus database yielded 96 documents. This publication focuses on 2013 to 2023, as shown in figure 6, indicating an upward trend in research on artificial intelligence in STEM education over the years, even though 2013 and 2014 had the same number of publications. It can be seen that in 2023, there were 19 documents about research on artificial intelligence in STEM education (see figure 6).

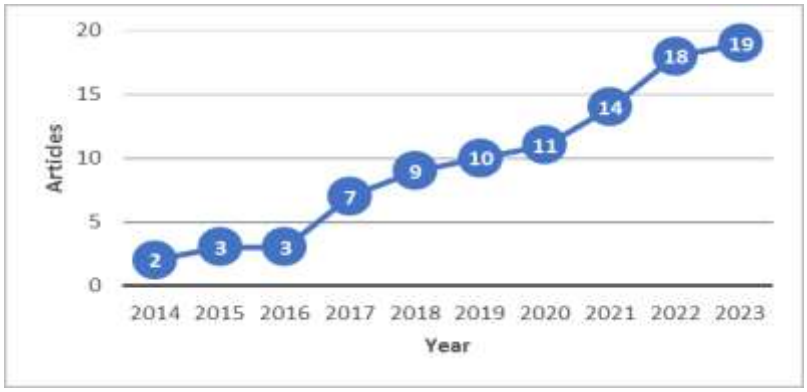

Figure 6. Number of research documents on artificial intelligence in STEM education in 2013-2023

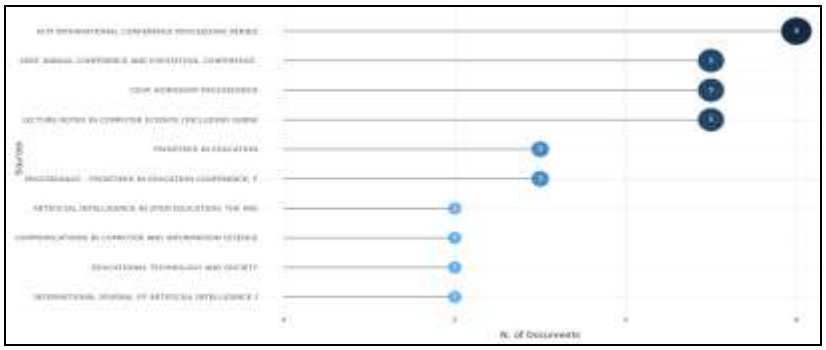

Figure 7. Top 10 most relevant sources of research on artificial intelligence in STEM education.

Figure 7 shows that research on artificial intelligence in STEM education is most frequently published in the ACM International Conference Proceeding Series, with a total of 6 documents.

Distribution of Publications on Artificial Intelligence in STEM Education among Countries and Affiliations Worldwide

Based on the number of documents among countries, it is evident that the United States ranks first with a total of 11 documents, followed by China in second place with 10 documents. Several researchers conduct collaborative research between countries (MCP), as well as collaboration with a single country (SCP). It can be observed that researchers who have established research collaborations between countries are Hong Kong, India, Italy, Spain, Georgia, Greece, Singapore, and Colombia. Meanwhile, the USA, China, Australia, Japan, and other countries, including Indonesia still collaborate within their own countries.

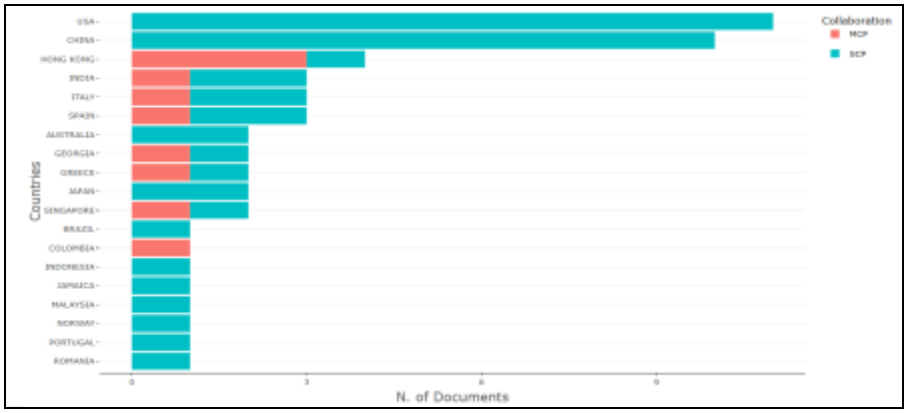

Figure 8. Number of research documents on artificial intelligence in STEM education by country

Based on the number of documents analyzed (2013-2023) distributed across various institutions, as depicted in figure 9. It can be observed that the University of Georgia has published the most research on artificial intelligence in STEM education, with a total of seven documents. This is followed by Sapienza University of Rome, Universidad De Granada, University of Turin, and Western Michigan University, which are ranked second with a total of 5 documents.

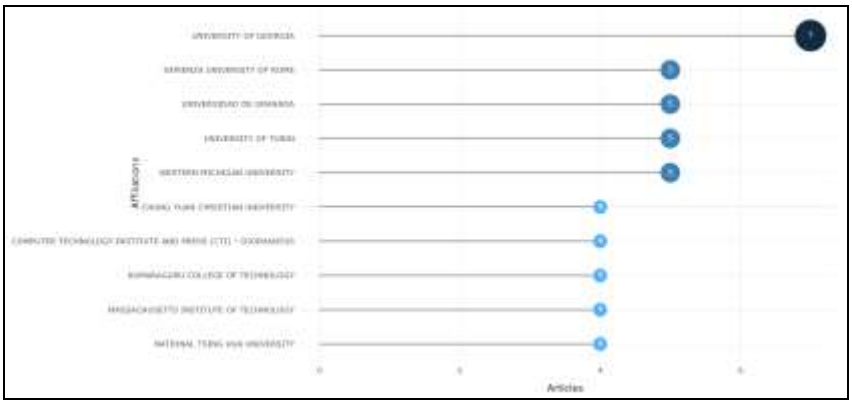

Figure 9. Top 10 most dominant institutions in artificial intelligence research in STEM education

Table 2. The institution that has produced the most research on artificial intelligence in STEM education

No	Affiliation	Articles
1	UNIVERSITY OF GEORGIA	7
2	SAPIENZA UNIVERSITY OF ROME	5
3	UNIVERSIDAD DE GRANADA	5
4	UNIVERSITY OF TURIN	5
5	WESTERN MICHIGAN UNIVERSITY	5
6	CHUNG YUAN CHRISTIAN UNIVERSITY	4
7	COMPUTER TECHNOLOGY INSTITUTE AND PRESS (CTI) – DIOPHANTUS	4
8	KUMARAGURU COLLEGE OF TECHNOLOGY	4
9	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	4
10	NATIONAL TSING HUA UNIVERSITY	4

Primary Authors in Artificial Intelligence in STEM Education Research Worldwide

In terms of the most productive authors researching artificial intelligence in STEM education, figure 10 illustrates the number of the most productive authors on this topic. The blue dots represent the number of publications, with larger circles indicating a higher number of publications. Meanwhile, the color intensity indicates the number of citations, with darker colors signifying a higher number of citations. Ouyang is the most productive author, producing research on artificial intelligence in STEM education with a total of 3 documents.

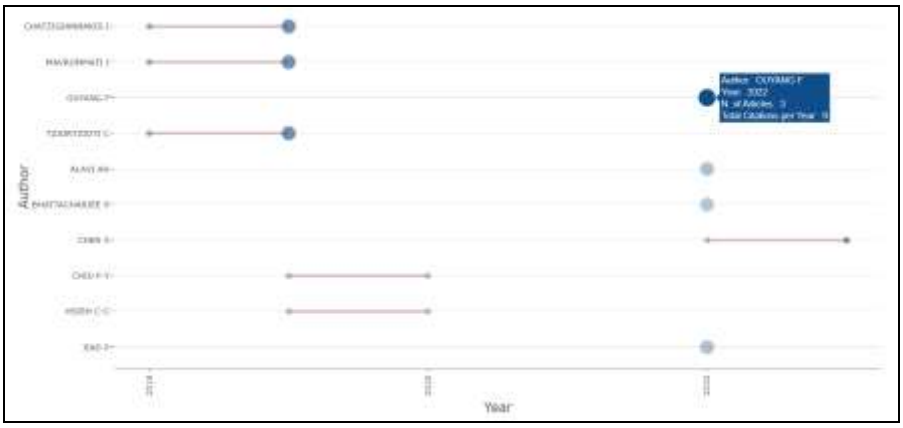

Figure 10. Most productive author on artificial intelligence in STEM education research

In terms of the number of citations, the top author is Manduca, C.A., et al. with a total of 83 citations, followed by Gamage, et al. in second place with 48 citations. Each of the cited publications comes from journals

Table 3. Top citation of article/document of 2013-2023

No	Author	Year	Source	∑citation
1	Manduca, C.A., Iverson, E.R., Luxenberg, M., ...Mogk, D.W., Tewksbury, B.J.	2022	Science Advances	83
2	Gamage, S.H.P.W., Ayres, J.R., Behrend, M.B.	2020	International Journal of STEM Education	48
3	Wan, X., Zhou, X., Ye, Z., Mortensen, C.K., Bai, Z.	2019	Proceedings of the Interaction Design and Children Conference	34
4	How, M.-L., Hung, W.L.D.	2017	Education Sciences	34
5	Yannier, N., Hudson, S.E., Koedinger, K.R.	2020	International Journal of Artificial Intelligence in Education	32
6	Jeong, J.S., González-Gómez, D.	2017	Journal of Cleaner Production	21
7	Tziortzioti, C., Amaxilatis, D., Mavrommati, I., Chatzigiannakis, I.	2021	Electronic Notes in Theoretical Computer Science	20
8	Lin, C.-H., Yu, C.-C., Shih, P.-K., Wu, L.Y.	2020	Educational Technology and Society,	18
9	Xu, W., Ouyang, F.	2019	International Journal of STEM Education	17
10	Nguyen, H.D., Do, N.V.	2022	Frontiers in Artificial Intelligence and Applications	13

Visualization of the Trends in Artificial Intelligence in STEM Education

Based on the analysis of 96 articles related to artificial intelligence in STEM education available in the Scopus database, the researchers were able to generate findings about a thematic map using the biblioshiny application. This research analyzed the thematic map by dividing it into four theme quadrants based on density and centrality. Themes in the upper-right quadrant should be further developed and studied due to their high density and centrality. On the other hand, specific themes that are rare but highly developed, with high density and low centrality, are located in the upper-left quadrant. In addition, themes

with declining trends are in the lower-left quadrant, while fundamental themes with high centrality but low density are in the lower-right quadrant. The Thematic Map indicates a connection between three themes, these three themes are artificial intelligence, STEM education, and students. There is a great potential for further research related to the relationship between artificial intelligence and STEM education to be developed and studied. This means that future research can investigate the impact of artificial intelligence and STEM education on student learning.

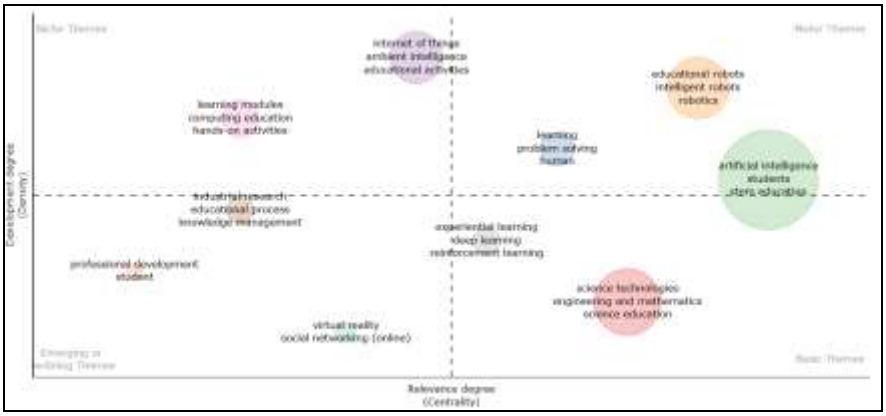

Figure 11. Thematic map

From the above data, additional tests will be conducted using the VOSViewer application. This helps to confirm the data obtained from biblioshiny regarding the novelty of research in this domain. Figure 12 shows an overall picture of research on artificial intelligence in STEM education research. Researchers around the world have produced three clusters (red, green, and blue). The first cluster (red) is the management of artificial intelligence in STEM education worldwide. The second cluster (green) is artificial intelligence in STEM education related to learning domains, practices, and other social sciences. The third cluster (blue) represents artificial intelligence in STEM education related to the tools used.

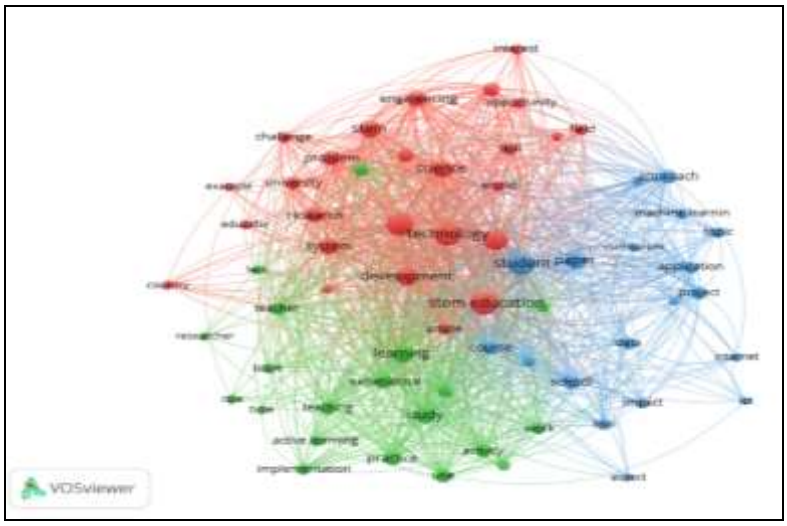

Figure 12. The whole picture of research on artificial intelligence in STEM education in 2013-2023

To determine the novelty of AI research in STEM education can be done by outlining the specific relationships between variables. This is illustrated in figure 13.

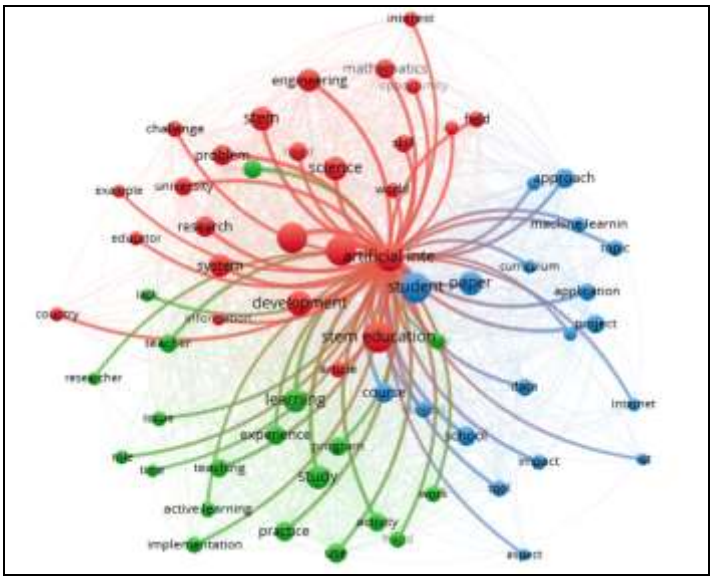

Figure 13. The relationship of artificial intelligence and STEM education with other domains

Figure 14 illustrates that research on artificial intelligence and STEM education is interrelated with active learning, teachers, practices, and instruction. In addition to the education domain, research on artificial intelligence in STEM education is also related to the tools used, such as machine learning, the internet, and the IoT.

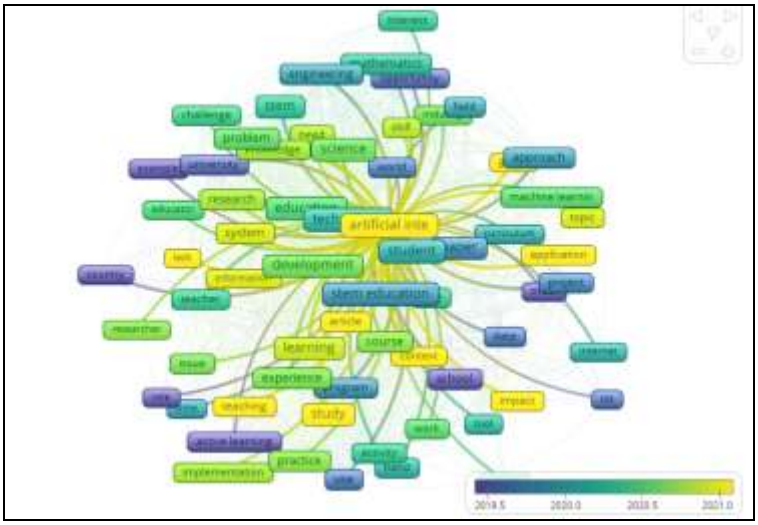

Figure 14. Thematic Map VOSViewer

Figure 14 shows that keywords related to artificial intelligence and STEM education are commonly used by researchers. In 2023 (highlighted in yellow), several themes remain interesting issues for ongoing research. Future research could follow the latest trends in topics, such as the study of the impact of artificial intelligence in education.

Contribution of AI-oriented STEM Education Research to Elementary Education

Based on the number of research documents on the topic of artificial intelligence in STEM education, there are 3 relevant articles for elementary education. The rest are at the level of early childhood education, secondary education, and universities. The lack of research on artificial intelligence

in STEM education in elementary school presents a significant opportunity for further exploration of this topic. Based on the Scopus database, table 4 provides an overview of the research related to artificial intelligence in STEM education and elementary education.

Table 4. Research on artificial intelligence in STEM education and elementary education

No	Author	Year	Title	Result
1	Mehdipour, F., Pashma, M., Mahanti, A.	2021	A 3-Tier Solution for Facilitating STEM Education in Primary Schools	Artificial intelligence with various interactive platforms makes STEM education more innovative.
2	Ponce, P., Molina, A., Mata, O., Baltazar, G.	2019	LEGO® EV3 Platform for STEM Education in Elementary School	Artificial intelligence is used as a tool in STEM education using LEGO® robotic devices as a tool to measure student assessment/knowledge.
3	Jeon, M., et al.	2017	Robot Opera: A modularized afterschool program for STEAM education at local elementary school	The importance of STEM education in elementary schools continues to be updated to STEAM. Promoting STEAM education using robots in elementary schools is an innovation in improving teachers' pedagogical competence.

Among all the articles discussing the importance of artificial intelligence in STEM education in elementary schools, it presents a significant opportunity for researchers to explore and develop this topic further. The articles also explain that artificial intelligence can be used as a tool to improve teachers' competence, especially in pedagogical development, and to help students develop their knowledge. In summary, artificial intelligence in STEM education in elementary education makes STEM education more engaging and enjoyable.

Discussion

The field of research on artificial intelligence in academia began in 1956. Artificial intelligence in education was first introduced in the 1970s. Researchers were initially interested in seeing how computers could be used as effective learning tools (Bloom, 1984). The application of artificial intelligence in education has evolved in various directions, ranging from artificial intelligence used by students as learning and assessment support, and artificial intelligence used by teachers to support the teaching process and as a support in management in educational institutions (Baker et al., 2019). Artificial intelligence has become a relevant tool in STEM education. STEM education encourages students to develop artificial intelligence effectively, Artificial intelligence plays a major role in the development of knowledge in fun STEM education. The synergy between artificial intelligence and STEM can make it easier for students to create STEM projects and develop artificial intelligence literacy (X. Chen et al., 2020; Holmes et al., 2023; Hwang, 2022; KONG et al., 2021).

Artificial intelligence in STEM education has a significant impact in the United States. The data shows that the United States is the most productive country in conducting research on this topic. China and Hong Kong also are influential in the research of artificial intelligence in STEM education. Gursoy & Kakadiaris explain that the United States continues to maintain its leading role in research and development, particularly in artificial intelligence research. This is stated in the US National Artificial Intelligence Research and Development Strategic Plan. Its goal is to improve future research strategies in

the United States and worldwide. The National Artificial Intelligence Research and Development Strategic Plan (National Science and Technology Council) is an important document that highlights key priorities in artificial intelligence research and development (Gursoy & Kakadiaris, 2023).

Artificial intelligence in STEM education remains a research trend that has not been widely explored, especially in elementary school education. STEM education in elementary schools is a relatively new concept and thus presents challenges for teachers to develop STEM education in elementary school education (Mehdipour et al., 2018). The utilization of artificial intelligence in STEM has proven to be more engaging and efficient for learning. It certainly helps students in expanding their knowledge.

Conclusion

The research findings suggest a strong relationship between artificial intelligence and STEM education. In terms of document types, conference articles are the most common source compared to other document types. Additionally, based on the countries, the United States contributes the most to research in STEM education and artificial intelligence, followed by China and Hong Kong. An interesting finding is that the contribution of artificial intelligence in STEM education is still low in elementary school, so research on this topic can be further developed in elementary education. A suggestion for future research is to conduct a literature review on the impact of artificial intelligence in STEM education for students, for example focusing on technology literacy, creative thinking skills, and problem-solving skills.

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