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Artificial intelligence (AI) in mathematics education: Bibliometric analysis for the period 2020-2025

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ABSTRACT

This study conducted a bibliometric analysis to investigate the trends and patterns in the application of artificial intelligence (AI) in mathematics education during the period 2020-2025. By analyzing a large dataset of scholarly publications, the study aims to identify the key research areas, influential researchers, and emerging trends in this field. The findings of this study provide valuable insights into the current state of AI research in mathematics education and highlight the potential of AI to revolutionize teaching and learning mathematics.

Keywords: artificial intelligence, mathematics education, bibliometric analysis, machine learning, deep learning, educational technology

INTRODUCTION

Bibliometric analysis is a quantitative method used to evaluate and analyze academic literature within a specific field. This approach employs statistical and mathematical techniques to assess various aspects of publications, such as citation counts, authorship patterns, and publication trends (Marvi & Foroudi, 2023; Riaman et al., 2022; Wulansari et al., 2020). It helps in identifying influential researchers, key studies, and emerging research areas by visualizing data through tools like VOSviewer and CiteSpace (Yardibi & Demirci, 2025; Donthu et al., 2021; Grassia et al., 2025). Bibliometric analysis can map relationships between concepts, track the evolution of research topics, and provide insights into the state of the art in a particular domain (Aleixandre-Benavent et al., 2017; Abd Kadir et al., 2024; Irwanto et al., 2023). It is widely used across different scientific disciplines, including educational science, medicine, environmental science, and business research, to guide future research directions and policymaking (Benavides-Sánchez et al., 2025; Koo & Lin, 2023). Despite its popularity, there is a need for standardized reporting guidelines to ensure consistency and reliability in bibliometric studies (Koo & Lin, 2023).

Through stages of development, bibliometric analysis has had strong influences on the development of educational science in the world, attracting the attention of many researchers (Awang et al., 2025; Kondrashev et al., 2024; Pavlova, 2024).

Currently, bibliometric analysis has been widely applied in many research fields such as information technology, religion, biology, science and technology, etc. In particular, many scientific topics have conducted bibliometric analysis in the field of educational science, typically including development of physics teaching aids (Krismayani et al., 2021), trends in using information technology in teaching mathematics (Muhammad et al., 2022), technology-based learning (Putri, 2017), technology-based biology teaching aids (Muhammad et al., 2022), creating dynamic graphics as digital learning aids (Rahmawati et al., 2022).

Many previous studies have leveraged bibliometric analysis tools such as VOSviewer and Bibliometrics with data from Google Scholar to explore trends in education, such as the Metaverse Trends Computational Mapping (Muktiarni et al., 2023) and the education research bibliometric analysis (Al Husaeni & Nandiyanto, 2022). However, these tools are only a small part of the tools available. To conduct a more comprehensive analysis of AI research in mathematics education, we used CiteSpace, a powerful tool that provides visualizations of relationships between authors, institutions, and collaboration networks.

A review of the literature shows that no prior study has combined CiteSpace with both Scopus and Web of Science data sources to conduct a bibliometric analysis on the development of AI in mathematics education. This study aims to fill that gap by applying this integrated model to analyze the trends and knowledge structure in this particular field.

AI applications are gaining significant traction in education, particularly in mathematics. Research has explored AI's potential in various educational contexts (Chen et al., 2020a; Cope et al., 2020; He et al., 2019; Schiff, 2021; Vaishya et al., 2020). AI's rapid evolution (Gao, 2020) can enhance student learning by improving mathematical skills and cognitive abilities. While technology should augment human thinking (Popenici & Kerr, 2017), AI can facilitate faster and easier access to information, empowering

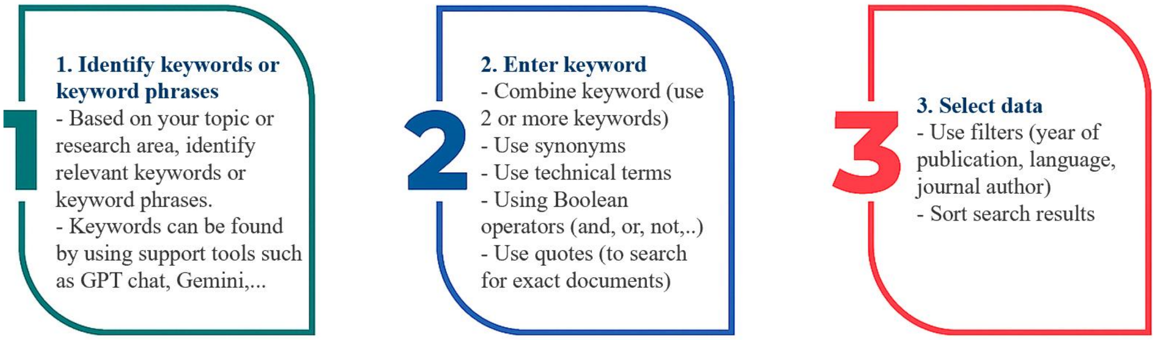

Figure 1. Data collection process (Source: Author's own elaboration)

independent learning. However, AI will not replace educators (Cope et al., 2020) and challenges remain in effectively integrating these technologies (Popenici & Kerr, 2017).

AI, encompassing expert systems, natural language processing, speech recognition, and machine vision, aims to replicate human intelligence in machines. Pedagogical agents, a type of AI software, can personalize learning experiences. While AI excels at complex tasks, concerns exist about its potential impact on human jobs. These concerns, termed "risk perception of AI" (Neri & Cozman, 2020), stem from anxieties about potential negative consequences. Despite these concerns, AI offers significant benefits in education, such as enhancing student engagement (Francis & Davis, 2018). Research has explored the use of robotics in mathematics education (Lopez-Caudana et al., 2020), particularly to address the challenges of learning programming and problem-solving at a young age.

Existing systematic literature reviews (SLRs) exploring educational robotics in education, including mathematics, are limited (Chen et al., 2020a; Guan et al., 2020; Zhong & Xia, 2020). While Zhong and Xia (2020) focus on empirical evidence for robotics in mathematics, previous SLRs have primarily concentrated on AI applications in fields like engineering and computer science, neglecting its potential in mathematics education. This review aims to fill this gap by providing a comprehensive overview of AI's role in teaching and learning mathematics across all educational levels. It will investigate the impact of AI, including personalized learning, adaptive learning, intelligent tutoring systems, virtual learning environments, educational chatbots, automated grading, expert system.

This paper answers the following two research questions:

RQ1 How is the research landscape of artificial intelligence in mathematics education geographically distributed across different countries and institutions?

RQ2 What are the current and emerging research topics in this field?

METHODOLOGY

Research Design

A comprehensive literature review was conducted to answer our research questions. This study only considered articles published between 2020 and 2025; no older articles were included. The review process we followed was as follows:

Step 1: Collect data

To conduct a systematic study, the first step is to identify the appropriate database for the research area. Popular academic databases include Scopus, Web of Science, and Google Scholar. In this study, we will focus on two main data sources, Scopus and Web of Science (WoS). Data will be extracted from both platforms to ensure comprehensiveness. For the data source from Scopus, the extraction process will be conducted according to a specific scheme to ensure efficiency and accuracy (see **Figure 1**).

To collect data effectively, the researcher first needs to build a detailed list of keywords related to his research topic (**Table 2**). This list should include synonyms and related terms to ensure the search is comprehensive. Once a list of keywords is compiled, the database search tools are used to find and download the appropriate data. Make sure that the data is formatted consistently to facilitate the next steps of analysis.

Step 2: Data preprocessing

In the data preprocessing step, the first step is to clean the data to remove duplicate, irrelevant records, and errors. This process helps ensure that each piece of information is unique and accurate. Next, data normalization is performed to ensure consistency. This includes normalizing keywords, author names, and organization names so that different variations of the same entity are treated the same. By combining these two steps, the data becomes clean and consistent, creating a solid foundation for the subsequent analysis steps.

Table 1. Data description

Inclusion criteria	Exclusion criteria
Published between 2020 and 2025	<2020
Document type	Not Article
English language	Not English

Table 2. Synonyms and alternatives terms for main search terms

Artificial intelligence in mathematics education	Math
Machine learning	Math
Personalized learning	Mathematics
Adaptive learning	Mathematics
Intelligent tutoring systems	Mathematics education
Educational chatbots	Mathematics education
Automated grading	Mathematics education
Expert system	Mathematics education

Step 3: Network construction

After collecting and preprocessing the data, the next step is to build networks to analyze the relationships between research entities. Citation networks are created based on the citation relationships between documents, helping to visualize how ideas and research influence each other over time. Meanwhile, co-authorship networks are built to represent collaboration between researchers, allowing the identification of influential research groups and authors. Finally, keyword networks are formed based on the co-occurrence of keywords in the same document, thereby helping to highlight related research topics and the structure of a scientific field. The construction of these three types of networks provides a comprehensive view of the internal structure and dynamics of a research field.

Step 4: Network analysis

Network analysis is a powerful method used to reveal the underlying structure of a research field. By treating research data as a network of interconnected nodes and links, researchers can gain a deeper understanding of its key components and their relationships. Clustering algorithms are used to group nodes (e.g., documents, authors) into smaller, more manageable clusters, with each cluster representing a distinct research topic or subfield. This helps to identify the major themes within the larger network. Centrality analysis helps identify the most important nodes. A node with high centrality, such as an influential document or a key author, is a central hub in the network, often connecting different research topics or having a significant impact on the field. Finally, shortest path analysis helps researcher map the connections and intellectual evolution within the network. By finding the shortest paths between nodes, you can trace how one idea or paper influenced another, revealing the direct relationships and flow of information between concepts, authors, or research topics.

Step 5: Visualize the results

The analysis and interpretation process is an important step in assessing the current state of a field and determining its future direction. First, researchers need to identify trends by identifying emerging and declining research topics. Emerging topics often have a rapid increase in publications, attract new researchers, and are increasingly cited. Conversely, declining topics may have been fully exploited or have lost much potential. Next, to assess the importance of a topic, researchers should rely not only on the number of papers but also on the number of citations, as this is a measure of its influence and impact. Other indicators such as funding and media attention also reflect the importance of a topic. Finally, identifying research gaps is essential for researchers to make a valuable contribution. This gap may be an under-researched problem, an under-applied method, or an area of conflict that needs to be resolved. This process helps you not only understand the big picture of the industry but also find opportunities to explore and develop new ideas.

FINDINGS

This section presents some results obtained from the CiteSpace-Scopus-Web of Science model. Accordingly, the results are focused on the development trend of AI in mathematics education. To serve this research, 365 articles were collected from Scopus and Web of Science database, the number and selection criteria are described in **Table 1**.

Visual Analysis of AI Distribution Map between Author, Countries, Affiliation and Subject Area

Figure 2 shows the number of papers published by country or region, with China leading the way with 78 papers, dominating the rest. Saudi Arabia is second with 63 papers, followed by the South Korea with 49 papers, showing the strong contribution of these three countries to the field of scientific research. Other countries such as Spain (39), India (33) and Romania (26) have lower numbers of papers but still show significant efforts. In addition, United States (30) and Pakistan (350) also contribute to the overall number of scientific publications. The chart shows a clear division between China and the rest and reflects the development of science on an international scale.

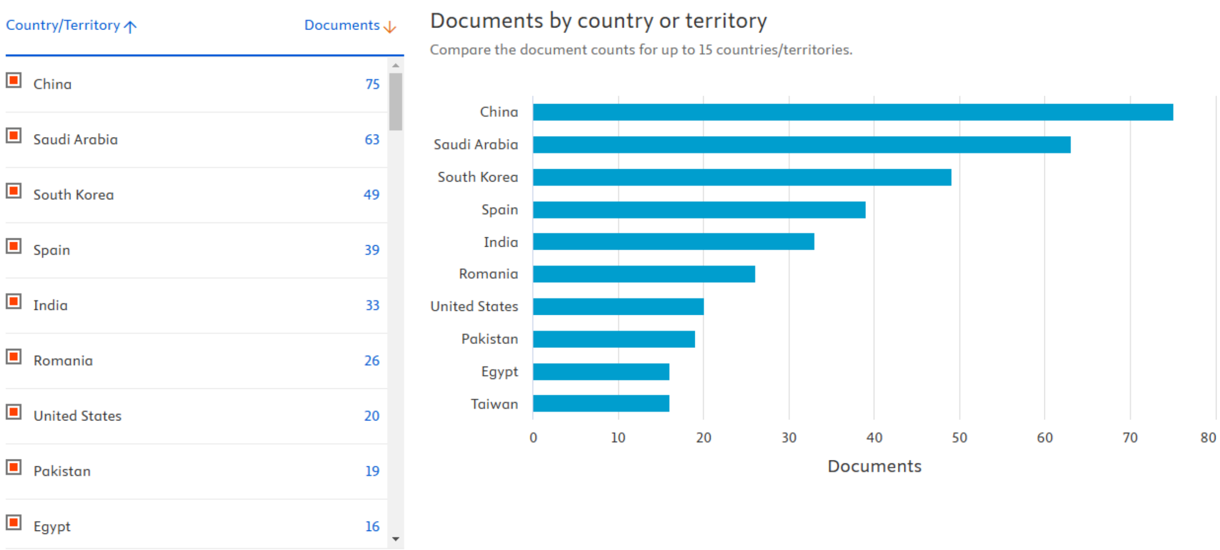

Figure 2. Number of papers published by country or region (Source: Authors' own elaboration)

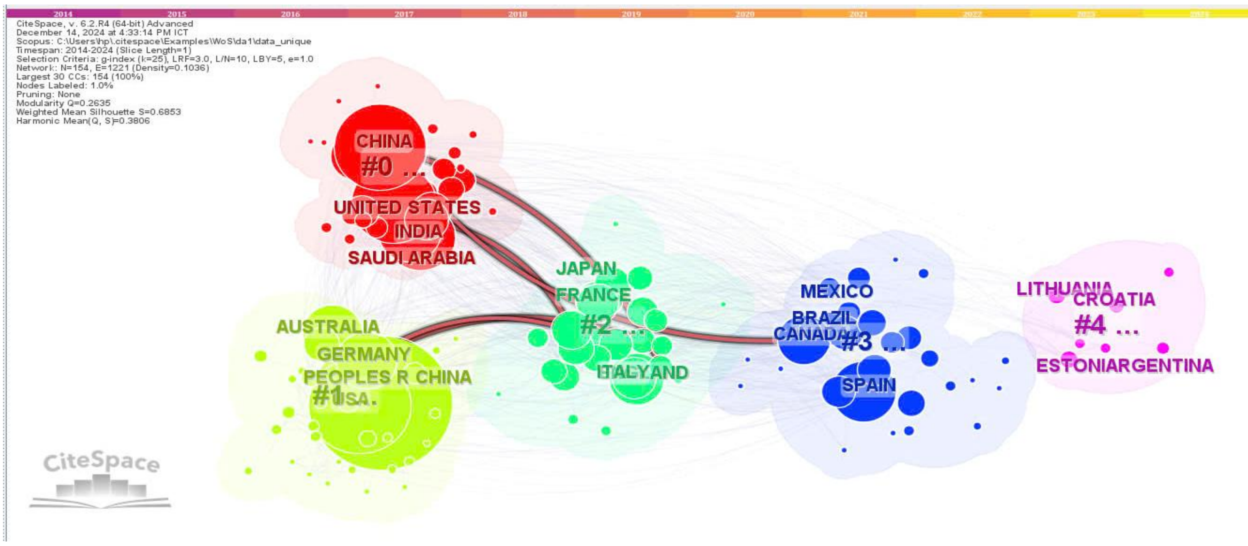

Figure 3. Visual map of research on artificial intelligence (AI) in mathematics education of countries in the period 2020-2025 (Source: Authors' own elaboration)

Figure 3 illustrates the global research landscape of AI in Mathematics Education. China and the United States emerge as leaders, exhibiting high publication output and extensive collaborations. They form strong research connections with India, Saudi Arabia, and other nations. A distinct cluster comprising Germany, France, Italy, Japan, and Australia showcases active regional and international cooperation among developed countries. Latin American and North American countries, including Mexico, Brazil, and Canada, also contribute significantly. While larger countries dominate, smaller nations like Lithuania, Croatia, Estonia, and Argentina demonstrate growing research activity. This period signifies robust growth in AI research within Mathematics Education, characterized by the dominance of major players and the emerging contributions of developing countries.

Figure 4 and **Figure 5** depict global research activity in AI for Mathematics Education, visualized through the size and connectivity of country nodes. Larger and more interconnected nodes signify higher research activity. A marked increase in both the number of nodes and the degree of connectivity between 2020 and 2025 indicates growing research interest in this field. China, the United States, and South Korea emerge as leading players, forming prominent red clusters that signify high research output and extensive collaborations. European countries like Germany, Romania, and Switzerland, alongside Asian nations such as Singapore and Bangladesh, demonstrate a growing global research network. Notably, developing countries like Nigeria, Kenya, Zambia, and Paraguay are increasingly contributing to the field through international research collaborations. Furthermore, smaller Eastern European and Baltic states, including Lithuania, Latvia, and Estonia, are actively joining the global scientific network. This signifies that the spread of AI in Mathematics Education extends beyond major powers, encompassing a diverse range of countries. This global reach underscores the inevitable trajectory of AI integration in the era of digital transformation and smart education.

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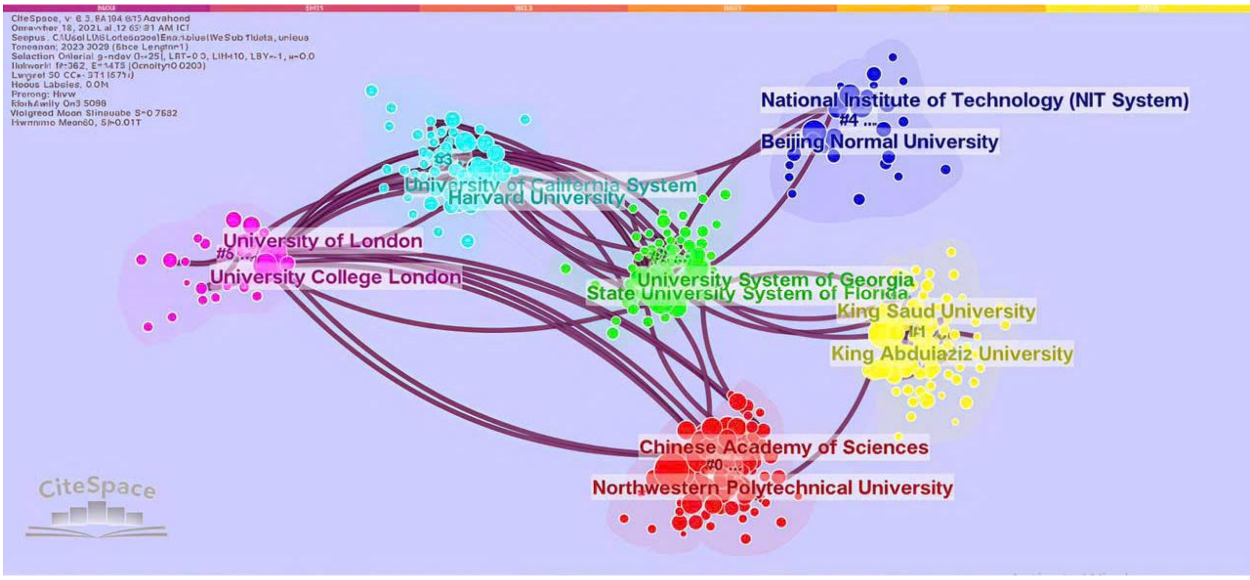


Figure 4. Collaborative network on AI in mathematics education among research institutes for the period 2020-2025 (Source: Authors' own elaboration)

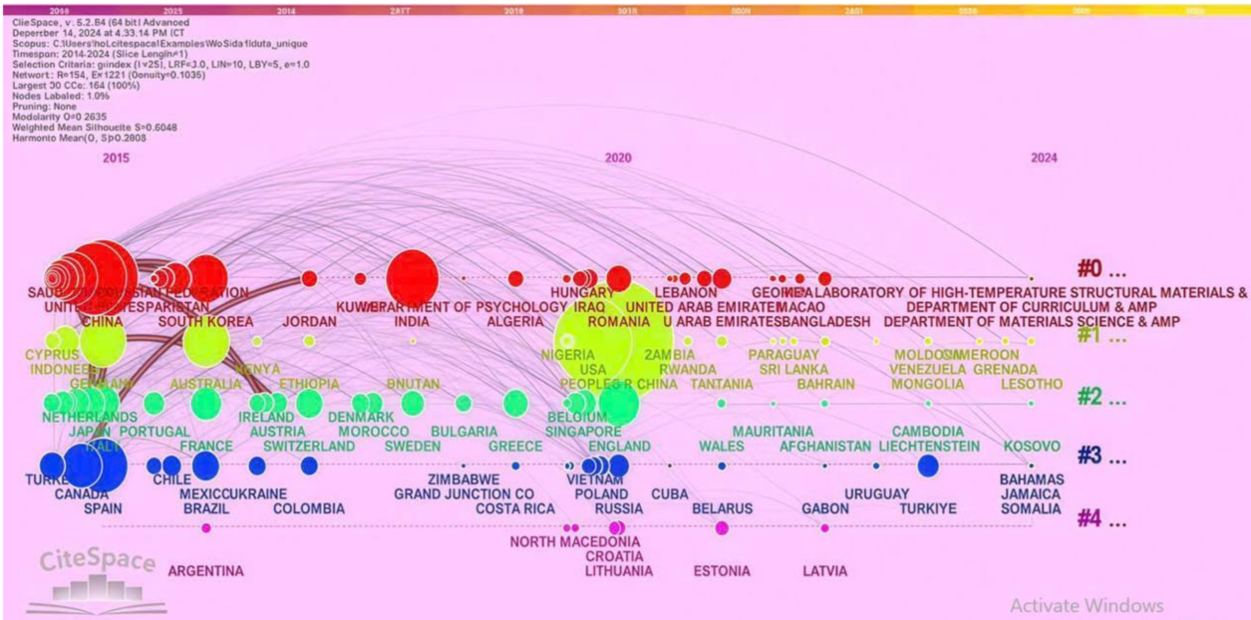


Figure 5. Map of the AI collaboration network in mathematics education among countries (2020-2025) (Source: Authors' own elaboration)

Baltic states, including Lithuania, Latvia, and Estonia, are actively joining the global scientific network. This signifies that the spread of AI in Mathematics Education extends beyond major powers, encompassing a diverse range of countries. This global reach underscores the inevitable trajectory of AI integration in the era of digital transformation and smart education.

AI Development Trends for Specific Fields in Mathematics Education

AI in Mathematics education enhances teaching and learning through various applications. Virtual tutors and intelligent assistants, leveraging natural language processing and rule-based systems, provide personalized explanations and instant feedback, fostering problem-solving skills. AI also automates scoring and assessment, analyzing both answers and problem-solving processes, saving teachers time and providing accurate results. AI learning analytics platforms utilize big data to identify learning trends, predict outcomes, and offer personalized recommendations. Chatbots and intelligent assistants provide 24/7 support, answering questions and delivering flexible learning materials. Furthermore, machine learning and deep learning algorithms optimize teaching methods and facilitate early identification of struggling students.

The map in **Figure 6** and **Figure 7** shows prominent clusters of potential research findings according to topics on AI in Mathematics education such as artificial intelligence, machine learning and deep learning, etc. Machine learning and deep learning are widely applied thanks to their ability to build effective predictive models and analyze data, in which the concepts of convolutional neural networks and explainable artificial intelligence stand out as a new trend to solve the problem of transparency

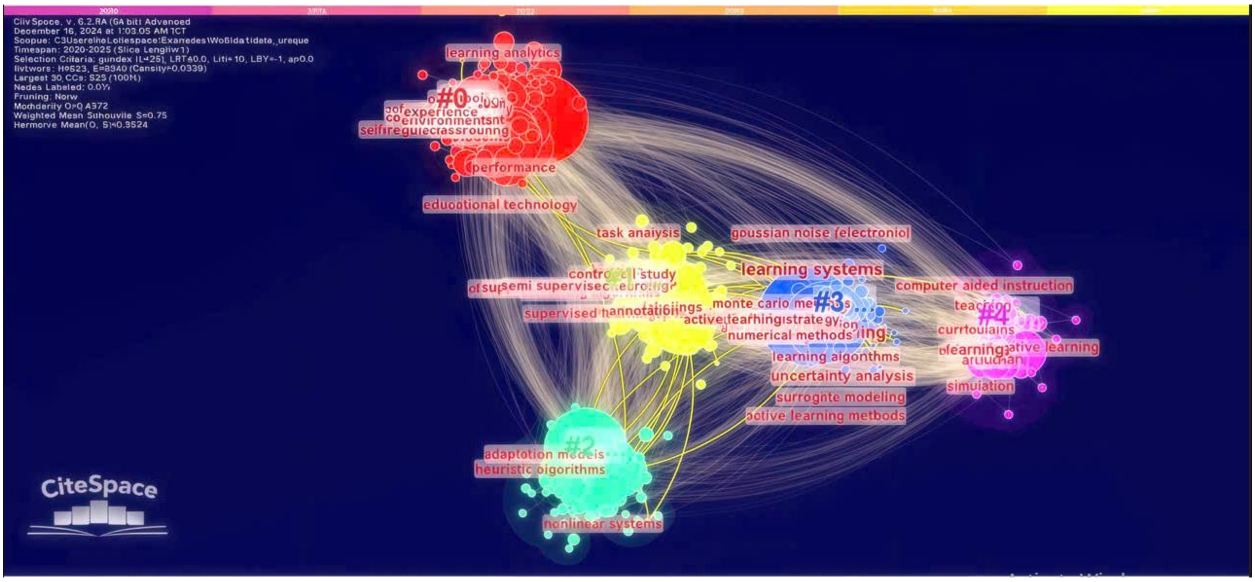


Figure 6. Visual analytics map to uncover potential trends and emerging research directions in AI (Source: Authors' own elaboration)

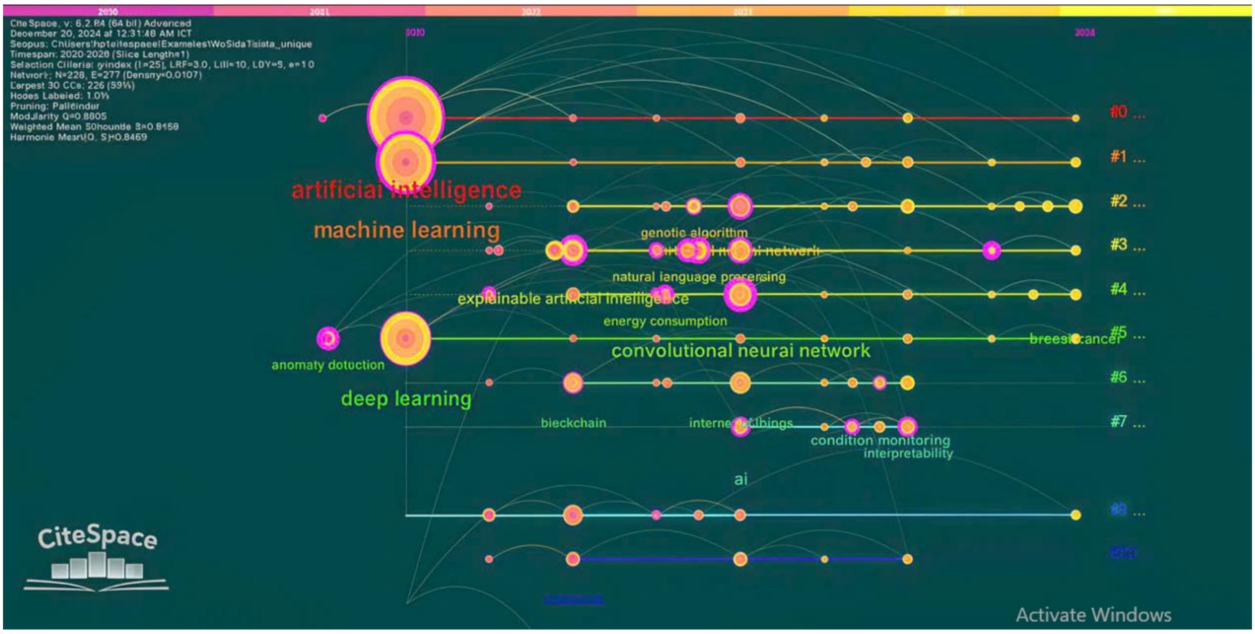
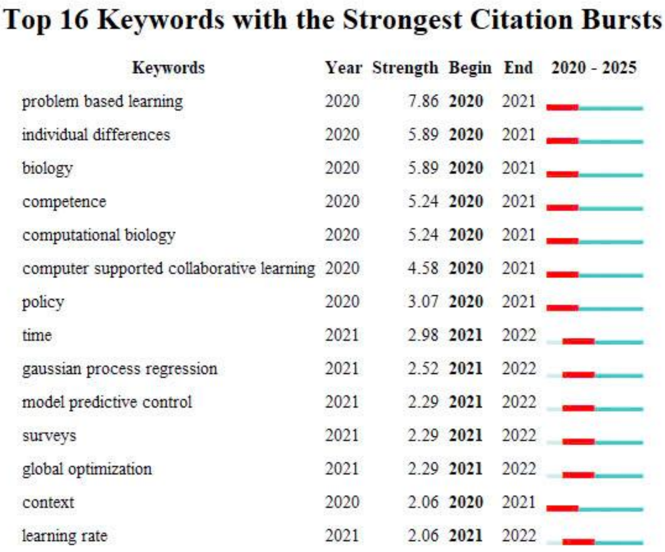


Figure 7. Map of distribution of AI keywords by time slice (Source: Authors' own elaboration)

and explain how AI models work, thereby enhancing the applicability in mathematics education. In addition, topics such as big data, blockchain, etc. have expanded the scope of AI applications to the education field, especially in analyzing large amounts of learning data and monitoring students' learning outcomes. Big data helps process and optimize the education system through advanced machine learning algorithms, while blockchain can improve security and transparency in learning material management. In addition, hybrid models and soft computing also show the potential to combine multiple AI techniques to improve the effectiveness of teaching and learning mathematics. This trend affirms that AI not only helps improve the quality of education but also plays an important role in personalizing teaching methods, meeting increasingly diverse and complex learning needs.

The map in **Figure 8** shows 16 keywords with a spike in citations, reflecting research trends ranging from pedagogical theory to advanced AI application in the 2020-2025 period. These keywords are ranked according to: Year (the time when the keyword started to have an impact), strength (the intensity of the citation explosion, the higher the value, the greater the level of interest), begin-end (the period when the strong citation occurred (shown by the horizontal bar). In the period (2020 - 2021), keywords such as "problem-based learning" and "individual differences" had the highest citation intensity, 7.86 and 5.89 respectively. The above figures reflect the strong level of interest in problem-based learning methods and AI-based personalized learning to improve the learning experience in mathematics education. In addition, concepts such as "competence" and "computer-supported collaborative learning" are also noted, from which we see the role of technology in supporting collaborative learning and developing learners' competencies is being emphasized. Moving into the period 2021 - 2022, the research trend there is a clear



Top 16 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2020 - 2025
problem based learning	2020	7.86	**2020**	2021	
individual differences	2020	5.89	**2020**	2021	
biology	2020	5.89	**2020**	2021	
competence	2020	5.24	**2020**	2021	
computational biology	2020	5.24	**2020**	2021	
computer supported collaborative learning	2020	4.58	**2020**	2021	
policy	2020	3.07	**2020**	2021	
time	2021	2.98	**2021**	2022	
gaussian process regression	2021	2.52	**2021**	2022	
model predictive control	2021	2.29	**2021**	2022	
surveys	2021	2.29	**2021**	2022	
global optimization	2021	2.29	**2021**	2022	
context	2020	2.06	**2020**	2021	
learning rate	2021	2.06	**2021**	2022	

Figure 8. Visualization map of the most cited keywords for artificial intelligence (AI) research in mathematics education 2020-2025 (Source: Authors' own elaboration)

shift in research toward advanced applications and techniques in AI, such as "Gaussian process regression", "global optimization", and "model predictive control". These terms reflect an interest in machine learning and optimization tools to improve the teaching and learning of mathematics. In particular, "learning rate" shows a focus on improving algorithmic efficiency in the process of applying AI to education. Although the citation intensity of these keywords is not very high, it reflects the development of AI technology and the combination of mathematical theory and modern machine learning tools.

DISCUSSION

This bibliometric analysis explores the growing integration of Artificial Intelligence (AI) in mathematics education between 2020 and 2025. As the use of AI continues to expand across various fields, its applications in education, particularly mathematics, have shown significant potential. Our findings reveal a noticeable increase in the number of publications focusing on AI in mathematics education, indicating an expanding interest in this area among researchers and practitioners.

Early research topics in AI focused on fundamental concepts such as "machine learning", "deep learning", and "feature extraction". These pioneering studies were quickly integrated into the field of education, as evidenced by strong connections to applications such as "student learning systems" and "educational technology". In the mid-2010s, the focus of research shifted to more specialized applications, as AI began to be applied to specific subjects such as "college English", "classroom teaching", and "mathematics". The emergence of topics such as "virtual reality" and "federated learning" signaled a trend towards more interactive and distributed learning environments. During the late 2010s and early 2020s, AI research in education shifted to exploring more complex models. Keywords such as "deep neural networks," "generative adversarial networks," and "adversarial machine learning" emerged, reflecting a shift from generic machine learning algorithms to more specialized and sophisticated AI technologies, especially in areas such as "data technology" and "English teaching." Recently, emerging and interdisciplinary topics have attracted attention, including "genetic algorithms," "fuzzy neural networks," and "interpretability." The emergence of terms like "energy consumption" and "conscious learning" reflects growing interest in the efficiency, ethical issues, and cognitive aspects of AI in education.

Between 2020 and 2025, the distribution of AI research in mathematics education has been notably concentrated in a few key countries and institutions. China and the United States have emerged as leaders in both scientific output and international collaboration (Hossein-Mohand et al., 2025; Kavitha et al., 2024; Widayanti et al., 2024). This is further supported by a bibliometric study showing that China has surpassed the US in the number of AI-related publications in higher education (Ojha et al., 2024). Beyond the two major players, other nations are also significant contributors. The United States, Malaysia, and Spain, for instance, are prominent in research on augmented reality within mathematics education (Gusteti et al., 2025). This global effort is also reflected in strong co-authorship networks, which include countries like Saudi Arabia and the United Kingdom, indicating a collaborative push to advance the field (Kavitha et al., 2024). Leading research institutions, such as Chitkara University in India and Johannes Kepler University Linz in Austria, are pivotal in driving this research, particularly in areas like augmented reality (Gusteti et al., 2025). Furthermore, institutions are directly integrating AI into their curricula; for example, the Department of Applied Mathematics and Artificial Intelligence at NRU MPEI has developed new educational programs focused on AI methods and technologies (Eremeev et al., 2022). This concentration of research in well-resourced contexts highlights a potential gap in underrepresented regions, underscoring the need for more inclusive studies to address these disparities (Castillo et al., 2025).

Through bibliographic analysis, one prominent trend identified in this study is the diverse range of AI technologies being incorporated into mathematics teaching and learning. These include adaptive learning systems, intelligent tutoring systems (ITS), and machine learning algorithms. Adaptive learning systems, in particular, are gaining traction for their ability to personalize learning experiences, adapting to the needs of individual students based on their performance and learning styles. This is particularly relevant in mathematics education, where students often struggle with abstract concepts and benefit from tailored Moreover, the analysis highlights the growing intersection between AI and educational theories, such as constructivism and behaviorism, with AI tools being developed to enhance student engagement, foster active learning, and promote deeper understanding. The collaboration between AI and educators in creating effective, data-driven teaching methods is vital for advancing educational outcomes in mathematics. The integration of AI in mathematics education has seen significant growth from 2020 to 2025, with a notable increase in publications and research interest. Key themes identified include the use of generative AI, such as deep learning and ChatGPT, for assessment and personalized learning (Hossein-Mohand et al., 2025; Opesemowo & Adewuyi, 2024). The focus has been on enhancing mathematics instruction, providing real-time feedback, and developing AI-driven personalized learning experiences (Opesemowo & Adewuyi, 2024). Additionally, the role of AI in addressing educational disparities and preparing learners for the demands of the 4th Industrial Revolution (4IR) has been highlighted (Opesemowo & Adewuyi, 2024). The emergence of generative AI research in education, particularly in 2023, underscores the growing interest in leveraging AI technologies to improve educational outcomes (Dúo-Terrón, 2024). The study also reveals a rising focus on addressing challenges such as educational equity and accessibility. AI tools have the potential to bridge educational gaps, offering students from various socio-economic backgrounds access to high-quality mathematics instruction. However, this potential is contingent on addressing issues such as digital literacy, resource availability, and the ethical implications of AI deployment in classrooms. As AI continues to develop, it is essential that researchers and policymakers work together to ensure that these technologies are accessible and beneficial to all students.

The keyword analysis from various studies highlights several emerging themes and research directions. Keywords such as "Technology," "Chatbot," "Experience," and "Neural Networks" are identified as potential research frontiers (Liu et al., 2024). The thematic analysis also reveals a focus on the ethical implications of AI in education, the development of AI tools for curriculum enhancement, and the role of AI in higher education (Pituy et al., 2024; Trošelj et al., 2024). The evolution of AI research in education is becoming increasingly complex, involving a wide range of fields and forming multiple evolution paths (Liu et al., 2024). This indicates dynamic and rapidly evolving research.

Recent studies highlight several emerging trends in the application of artificial intelligence (AI) in mathematics education. One significant trend is the increasing use of generative AI technologies, such as deep learning and ChatGPT, for educational purposes, particularly in assessment and personalized learning (Hossein-Mohand et al., 2025). These technologies are being leveraged to create adaptive learning systems that tailor educational content to individual student needs, thereby enhancing engagement and learning outcomes (Canonigo, 2024; Inderjeet & Bhardwaj, 2024). Additionally, there is a notable rise in the use of AI-driven tools like GeoGebra and intelligent tutoring systems, which have shown to improve students' conceptual understanding and self-efficacy in mathematics (Canonigo, 2024). The integration of AI in mathematics education is also marked by a growing interest in interdisciplinary collaboration, with China and the United States leading in scientific productivity and international partnerships (Hossein-Mohand et al., 2025). The research on AI in mathematics education is evolving to address various educational challenges and opportunities. One emerging direction is the development of AI-powered adaptive learning systems that provide real-time feedback and personalized learning pathways (Chen, 2025; Inderjeet & Bhardwaj, 2024). These systems utilize machine learning algorithms to diagnose individual learning needs and adjust instructional content, accordingly, making learning more interactive and engaging (Inderjeet & Bhardwaj, 2024; Moussa, 2024). Another promising area is the use of AI in creating immersive learning environments through technologies like virtual reality (VR) and augmented reality (AR), which can simulate real-world scenarios and enhance students' problem-solving skills (Haq et al., 2025). Furthermore, there is a growing focus on the ethical implications of AI in education, including concerns about potential biases in AI systems and the need for transparent communication and teacher oversight to ensure responsible use (Alvarez, 2024; Canonigo, 2024).

Future research in AI in mathematics education is likely to explore the integration of AI with other emerging technologies and pedagogical approaches. For instance, the combination of AI with extended reality (XR) technologies is expected to create more inclusive and sustainable learning environments, particularly in STEM education (Haq et al., 2025). Additionally, there is a need for more empirical studies to provide evidence-based support for the use of AI in early childhood mathematics education, as well as to understand the long-term impacts of AI on student learning and engagement (Zhang & Chen, 2022). However, several challenges remain, including the need for robust datasets to train AI models, addressing technological and ethical concerns, and ensuring that AI tools complement rather than replace traditional teaching methods (Canonigo, 2024; Moussa, 2024). Addressing these challenges will require ongoing collaboration between educators, researchers, and policymakers to optimize the use of AI in mathematics education and maximize its benefits for students. In another aspect, the integration of AI in mathematics education has led to several emerging trends and themes. There is a growing interest in generative AI, including deep learning and ChatGPT, for assessment and personalized learning (Hossein-Mohand et al., 2025; Opesemowo & Adewuyi, 2024). AI tools such as MATLAB, GeoGebra, and Khan Academy are transforming mathematics teaching by enhancing visualization, interactivity, and immediate feedback (Castillo et al., 2025). Additionally, the application of AI in elementary education shows a small but significant effect on students' mathematics achievement, moderated by variables such as grade level and learning topics (Hwang, 2022). These trends highlight the transformative potential of AI in addressing educational disparities and preparing learners for the demands of the 4th Industrial Revolution (Opesemowo & Adewuyi, 2024). However, challenges related to data privacy, equity, and reliance on technology must be carefully considered to maximize the benefits of AI integration in mathematics education (Dias Rasteiro & Thiele, 2024).

Finally, bibliometric analysis also uncovers several gaps in literature. While there is substantial research on the technological aspects of AI in education, less attention has been given to the social, psychological, and ethical dimensions of AI integration. Questions surrounding data privacy, AI biases, and the potential for the depersonalization of teaching need further exploration.

Furthermore, research on long-term impacts, including the effectiveness of AI in improving mathematics learning outcomes and the role of AI in the future of mathematics curricula, remains limited instruction.

CONCLUSION

Bibliometric analysis has shown a significant growth in the integration of Artificial Intelligence (AI) into mathematics education from 2020 to 2025. Research topics have shifted from basic concepts such as machine learning and deep learning to more complex applications such as adaptive learning systems, intelligent tutoring systems (ITS), and generative AI technologies such as ChatGPT. China and the United States emerged as the leading countries in terms of the number of publications and international collaborations, affirming their pioneering position in the field. The concentration of research in well-resourced countries and institutions also shows a notable trend, reflecting the rapid development and increasing importance of AI in mathematics education.

Research on AI in mathematics education is evolving in a variety of directions, including the integration of emerging technologies such as virtual reality (VR), augmented reality (AR), and fuzzy neural networks. These trends represent a strong shift toward more interactive, personalized, and immersive learning environments. In particular, the emergence of keywords such as "energy consumption" and "conscious learning" reflects growing interest in the ethical, efficient, and cognitive aspects of AI. These advances are aimed not only at improving learning outcomes but also at preparing learners with the skills needed to meet the demands of the Fourth Industrial Revolution.

Despite these significant advances, the analysis also highlighted some important research gaps. Specifically, while the technical aspects of AI have been widely studied, its social, psychological, and ethical implications have received less attention. Further research is needed to address issues of data privacy, bias in AI, and the long-term impact of technology on teacher-student interactions. In addition, the lack of research in underserved geographic areas and lower levels of education such as early childhood education highlights the urgent need for more comprehensive and inclusive research. Addressing these gaps will require close collaboration between educators, researchers, and policymakers to ensure AI is integrated responsibly and benefits all learners.

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AI statement: The authors stated that no artificial intelligence (AI) tools were used to generate the content of this manuscript.

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REFERENCES

Abd Kadir, K., Idris, N., & Izzati Anuar, A. (2024). Exploring surah ad- dhuha: A fun and educational tafsir app for kids. *International Journal of Advanced Research in Future Ready Learning and Education 34*(1), 31-52. https://doi.org/10.37934/frle.34.1.3152

Al Husaeni, D. F., & Nandiyanto, A. B. D. (2022). Bibliometric using Vosviewer with Publish or Perish (using google scholar data): From step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post Covid-19 pandemic. *ASEAN Journal of Science and Engineering, 2*(1), 19-46. https://doi.org/10.17509/ajse.v2i1.37368

Aleixandre-Benavent, R., Aleixandre-Tudó, J. L., Castelló-Cogollos, L., & Aleixandre, J. L. (2017). Trends in scientific research on climate change in agriculture and forestry subject areas (2005–2014). *Journal of Cleaner Production, 147*, 406-418. https://doi.org/10.1016/j.jclepro.2017.01.112

Alvarez, J. I. (2024). Evaluating the impact of AI–powered tutors mathgpt and flexi 2.0 in enhancing calculus learning. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi, 8*(2), 495-508. https://doi.org/10.22437/jiituj.v8i2.34809

Awang, L. A., Yusop, F. D., & Danaee, M. (2025). Current practices and future direction of artificial intelligence in mathematics education: A systematic review. *International Electronic Journal of Mathematics Education, 20*(2), Article em0823. https://doi.org/10.29333/iejme/16006

Benavides-Sánchez, E. P., Moya-Clemente, I., & Ribes-Giner, G. (2025). Bibliometric analysis and systematic literature review of the relationship between sustainable development goals and sustainable entrepreneurship over time. *Discover Sustainability, 6*(64). https://doi.org/10.1007/s43621-024-00572-0

Canonigo, A. M. (2024). Levering AI to enhance students' conceptual understanding and confidence in mathematics. *Journal of Computer Assisted Learning*, *40*(6), 3215-3229. https://doi.org/10.1111/jcal.13065

Castillo, E. R., León, J. A. M., Celiz, E. B., Alarcón, T. J. J., & Chunga More, Y. D. M. (2025). Technological tools used in mathematical thinking at the university level: A systematic review. *Journal of Educational and Social Research*, *15*(2), 73-84. https://doi.org/10.36941/jesr-2025-0043

Chen, L., Chen, P., & Lin, Z. (2020a). Artificial intelligence in education: A review. *IEEE Access*, *8*, 75264-75278. https://doi.org/10.1109/ACCESS.2020.2988510

Chen, Y. (2025). Evaluation of the application effect of intelligent teaching systems in mathematics education. *International Journal of Web-Based Learning and Teaching Technologies*, *20*(1), 1-19. http://doi.org/10.4018/IJWLTT.368027

Cope, B., Kalantzis, M., & Searsmith, D. (2020). Artificial intelligence for education: Knowledge and its assessment in AI-enabled learning ecologies. *Educational Philosophy and Theory, 53*(12), 1229-1245. http://doi.org/10.1080/00131857.2020.1728732

Dias Rasteiro, D. L., & Thiele, K. (2024). AI and ICT integration in mathematics engineering education: Enhancing learning and teaching. In *Proceedings of the 52nd Annual Conference of SEFI*. https://doi.org/10.5281/zenodo.14260983

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research, 133*, 285-296. https://doi.org/10.1016/j.jbusres.2021.04.070

Dúo-Terrón, P. (2024). Generative artificial intelligence: Educational reflections from an analysis of scientific production. *Journal of Technology and Science Education*, *14*(3), 756-769. https://doi.org/10.3926/jotse.2680

Eremeev, A. P., Paniavin, N. A., & Marenkov, M. A. (2022). An object-oriented approach to ontology modelling in specialists education of methods and technologies of artificial intelligence. In *2022 6th International Conference on Information Technologies in Engineering Education, Inforino 2022 – Proceedings* (pp. 1-4). https://doi.org/10.1109/Inforino53888.2022.9782954

Francis, K., & Davis, B. (2018). Coding robots as a source of instantiations for arithmetic. *Digital Experiences in Mathematics Education, 4*(1), 71-86. https://doi.org/10.1007/s40751-018-0042-7

Gao, S. (2020). Innovative teaching of integration of artificial intelligence and university mathematics in big data environment. *IOP Conference Series: Materials Science and Engineering, 750*, Article 012137. https://doi.org/10.1088/1757-899X/750/1/012137

Grassia, V., Fiori, A., Diodati, F., Sayahpour, B., Jamilian, A., Armogida, N. G., d'Apuzzo, F., & Nucci, L. (2025). Clear aligners: A network and bibliometric analysis of 50 pivotal articles. *Dental and Medical Problems, 62*(1), 161-171. https://doi.org/10.17219/dmp/188319

Guan, C., Mou, J., & Jiang, Z. (2020). Artificial intelligence innovation in education: A twenty- year data-driven historical analysis. *International Journal of Innovation Studies*, *4*(4), 134-147. https://doi.org/10.1016/j.ijis.2020.09.001

Gusteti, M. U., Musdi, E., Dewata, I., & Rasli, A. M. (2025). A ten-year bibliometric study on augmented reality in mathematical education. *European Journal of Educational Research*, *14*(3), 723-741. https://doi.org/10.12973/eu-jer.14.3.723

Haq, I. U., Mohiz, A., Spadafora, G., Palermo, A. M., Bilotta, E., Felicetti, F., & Lamonaca, F. (2025). AI in the network of extended reality-enabled laboratories for STEM education: Current applications and future potential for adaptive learning. In G. Carbone, & G. Quaglia (Eds.), *Proceedings of I4SDG Workshop 2025 - IFToMM for Sustainable Development Goals. Mechanisms and Machine Science* (Vol. 180, pp. 373-382). Springer. https://doi.org/10.1007/978-3-031-91179-8_39

He, J., Baxter, S. L., Xu, J., Xu, J., Zhou, X., & Zhang, K. (2019). The practical implementation of artificial intelligence technologies in medicine. *Nature Medicine*, *25*(1), 30-36. https://doi.org/10.1038/s41591-018-0307-0

Hossein-Mohand, H., Hossein-Mohand, H., Albanese, V., & Gómez, M. D. C. O. (2025). AI in mathematics education: A bibliometric analysis of global trends and collaborations (2020-2024). *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(2), Article em2576. https://doi.org/10.29333/ejmste/15915

Hwang, S. (2024). Examining the effects of artificial intelligence on elementary students' mathematics achievement: A meta-analysis. *Sustainability*, *14*(20), Article 13185. https://doi.org/10.3390/su142013185

Inderjeet, & Bhardwaj, R. (2024). AI integrated model design for education system for analytical computation (mathematics). In *2024 4th International Conference on Advance Computing and Innovative Technologies in Engineering* (ICACITE) (pp. 1412-1417). https://doi.org/10.1109/ICACITE60783.2024.10616503

Irwanto, I., Wahyudiati, D., Saputro, A. D., & Laksana, S. D. (2023). Research trends and applications of gamification in higher education: A bibliometric analysis spanning 2013–2022. *International Journal of Emerging Technologies in Learning*, *18*(05), 19–41. https://doi.org/10.3991/ijet.v18i05.37021

Kavitha, K., Joshith, V. P., Rajeev, N. P., & Asha, S. (2024). Artificial intelligence in higher education: A bibliometric approach. *European Journal of Educational Research*, 1*3*(3), 1121- 1137. http://doi.org/10.12973/eu-jer.13.3.1121

Kondrashev, S. V., Sokolova, N. L., Zaripova, Z. F., & Khairullina, E. R. (2024). Innovations in science education: A bibliometric exploration of trends and future directions. *Eurasia Journal of Mathematics, Science and Technology Education, 20*(6), Article em2453. https://doi.org/10.29333/ejmste/14591

Koo, M., & Lin, S.-C. (2023). An analysis of reporting practices in the top 100 cited health and medicine-related bibliometric studies from 2019 to 2021. *BMC Medical Research Methodology, 9*(6), Article e16780. https://doi.org/10.1016/j.heliyon.2023.e16780

Krismayani, F. (2021). Analisis sitasi pada artikel Jurnal Anuva tahun 2017 [Citation analysis in Anuva Journal Article in 2017]. *Anuva: Jurnal Kajian Budaya, Perpustakaan, dan Informasi, 5*(2), 307-314. https://doi.org/10.14710/anuva.5.2.307-314

Liu, H., Huang, L., Xu, S., & Luo, W. (2024). Dynamic evolution analysis of AI in education based on SciMAT. In *IEIR 2024 - Proceedings of the 3rd International Conference on Intelligent Education and Intelligent Research* (pp. 1-8). https://doi.org/10.1109/IEIR62538.2024.10959926

Lopez-Caudana, E., Ramirez-Montoya, M. S., Martínez-Pérez, S., & Rodríguez-Abitia, G. (2020). Using robotics to enhance active learning in mathematics: A multi-scenario study. *Mathematics, 8*(12), Article 2163. https://doi.org/10.3390/math8122163

Marvi, R., & Foroudi, M. M. (2023). Bibliometric analysis: Main procedure and guidelines. In P. Foroudi, & C. Dennis (Eds.), *Researching and analysing business: Research methods in practice* (pp. 43-54) https://doi.org/10.4324/9781003107774-4

Moussa, Y. (2024). Advancing learning systems: Enhancing explanation generation through AI innovations. In K. Daimi, & A. Al Sadoon (Eds.), *Proceedings of the Third International Conference on Innovations in Computing Research (ICR'24)* (Vol. 1058, pp. 334-347). Springer. https://doi.org/10.1007/978-3-031-65522-7_30

Muhammad, I., Marchy, F., Rusyid, H. K., & Dasari, D. (2022). Analisis bibliometrik: Penelitian augmented reality dalam pendidikan matematika. *JIPM (Jurnal Ilmiah Pendidikan Matematika)*, *11*(1), 141-155. https://doi.org/10.25273/jipm.v11i1.13818

Muktiarni, M., Rahayu, N. I., Ismail, A., & Wardani, A. K. (2023). Bibliometric computational mapping analysis of trend metaverse in education using VOSviewer. *Journal of Advanced Research in Applied Sciences and Engineering Technology, 32*(2), 95-106. https://doi.org/10.37934/araset.32.2.95106

Neri, H., & Cozman, F. (2020). The role of experts in the public perception of risk of artificial intelligence. *AI & Society, 35*, 663-673. https://doi.org/10.1007/s00146-019-00924-9

Ojha, M., Mishra, A. K., Kandpal, V., & Singh, A. (2024). The ethical dimensions of AI development in the future of higher education: Balancing innovation with responsibility. In P. Bhattacharya, A. Hassan, H. Liu, & B. Bhushan (Eds.), *Ethical Dimensions of AI Development* (pp. 401-436). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-4147-6.ch018

Opesemowo, O. A. G., & Adewuyi, H. O. (2024). A systematic review of artificial intelligence in mathematics education: The emergence of 4IR. *Eurasia Journal of Mathematics, Science and Technology Education*, 20(7), Article em2478. https://doi.org/10.29333/ejmste/14762

Pavlova, N. H. (2024). Flipped dialogic learning method with ChatGPT: A case study. *International Electronic Journal of Mathematics Education, 19*(1), Article em0764. https://doi.org/10.29333/iejme/14025

Pituy, Y. I. J. D. D., Gutiérrez, J. N. M., Sánchez, O. S., & Montalvo, M. Y. B. (2024). The trajectory of artificial intelligence in postsecondary education: A systematic review of the literature 2019-2023. In *Sustainable Engineering for a Diverse, Equitable, and Inclusive Future at the Service of Education, Research, and Industry for a Society 5.0.* https://doi.org/10.18687/LACCEI2024.1.1.887

Popenici, S. A., & Kerr, S. (2017). Exploring the impact of artificial intelligence on teaching and learning in higher education. *Research and Practice in Technology Enhanced Learning*, *12*, Article 22. https://doi.org/10.1186/s41039-017-0062-8

Putri, Y. D. (2017). Pembuatan motion graphic sebagai media sosialisasi dan promosi untuk aplikasi mobile trading online Mandiri Sekuritas [Creation of motion graphics as a medium for socialization and promotion for the Mandiri Sekuritas online mobile trading application]. *Jurnal Ilmiah Manajemen Informatika dan Komputer, 1*(2), 85-92. https://doi.org/10.32485/kopertip.v1i02.16

Rahmawati, Y., Taylor, E., Taylor, P. C., Ridwan, A., & Mardiah, A. (2022). Students' engagement in education as sustainability: Implementing an ethical dilemma-STEAM teaching model in chemistry learning. *Sustainability, 14*(6), Article 3554. https://doi.org/10.3390/su14063554

Riaman, Sukono, Supian, S., & Ismail, N. (2022). Mathematical modeling for estimating the risk of rice farmers' losses due to weather changes. *Computation, 10*, Article 140. https://doi.org/10.3390/computation10080140

Schiff, D. (2021). Out of the laboratory and into the classroom: The future of artificial intelligence in education. *AI & Society*, *36*(1), 331-348. https://doi.org/10.1007%2Fs00146-020-01033-8

Trošelj, D. B., Maricic, S., & Curic, A. (2024). Growing interest in AI in education: Systematic literature review. In *Proceedings of International Conference on Research in Education and Science* (pp. 2410-2427). ISTES.

Vaishya, R., Javaid, M., Khan, I. H., & Haleem, A. (2020). Artificial intelligence (AI) applications for COVID-19 pandemic. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, *14*(4), 337-339. https://doi.org/10.1016/j.dsx.2020.04.012

Widayanti, Haryanto, Istiyono, E., Saregar, A., & Amaliah, K. (2024). How is the insight overview of artificial intelligence research in high school? *European Journal of Educational Research*, *13*(4), 1917-1930. https://doi.org/10.12973/eu-jer.13.4.1917

Wulansari, L., Ahmar, A. S., Rochmat, A., Nurmawati, & Iskandar, A. (2020). The most-cited articles in data in brief journal: A bibliometric analysis using Scopus data. *Library Philosophy and Practice*, Article 4566.

Yardibi, F., & Demirci, S. (2025). Global trends and hot spots in cerebral venous sinus thrombosis research over the past 50 years: A bibliometric analysis. *Neurological Research, 47*(1), 23–34. https://doi.org/10.1080/01616412.2024.2430999

Zhang, S., & Chen, X. (2022). Applying artificial intelligence into early childhood math education: Lesson design and course effect. In *Proceedings - 2022 IEEE International Conference on Teaching, Assessment and Learning for Engineering* (pp. 635-638). Hung Hom. https://doi.org/10.1109/TALE54877.2022.00109

Zhong, B., & Xia, L. (2020). A systematic review on exploring the potential of educational robotics in mathematics education. *International Journal of Science and Mathematics Education*, *18*(1), 79-101. https://doi.org/10.1007/s10763-018-09939-y