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The evolving landscape of AI integration in mathematics education: A systematic review of trends (2015-2025)

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Abstract

Over the past 10 years (2015-2025), the rapid development of artificial intelligence (AI) has brought educational technology to a new level, especially in the field of mathematics education. However, although there are many individual studies on specific applications of AI, a systematic and comprehensive overview of the main trends is still lacking. To fill this gap, this study conducts a systematic review aimed at exploring the development landscape of AI integration in mathematics education from 2015 to 2025. The study focuses on answering four main questions: (1) What is the level of research contribution on AI in mathematics education across regions and countries in the world? (2) What are the emerging trends in AI integration in mathematics education from 2015 to 2025? (3) Which AI tools are most commonly used in mathematics education? (4) How is the use of AI tools reflected at different educational levels? This study uses a systematic review approach to analyze academic literature published during the period 2015-2025. The results will provide a detailed map of technological trends, pedagogical models, and main application areas of AI in mathematics education at different levels. At the same time, the study also identifies common challenges and potential areas for future research. The results of this study will provide a valuable reference for educational policy makers, technology developers, teachers, and researchers, helping them make more informed decisions in exploiting the potential of AI to improve the quality of mathematics education.

Keywords: artificial intelligence, bibliometric analysis, mathematics education, systematic review, educational technology trends

INTRODUCTION

In recent years, the rapid development of science and technology, especially the application of big data and artificial intelligence (AI), has brought educational technology to a new level (Luan et al., 2020). In this context, mathematics education is facing an important turning point. AI-based tools and platforms are not only playing a teaching support role but are also raising fundamental questions about the nature of teaching and learning mathematics in the 21st century. From a traditional model that was previously mainly based on memorizing formulas and practicing problem-solving skills according to patterns, mathematics education is gradually shifting to a more dynamic, flexible, personalized and interactive model.

Over the past decade (2015-2025), the rapid growth of AI has opened new doors for education, particularly in mathematics-a subject that relies heavily on logical thinking and problem-solving. AI tools like machine learning, natural language processing, and intelligent recommendation systems offer significant potential to enhance teaching and learning outcomes (Awang et al., 2025; Putri et al., 2025). Research consistently shows the positive impact of AI on student learning. Studies have demonstrated that AI-based systems can improve problem-solving skills and academic performance in mathematics (Cuong et al., 2025; Rizos et al; 2024; Van Vaerenbergh & Pérez-Suay, 2022). For instance, AI chatbots have been found to specifically enhance mathematical thinking skills among secondary students (Van Doc et al., 2023). Beyond cognitive benefits, AI also

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Contribution to the literature

- This systematic review provides a comprehensive synthesis of the trends and patterns in AI integration within mathematics education over the last decade (2015-2025), a period of significant technological advancements.
- The study identifies key research gaps and emerging topics, offering a roadmap for future research directions. It highlights under-researched areas such as the ethical implications of AI in learning assessments and the long-term impacts on student problem-solving skills.
- By categorizing and analyzing the diverse applications of AI-from personalized tutoring systems to automated feedback tools-this review offers a structured framework for educators, policymakers, and researchers to understand and navigate the complex landscape of AI in mathematics educational settings.

positively influences student attitudes. Learners tend to adapt well to AI-based mathematics tools (Soesanto et al., 2022), and these systems can stimulate students' curiosity and reduce learning-related stress (Pavlova, 2024). The integration of AI in mathematics education has been a major focus of recent research, which highlights its transformative potential and key applications. AI can provide personalized learning experiences, offer real-time feedback, and support curriculum development, helping to address educational disparities and prepare students for the 4th Industrial Revolution (4IR) (Awang et al., 2025; Hwang & Tu, 2021; Opesemowo & Adewuyi, 2024). Tools like ChatGPT, for example, have proven effective in boosting student engagement and learning outcomes through personalized learning and real-time assessment (Opesemowo & Adewuyi, 2024; Torres-Peña et al., 2024). Despite these advancements, there remains a notable gap in comprehensive, holistic reviews that fully explore AI's role in mathematics education from diverse perspectives (Hwang & Tu, 2021; Kaushik et al., 2021).

Several systematic reviews and bibliometric studies have been conducted to analyze the trends and applications of AI in mathematics education. These studies typically categorize AI tools based on their function, from those designed to solve specific mathematical problems to broader pedagogical platforms like adaptive learning systems and generative AI (Awang et al., 2025; Panqueban & Huincahue, 2024). This body of research highlights the importance of interdisciplinary collaboration and the need for more empirical studies that focus on diverse student populations and ethical considerations (Hossein-Mohand et al., 2025; Zhai & Krajcik, 2024). Despite these efforts, a clear gap exists in the research regarding AI's role in early childhood education and teacher training, which are areas ripe for further exploration (Panqueban & Huincahue, 2024; Pham The et al., 2025). In addition, the promise of AI in mathematics education comes with its own set of challenges. The integration of these technologies raises critical questions about effective implementation models, ethical implications, equity, and the evolving roles of both teachers and students.

The rapid and complex development of AI in mathematics education necessitates a comprehensive and structured overview of the field. While many individual studies exist on specific AI applications, there is a lack of a systematic review that synthesizes the most prominent trends, identifies successful approaches, and outlines key research gaps from 2015-2025. This study, "The evolving landscape of AI integration in mathematics education: A systematic review of trends (2015-2025)," aims to fill that gap. To fully harness the transformative potential of AI to personalize learning and improve teaching, a holistic view of the current research landscape is essential. By systematically reviewing research contributions from different countries, emerging trends, common AI tools, and their application across various educational levels, this study will provide a solid foundation for guiding future research and practical implementation. To this end, our research will focus on answering the following research questions (RQ):

1. RQ1. How is the level of research contribution on AI in mathematics education among regions and countries in the world in the period 2015-2025 expressed?
2. RQ2. What are the emerging trends in AI integration within mathematics education from 2015 to 2025?
3. RQ3. Which AI tools have been and are being used most commonly in mathematics education in the period 2015-2025?
4. RQ4. How is the use of AI tools in mathematics education reflected across grade levels/grades in the period 2015-2025?

It aims not only to provide a detailed map of technological trends, pedagogical models, and major application areas of AI in mathematics education at different levels, but also to identify common research approaches, common challenges, and potential areas for future research. The results of this study will be a valuable reference for education policy makers, technology developers, teachers and researchers, helping them make more informed decisions in exploiting the full potential of AI to improve the quality of mathematics education.

METHODOLOGY

Research Design

Our investigation necessitated a comprehensive systematic literature review (SLR), which was undertaken to address our predefined RQs. An SLR represents a methodological approach to data collection, focusing on specific topics and adhering to pre-established eligibility criteria (Mengist et al., 2020). The scope of this study was restricted to journal publications disseminated between 2015 and 2025, with all earlier articles excluded. The analysis of the compiled journal articles was conducted in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) framework. PRISMA provides a standardized, peer-reviewed methodology, incorporating guideline checklists to ensure the quality and replicability of the review process (Moher et al., 2015). The PRISMA protocol comprises four sequential steps: identification, screening, eligibility, and inclusion, commencing with identification. A detailed exposition of these steps is provided in the subsequent sub-sections. This methodology was selected due to its efficacy in synthesizing salient journal publications, thereby facilitating an accurate identification of best practices in AI within mathematics education. **Figure 1** presents the adapted PRISMA flow chart for this study, based on Moher et al. (2009).

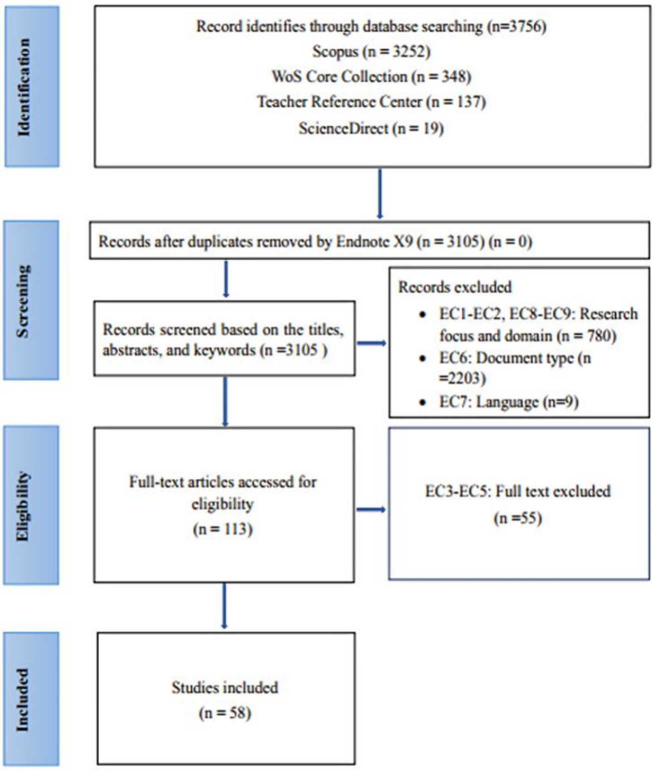

Figure 1. Flowchart of the study (Source: Authors' own elaboration)

Data Sources and Search Strategies

Our systematic review was conducted in accordance with the PRISMA guidelines (Moher et al., 2015). A comprehensive literature search was executed on June 20, 2025, across the following electronic databases:

(1) Web of Science,

(2) Scopus,

(3) ScienceDirect, and

(4) Teacher Reference Center.

These repositories were selected for their stringent indexing standards, international recognition, and comprehensive coverage of research pertinent to mathematics education. To maximize the retrieval of potentially relevant mathematics education research articles, a multifaceted search query was formulated to identify specified terms within article titles, abstracts, and keywords (**Table 1**).

Additionally, references of retrieved studies were manually reviewed to ensure inclusion of potentially relevant literature. The retrieval strategy used both the subject heading "AI in mathematics education (AI-iMath)" and keyword groups, namely "AI for

Table 1. The search strings

Database	Search equation
Scopus	TITLE-ABS-KEY ("AI in Math Education" OR "AI for Mathematics Learning" OR "Intelligent Tutoring Systems (ITS)" OR "Adaptive Learning" OR "Personalized Learning") AND PUBYEAR > 2014 AND PUBYEAR < 2027 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SUBJAREA, "MATH")) AND (LIMIT-TO (LANGUAGE, "English"))
	TITLE-ABS-KEY ("Ethical AI" OR "Bias in AI" OR "Data Privacy or Teacher Role" OR "Implementation Challenges" OR "Human-AI Collaboration") AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA, "MATH")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))
WoS	"AI in Math Education" OR "AI for Mathematics Learning" OR "Intelligent Tutoring Systems (ITS)" OR "Adaptive Learning" OR "Personalized Learning" (Title) and Preprint Citation Index (Exclude– Database) and Mathematics (Research Areas) and Article (Document Types) and English (Languages) and 2015 or 2016 or 2017 or 2018 or 2019 or 2020 or 2021 or 2022 or 2023 or 2024 or 2025 (Publication Years)
ScienceDirect	AI in Math Education OR AI for Mathematics Learning OR Intelligent Tutoring Systems (ITS) OR Adaptive Learning OR Personalized Learning

Table 2. The selection criterion is searching

IC	EC
IC1. Published between 2015 and 2025	EC1. < 2015
IC2. Indexed journal	EC2. Non-indexed journals, review journals, chapter in book, conference proceeding, master dissertation, prefaces, and opinion
IC3. Studies at all levels of mathematics education	EC3. Studies at all levels of mathematics education
IC4. Studies focus on AI implementations	EC4. AI is mentioned in the studies, but the focus is not on AI implementations
IC5. Studies report results on opportunities or pitfalls of AI in mathematics education	EC5. Studies do not report any opportunities or pitfalls of AI in mathematics education
IC6. Peer-reviewed research articles	EC6. Editorials, books, book chapters, conference papers
IC7. The language of the studies is English	EC7. The language of the studies is not English
IC8. Studies indexed in Web of Science, Scopus, ScienceDirect, or Teacher Reference Center databases	EC8. Studies indexed in a database other than databases in the left column
IC9. Specific application for mathematics or mathematics education	EC9. General application for professional learning (e.g., medical, public health, environmental science, and engineering)

mathematics learning", "intelligent tutoring systems (ITS)", "adaptive learning", "personalized learning", "ethical AI", "bias in AI", "data privacy or teacher role", "implementation challenges", "human-AI collaboration". The final search was conducted on June 24, 2025. All duplicate entries were removed using Endnote X 9.3.3. English is the only language selected during the article screening process.

Article Selection Criteria and Procedure

The current study focused on peer-reviewed research articles published in English in the field of mathematics education that have findings related to the opportunities, challenges, obstacles, or pitfalls of AI in teaching and learning mathematics. First, empirical studies were prioritized for inclusion, as we were interested in the potential opportunities and pitfalls of AI, which are highly relevant to teaching in the booming digital age. In addition, articles analyzing teachers' and lecturers' perceptions of the role and applications of AI in mathematics teaching were also selected. We excluded editorials, book chapters, and conference proceedings, as these are not always peer-reviewed. Our research included studies conducted at all levels of mathematics education between 2015 and 2025. The nine inclusion criteria (IC) and nine exclusion criteria (EC) that we applied are presented in **Table 2**.

Step 1. Identification

In this step, the researchers searched and identified potential articles from various databases. According to the flowchart, a total of 3,756 records were initially found. The search sources included Scopus (n = 3,252), Web of Science (n = 348), Teacher Reference Center (n = 137), and ScienceDirect (n = 19).

Step 2. Screening

This step focuses on removing irrelevant articles. First, duplicates are removed. According to the diagram, after using Endnote X9 software, there are no duplicate records, retaining 3,105 articles. Next, these articles are screened based on title, abstract, and keywords to remove irrelevant articles. There were 3,105 records screened, and 3,002 records were excluded for the following reasons: EC1-EC2 and EC8-EC9 (n = 780): not relevant to the research focus and field; EC6 (n = 2,203): not the appropriate research paper type; and EC7 (n = 9): language barrier (language other than English).

Step 3. Eligibility

The remaining articles after screening were assessed in more detail. Full-text access was provided to 113 articles for eligibility. Of these, 55 were excluded because they did not meet specific criteria (EC3-EC5), such as inappropriate methodology or unclear results.

Step 4. Included

After going through the filtering and evaluation steps, the final articles were selected for inclusion in the review. According to the flowchart, a total of 58 studies were included in the final analysis (see **Appendix A**).

RESULTS

RQ1. How Is the Level of Research Contribution on AI in Mathematics Education Among Regions and Countries in the World in the Period 2015-2025 Expressed?

Figure 2 and **Figure 3** show the uneven distribution among countries and also reflects the clear differences in the level of investment, interest and research development in each geographical area. Of the total 58 research works (69 countries) listed, China is the leading country with 9 publications, accounting for about 13.04%, showing China's increasingly prominent position in the field of combining technology and education, especially in the context of this country promoting comprehensive digital transformation in higher education. This is followed by South Africa with 4 publications, a remarkable result because it shows the

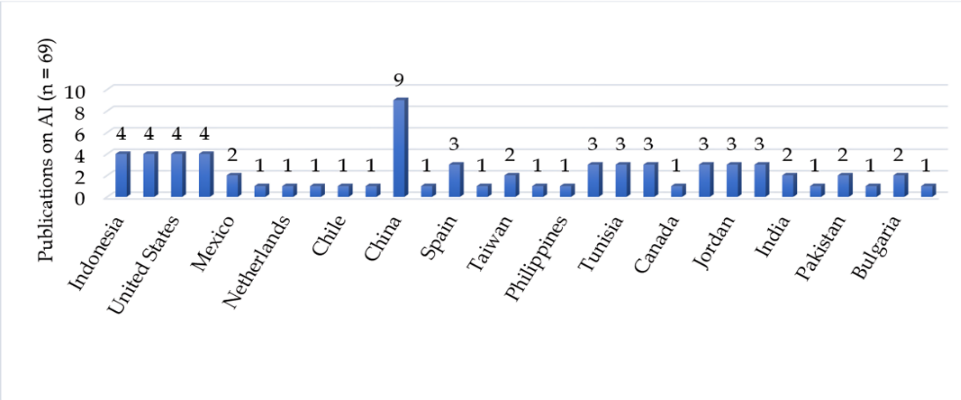

Figure 2. Distribution of AI research in mathematics education by country (Source: Authors' own elaboration)

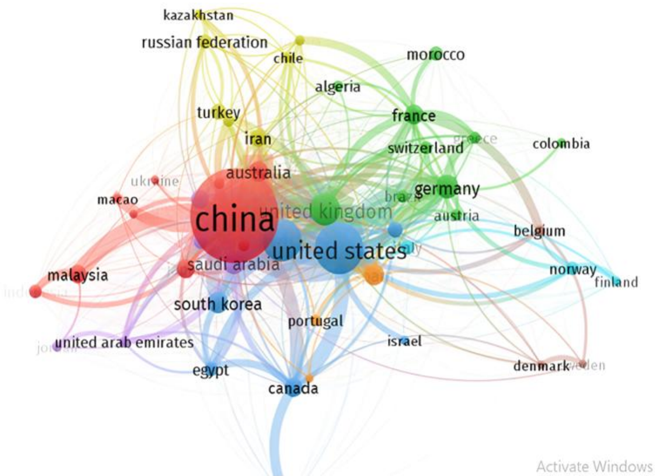

Figure 3. Network map of collaboration and research contributions on AI in mathematics education 2015-2025 (Source: Authors' own elaboration)

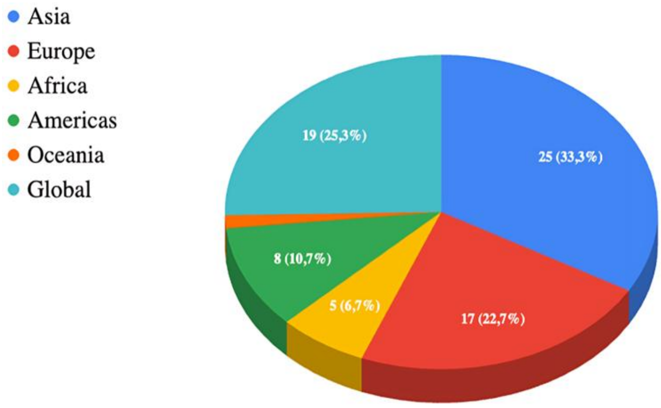

Figure 4. AI distribution in mathematics education by continent (Source: Authors' own elaboration)

rise of African countries in the global research space. The United States and the United Kingdom are two countries with advanced education, affirming their stable role in the development and application of advanced educational technologies, including AI.

In addition, the group of medium-level contributors, including Malaysia, Mexico, South Korea, Spain, Oman, Tunisia, India, and Saudi Arabia, shows the growing presence of Asian, Middle Eastern, and African countries in this interdisciplinary research field. The active participation of these countries may reflect policies promoting educational innovation through technology and also demonstrates the urgent need to improve the quality of teaching mathematics–a core subject–through AI tools. Notably, the majority of the countries listed have only 1 publication, including countries with developed education systems such as Germany, the Netherlands, Australia, and Canada, as well as developing countries such as Indonesia, Jordan, Pakistan, Morocco, and the Philippines. The presence of these countries, although modest in number, reflects the widespread global interest in applying AI in mathematics education. However, the limited number of publications also shows that the development of this field in those countries is still in its early stages, needing to be promoted through investment in research, training and international cooperation.

Finally, **Figure 4** shows the proportion of scientific publications on AI published from continents around the world. The results span continents such as Asia, Europe, Africa, America, Oceania and Global. Leading the way is the Asian region, with 25 articles, accounting for 33.3% of the total. This is a remarkable proportion, showing that this region is playing a central role in AI research. Countries such as China account for 10/25 of the total publications of the Asian region, other countries such as Singapore, Korea, etc. also have contributions in this field. Ranked second is the Global group, with 19 articles (25.3%). This proportion shows the increasing trend of expanding scientific cooperation in research on the topic of AI, promoting the development of technology evenly on a global scale.

In addition, the European region is also an important research center with 17 articles (22.7%). Countries in the Americas contributed 8 articles (10.7%). Africa contributed 5 articles (6.7%), and finally, Oceania had 1 article. Thus, **Figure 4** shows a clear difference between regions in terms of research and academic publications in the field of AI. Asia is emerging as an important research center. The increase in global work is a positive sign that AI is becoming a field of strong international cooperation, promising to bring widespread benefits to all humanity.

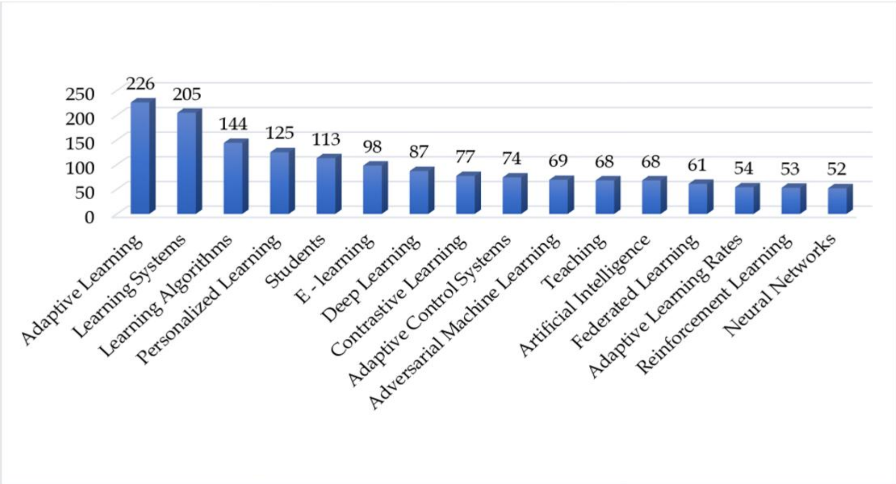

Figure 5. Group of 16 most searched keywords from Scopus data (Source: Authors' own elaboration)

Keyword	Occurrences	Total link strength
adaptive learning	226	186.00
learning systems	205	205.00
learning algorithms	144	143.00
personalized learning	125	113.00
students	113	112.00
e-learning	98	96.00
artificial intelligence	88	83.00
deep learning	87	80.00
contrastive learning	79	78.00
adaptive control systems	74	74.00
adversarial machine learning	71	71.00
teaching	68	68.00
federated learning	62	60.00
adaptive learning rates	54	53.00
neural networks	53	53.00
reinforcement learning	56	52.00
neural networks	53	53.00
reinforcement learning	56	52.00
machine learning	51	49.00
stochastic systems	47	47.00
optimization	50	48.00
human	46	46.00

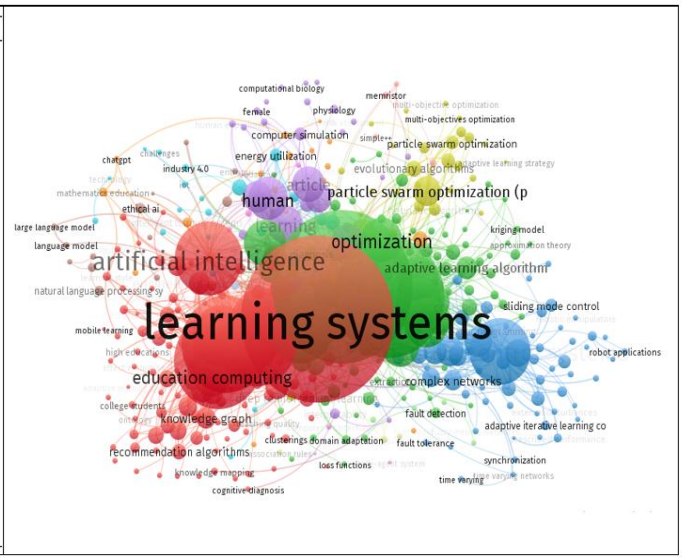

Figure 6. Keyword network visualization map of AI in mathematics education 2015-2025 (Source: Authors' own elaboration)

RQ2. What Are the Emerging Trends in AI Integration Within Mathematics Education from 2015 to 2025?

Figure 5 shows the top 16 most frequently mentioned keywords related to AI in mathematics education-taken from 1049 articles in Scopus data, reflecting the focus areas in AI research. Leading the way with the most mentions are "adaptive learning" (226) and "learning systems" (205), indicating the strong interest of the research community in systems that are adaptive and learnable. This may reflect the trend of developing flexible AI solutions that can self-adjust to data or environment to optimize performance. This is followed by keywords related to AI foundations and methods such as "learning algorithms" (144) and "deep learning" (87), demonstrating the continued interest in developing and improving core algorithms and deep learning models, which are the backbone of many modern AI applications. "personalized learning" (125 hits) and "students" (113 hits) also had high numbers, highlighting the growing interest in using AI to personalize learning experiences and the impact of AI on learners. Other keywords such as "e-learning" (98 hits), "teaching" (69 hits), and "artificial intelligence" (68 hits) had lower numbers but were still significant, demonstrating the deep integration of AI into online teaching and learning methods, as well as the overall role of AI in education. The appearance of more specialized keywords such as "contrastive learning" (77 hits), "adversarial control systems" (74 hits), "federated learning" (68 hits), "adaptive learning rates" (54 hits), and "reinforcement learning" (53 hits) shows the diversity and specialization in AI research areas, aiming to solve complex problems and optimize AI models. Finally, "neural networks" (52 hits) remains a basic but important keyword, reflecting the foundation of many deep learning models.

The keyword network visualization (see **Figure 6**), supplemented by frequency and association strength data, clearly outlines the interconnected research landscape of AI in mathematics education from 2015 to 2025. Centrally located and largest in size is the cluster "learning systems," which plays a foundational role with the highest overall association strength (205.00) and second highest number of occurrences (205), confirming its pivotal position in AI research in education. In the same dominant red cluster, "artificial intelligence" (88 occurrences, 83.00 association strength), "education computing," and "human" also stand out, highlighting the interaction between humans and computers and the systematic application of AI in educational settings, including emerging areas such as "large language models" and "ChatGPT." A separate green cluster focuses on "optimization" and "adaptive learning algorithms" (144 occurrences, 143.00 association strength), reflecting a significant interest in the algorithmic and methodological foundations of AI, with "adaptive learning" being the most frequently occurring term (226 occurrences, 186.00 association strength). Although "mathematics education" appears as a node in the network, its relatively small size compared to the hub terms suggests that it often serves as a specific application context for broader research on AI and learning systems. Other clusters represent diverse but related areas, such as "control systems" (blue cluster) and optimization techniques. Overall, **Figure 6** shows a strong focus on developing adaptive and personalized learning systems, powered by advanced AI algorithms, with a clear focus on practical implementations and their impact on the learning process.

RQ3. Which AI Tools Have Been and Are Being Used Most Commonly in Mathematics Education in the Period 2015-2025?

In the field of mathematics education, AI is considered a powerful and innovative tool, promising to bring about fundamental changes in the way this subject is taught and learned (Bin Mohamed et al., 2022; Gouia-Zarrad et al., 2024; Stefanova & Georgiev, 2024). Recent studies by Stefanova and Georgiev (2024) have focused on exploring the role and impact of AI, identifying development trends, AI methods, technology applications, and opportunities to leverage AI for both teachers and students. In the context of AI integration, Ren (2025) and Pavlova (2024) pointed out that the role of teachers and lecturers is undergoing a significant shift, from knowledge transmitters in the traditional teacher-centered approach to facilitators, facilitators, and promoters of student initiative and research. Specifically, according to Almarashdi et al. (2024), AI can assist teachers in lesson planning, providing personalized support to students, and answering questions, while Alier et al. (2024) showed that AI helps teachers gain deeper insight into students' learning progress. Flipped classroom learning methods are also enhanced when teachers can provide personalized instruction and interact more with students in class, although the application needs to be done in moderation (Pavlova, 2024). Not only that, Pavlova (2024) emphasized that AI also helps teachers detect gaps in

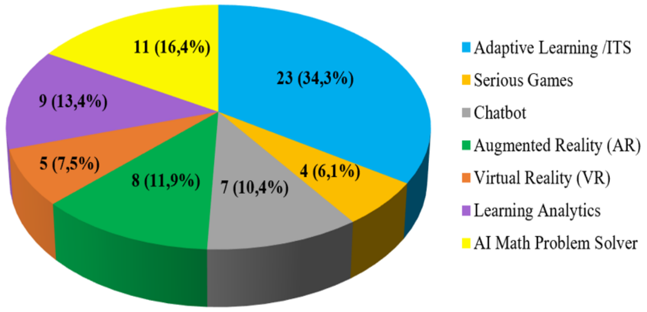

Figure 7. Weight distribution of each type of tool (Source: Authors' own elaboration)

students' knowledge and adjust teaching methods accordingly. Before we dive into the details, **Figure 7** shows the percentage distribution of the 7 AI tool groups we compiled.

Table 3 clearly presents a list of 67 educational tools applying AI that are being deployed globally. These tools are distributed diversely by function, educational level and geography, clearly reflecting the trend of digital transformation in modern education. In particular, the most prominent is the group of tools in the field of adaptive learning (adaptive learning/ITS) with 20 typical representatives such as Squirrel AI (China), AdLeS of Singapore, MATHia (USA, Korea, Pakistan), or DreamBox and Knewton (USA). These tools focus on supporting personalization of learning, adjusting content and progress according to learners' abilities, especially effective at high school and university levels. Another notable group of tools is chatbots, of which ChatGPT is mentioned with high frequency, appearing in many different countries and educational levels such as the United States, Nigeria, the Philippines, China, Australia, and Egypt. The integration of ChatGPT into many teaching contexts shows the strong spread of linguistic AI in education, especially in supporting math problem solving, answering questions, and personalizing learning communication. Besides ChatGPT software, there are also popular platforms such as SnatchBot, Microsoft Virtual Agents, and MathBot. This has demonstrated the expansion of functionality and flexibility of AI dialogue systems.

In their 2024 study, Son conducted a systematic review spanning from 2003 to 2023 to investigate the transformative impact of ITS on mathematics education, a gap identified despite claims of AI's potential in learning. The review utilized an extended SAMR model (Substitution, Augmentation, Modification, Redefinition) to analyze how ITSs were integrated, also considering the interplay of contexts and teacher roles. The findings indicate that while ITSs predominantly augmented existing learning, more recent research demonstrates their capacity to transform student learning experiences. The primary application of ITSs was found to be at the elementary school level, focusing on number and arithmetic, algebra, and geometry. The study also revealed that the SAMR level varied with research purpose, and most ITS implementations in mathematics education aimed to minimize teacher intervention. Ultimately, Son suggests that to fully realize the transformative power of ITSs in mathematics education, it is crucial to concurrently consider the affordances of the ITS, the educational context, and the teacher's role.

In addition, **Table 3** also mentions tools in the fields of serious games, augmented reality (AR), virtual reality (VR), and learning analytics. Tools such as GeoGebra AR, CalcVR, VLab, ENTiTi Creator, or 3D Minigames application show the trend of combining visual

Table 3. The list of identified AI educational tools

Category	Tool/application	Educational level	Country	Commercialized
Adaptive learning/ ITS	Squirrel AI	Secondary	China	Yes
	Intelligent English Teaching Platform	Vocational/college	China	No
	Vocabulary Resource Library	Vocational/college	China	No
	Intelligent Assistant System	Vocational/college	China	No
	AI Adaptive Systems	K-12	UAE	No
	Student Performance Monitoring	K-12	UAE	No
	Intelligent Tutoring Systems	All levels	Global	Yes
	Adaptive Assessment Platforms	All levels	Global	Yes
	GeoGebra + Gemini AI	University	Global	Yes
	Julius AI	University	Global	Yes
	Gradescope	University	Global	Yes
	Scantron	University	Global	Yes
	FT-CNN-LSTM-AM	Primary school	China	No
	Adaptive Learning/ITS	AdLeS–Adaptive learning system by Singapore University of Social Sciences	Singapore	No
	MATHia (Carnegie Learning)	Middle school-high school	USA, South Korea, Pakistan	Yes
	DreamBox, Knewton	Elementary-high school	USA	Yes
	MathE	Higher education	Portugal, Lithuania, Italy, Ireland, Romania, Russia, Spain, Slovenia	Yes
	ALEKS, MATHia, PAT2Math, GeoGebra Tutor	Secondary/higher education	USA	Yes
	Khan Academy	Adult learners	USA	No
Serious games	Gea2	Secondary	Spain	No
	Robotics	K-12	UAE	No
	Doulingo	All levels	Global, including Pakistan	Yes
	3D Minigames (e.g., Polygon Party, Function Analyzer)	Secondary	Greece	Yes
Chatbot	ChatGPT	Higher education/Adult learners	USA	Yes
	ChatGPT Algebra Tutor	College	Philippines	No
	ChatGPT (Numerical DEs)	University	Tunisia	Yes
	ChatGPT	University	Global	Yes
		Undergraduate	Egypt	Yes
		Preservice Teacher Education	China	Yes
		Secondary School	Nigeria	Yes
		All levels	Global	Yes
	DeepSeek	Preservice Teacher Education	China	Yes
	ChatGPT	Pre-service Teachers in Primary Education	Australia	Yes
	ChatGPT	Secondary School (JSS, SSS)	Nigeria	Yes
	ChatGPT	Lower & Upper Secondary Education	Nigeria	Yes
	Microsoft Virtual Agents, Intelligent Question Bot	University	Pakistan	Yes
	SnatchBot (chatbot development platform)	Higher education	Spain	Yes
	MathBot	Adult learners	USA	No

Table 3 (Continued). The list of identified AI educational tools

Category	Tool/application	Educational level	Country	Commercialized
AR	GeoGebra AR	Secondary	Spain	Yes
	AR application for learning functions (Del Cerro Velázquez & Morales Méndez, 2021)	Lower Secondary Education	Spain	No
	cleARmaths	Secondary	Portugal	Yes
	Zappar, HP Reveal (Aurasma), Vuforia	Secondary	Saudi Arabia/Indonesia	Yes
	ENTiTi Creator	Primary	Cyprus	Yes
	Mobile Math Trails App	Secondary	Indonesia	No
VR	CalcVR	Higher education	USA	Yes
	VR learning motivation projects	Pilot in multiple levels	Pakistan, USA	-
	NeoTrieVR	Primary	Spain	Yes
	Eclipse VR	Primary	China	Yes
	VLab	Secondary	Jordan	Yes
Learning analytics	Forum Graph (Moodle plugin)	Secondary	Italy	Yes
	Deep Learning	All levels	Global	Yes
	Neural Networks	All levels	Global	Yes
	SinGAN	Undergraduate	China	No
	Self-Attention Image Processing	Undergraduate	China	No
	Google Classroom, Edge Canvas LMS, KEA LXP	University, other levels	Pakistan	Yes
	GeoGebra (with integrated learning data analysis)	Primary – Higher education	Global	Yes
AI math problem solver	Photomath	Secondary	Philippines	Yes
	Symbolab, Microsoft Math Solver, Google Socratic	Secondary	Global	Yes
	Photomath	University	Global	Yes
	Socratic	University	Global	Yes
	Mathway	University	Global	Yes
	Chat-Mat (ChatGPT + math tool integration)	High school, university	Global	-
	ChatGPT 3.5/ MathGPT Chat	Secondary – Higher education	International	Yes
	Answer.AI, Question.AI, Nerd AI	Secondary	International	Yes

technology with mathematical content to enhance interaction and learning motivation for students. Meanwhile, deep learning tools such as SinGAN or self-attention image processing are mainly research-based, deployed in Chinese universities, reflecting the advanced approach to image processing and learning data in higher education.

In terms of educational levels, AI tools are widely applied from primary, middle, high school to university and graduate school. This shows the high flexibility of AI systems in serving different educational goals, from fostering basic knowledge to developing critical thinking and lifelong learning skills. Some tools are specifically designed for future teachers or teacher training, demonstrating the potential of AI not only in teaching but also in teacher training. These AI tools are deployed in various regions, with China, the United States, Spain, Nigeria, Pakistan, and European countries such as Portugal, Italy, and Lithuania leading the way. Some global tools such as Khan Academy, Photomath, GeoGebra, Symbolab, and Mathway reflect the cross-border reach of educational technology, especially when integrated with AI. While many tools have been commercialized, accounting for over 68% of the total, there are still products that are in the development, testing, or internal use stages at educational institutions.

Overall, **Table 3** presents a comprehensive picture of the strong and diverse development of AI-based educational tools in the world. The integration of AI into education is not only reflected in the increasing number of tools, but also in its multifunctionality, learner adaptability, and global reach.

In terms of tools and applications, AI includes machine learning algorithms that allow the educational system to flexibly adapt to the individual needs of learners, while providing tools that contribute to the development of logical and abstract thinking (Jia et al., 2024). According to the study of Steenbergen-Hu and Cooper (2013), ITS are one of the prominent AI applications, providing personalized instructions and instant feedback to students. The authors Wardat et al. (2023); Almarashdi et al. (2024) argue that ChatGPT, an AI-based chatbot, is considered a revolutionary tool for teaching and learning mathematics, supporting the creation of diverse responses, lesson planning, and answering students' questions. AI technologies such as TensorFlow, Azure or Amazon Web Services have become important platforms in learning management systems, enabling flexible connections between teachers and learners, while supporting data analysis and personalization of learning paths (Faiz Ulllah et al., 2024). The ease of access to these AI platforms is also a significant advantage (Pavlova, 2024), alongside tools such as ALEKS, Answer.AI, ASSISTments, Google Socratic, i-Ready, Knewton Alta and MATHia (Stefanova & Georgiev, 2024).

Overall, **Table 3** presents a comprehensive picture of the strong and diverse development of AI-based educational tools in the world. The integration of AI into education is not only reflected in the increasing number of tools, but also in its multifunctionality, learner adaptability, and global reach.

RQ4. How Is the Use of AI Tools in Mathematics Education Reflected Across Grade Levels/Grades in the Period 2015-2025?

The integration of AI in mathematics education has seen significant growth and diversification from 2015 to 2025. This period has been marked by the development of AI tools and their application across various educational levels, from K-12 to higher education. The use of AI in mathematics education has been driven by the need to enhance personalized learning, provide real-time feedback, and improve overall learning outcomes. Studies have shown that AI tools such as ChatGPT and generative AI platforms are increasingly being used to support personalized learning and adaptive learning systems, which cater to individual student needs and learning paces (Awang et al., 2025; Opesemowo & Adewuyi, 2024). Additionally, AI has been employed to automate assessment processes, develop new teaching methods, and create interactive learning environments that engage students more effectively (Chin & Ming, 2024; Dunaeva, 2024). The notable increase in scholarly publications and research on AI in mathematics education in this stage, reflecting the growing academic interest in this field (Bandara et al., 2024). Thematic analyses of the literature reveal diverse research trends, including the integration of intelligent technologies in teaching mathematics, the use of AI for measuring and evaluating learning outcomes, and the enhancement of student engagement through technological applications (Firda et al., 2024; Son et al., 2025). The emergence of generative AI and large language models, such as ChatGPT, has been particularly significant, with these tools being used for personalized feedback and real-time assessment (Dunaeva, 2024; Hossein-Mohand et al., 2025; Opesemowo & Adewuyi, 2024). These advancements highlight the transformative potential of AI in addressing educational disparities and preparing learners for the demands of the 4IR. Dias Rasteiro and Thiele (2024) explored the burgeoning role of AI in mathematics education, analyzing its potential advantages and disadvantages through various lenses such as pedagogy, accessibility, personalization, and data security. While acknowledging AI's promise in enhancing personalized learning, engagement, and accessibility, their research also highlighted significant challenges including concerns about data privacy, equity, over-reliance on technology, and implementation difficulties. To gather insights into these complex issues, the authors conducted a questionnaire and facilitated a debate with 20 teachers from 14 countries during the SEFI'2024 Conference's Mathematics Special Interest Group Workshop in Lausanne. This approach allowed for a comprehensive understanding of educators' perspectives on integrating AI and ICT into mathematics engineering education to improve both learning and teaching outcomes. Zreik (2024) investigates the extensive influence of AI on mathematics education, covering its effects on teaching, research, and administration. This study emphasizes AI's role in transforming mathematics learning and instruction. Zreik (2024) explains how AI can improve teaching through personalized learning and interactive tools that simplify complex math concepts. Beyond instruction, the chapter explores AI's significant contribution to mathematics research, especially its capacity to solve complex problems and shape the research field. Additionally, Zreik (2024) discusses AI's use in administrative tasks like curriculum development and policymaking via data analytics. This study also addresses key challenges, including ethical concerns and the necessity for educators to adapt to these technological changes. It concludes by examining the future of AI in mathematics education, advocating for a balanced approach that leverages AI's potential while upholding the core tenets of mathematical learning and inquiry. The study by Opesemowo and Adewuyi (2025) synthesized findings from 10 studies published between 2015 and 2023 on the integration of AI in mathematics education, particularly within the context of the 4IR. The analysis identified key areas of AI application, including personalized learning, enhanced instruction, real-time assessment, feedback mechanisms, curriculum development, and educator empowerment. The review, primarily based on qualitative research methods, found that questionnaires were the dominant data collection instrument, with students and teachers being the main study participants.

The integration of AI into primary school mathematics education has increased steadily from 2015 to 2025, with numerous studies highlighting its potential and effectiveness, with a significant increase in research output and international collaboration, especially from China and the United States (**Figure 8**) (Hossein-Mohand, 2025; Hursen & Beyoğlu, 2025). AI tools such as ITS and adaptive learning platforms have been used to personalize learning experiences, providing real-time feedback and tailored instruction to meet students' individual needs (Alvarez, 2024). Meta-analyses have shown that AI has a small to medium positive impact on

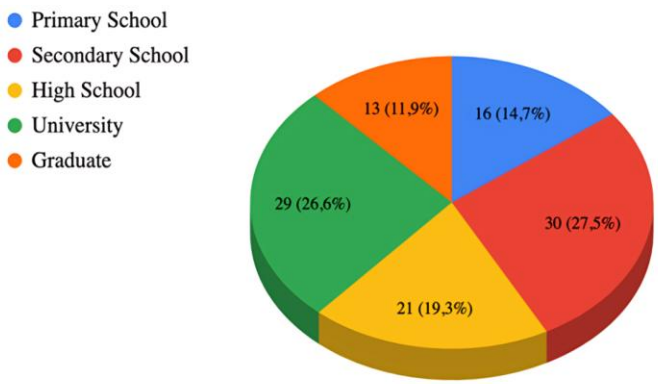

Figure 8. Distribution of AI in mathematics education by education level (Source: Authors' own elaboration)

mathematics achievement, with effect sizes ranging from 0.343 to 0.51 (Hwang, 2022; Topkaya et al., 2025; Yi et al., 2025). These tools are particularly beneficial in improving engagement and performance in mathematics, especially in resource-poor areas (Khazanchi et al., 2024). AI applications such as ChatGPT and other generative AI tools have been increasingly integrated into educational contexts, aiding in assessment and personalized learning (Hossein-Mohand et al., 2025). Despite the promising results, the overall impact of AI on mathematics achievement remains modest, suggesting that while AI can enhance learning, it is not a panacea (Hwang, 2022; Yi et al., 2025). However, the use of AI in primary education also comes with challenges, including ethical considerations and the need for appropriate implementation and monitoring to maximize its benefits (Akgün & Krajcik, 2024; Aravantinos et al., 2024; Galindo-Domínguez et al., 2024; Thomas et al., 2023). Future research should continue to explore the long-term impacts of AI on student learning outcomes and the best practices for its implementation in diverse educational settings.

The study by Alvarez et al. (2024) indicates a growing trend in the positive influence of AI applications, particularly when integrated with mobile devices, on enhancing primary school students' mathematics learning and academic performance. These applications provide personalized tools that cater to individual student needs, leading to effective improvement in mathematical skills. The research highlights that significant improvement is achievable with careful selection of appropriate applications, effective classroom implementation, and consistent monitoring of student progress. The instant feedback and interactive resources offered by AI applications are crucial in fostering more dynamic and efficient mathematics learning, specifically observed in primary school students in Peru. Hwang's (2022) meta-analysis, encompassing 21 empirical studies with 30 independent samples published between January 2000 and June 2022, investigated the overall effectiveness of AI on elementary students' mathematics achievement. The study revealed a small but positive effect size of 0.351 for AI under the random-effects model. The analysis also examined eight moderating variables: research type, research design, sample size, mathematics learning topic, intervention duration, AI type, grade level, and organization. Among these, mathematics learning topics and grade level were found to significantly moderate AI's effect on mathematics achievement, while the other moderator variables showed no significant impact. The study concludes with practical and research implications derived from these findings. The mixed meta-method study by Topkaya et al. (2025) explored the impact of AI applications in primary education, aligning with the United Nations' sustainable development goals. Analyzing data from 2005 to 2025 using CMA software, a meta-analysis revealed a medium effect size (g = 0.51) of AI in primary education. To bolster these findings, a meta-thematic analysis identified key themes related to AI's impact on learning environments, implementation challenges, and proposed solutions. Further supporting the data, a Rasch measurement model, administered to primary school teachers and analyzed with FACETS, indicated widespread AI application in science and mathematics curricula (FBP-4 and MP-2). The meta-analysis document review specifically highlighted that mathematics courses were the most common area for AI application in primary education studies. Interesting insights emerged from the Rasch analysis regarding rater leniency (J2 being the most lenient, J11 the strictest) and item difficulty, with "I can help students prepare a presentation describing their surroundings using AI tools" (I17) being the most challenging statement for teachers, while "I understand how to effectively use AI applications in classroom activities" (I14) was the easiest. The researchers conclude that these complementary findings offer significant guidance for future studies and applications, contributing to the field of AI in education for sustainable development.

Aravantinos et al. (2024) conducted a systematic review of 35 Scopus-indexed empirical studies on AI integration in primary education for children aged 4-12, adhering to PRISMA guidelines. The study also classified learning outcomes into cognitive, affective, and psychomotor levels, and the pedagogy of AI tools into constructivism, experiential learning, AI-assisted learning, and project-based learning. Beyond instructional impact, the review critically examines the complex ethical considerations surrounding personal data and individual student needs in AI's educational application and discusses implications for teacher professional development. In other study, the bibliometric analysis by Hursen and Beyoğlu (2025) investigated trends in studies on AI in primary education using the Scopus database. The review revealed that research in this area commenced as early as 1988, with the most cited studies appearing in 2021. Researchers' preferred keywords largely revolved around "artificial intelligence," "education," and "ChatGPT." Furthermore, the most frequently occurring keywords in titles and abstracts included "art," "mathematics," "professional development," "artificial intelligence integration," "primary school students," "ChatGPT integration and potential," "STEM," "ability," "perspective," and "computational identity."

At the secondary level, AI also has certain contributions in the field of mathematics education. The study by Simeunović and Ružičić (2024) focuses on the potential implementation of AI in secondary schools to improve the teaching process. AI applications can assist in routine tasks such as grading, provide personalized learning assistance, and recommend learning models based on student profiles. This integration aims to enhance both the efficiency and quality of teaching, making schools more competitive and attractive to students. In other study proposes a theoretical framework for incorporating AI chatbots into high school education to boost students' mathematical problem-solving skills. This framework includes teaching, assessment, feedback, and dynamic learning activity adjustments based on student data analysis. The AI chatbots provide personalized feedback, emphasizing error handling and information security (Chau et al., 2025). Samonte et al. (2025) conducted a study at a high school in the Philippines developed a web-based application incorporating gamification to teach probability to grade 8 students. The application aimed to enhance usability, motivation, and engagement. The findings revealed that students using the gamified application had significantly higher mean scores compared to those using traditional learning methods. Research in China analyzed the use of AI to construct a precision teaching model for high school students. This model aims to improve academic performance in science subjects, including mathematics, by providing comprehensive and in-depth teaching evaluations. The study found that the model significantly improved students' academic performance and self-directed learning abilities (Cheng, 2025; Galindo-Domínguez et al., 2024; Hao et al., 2024). The VioEdu online education system in Vietnam uses AI and big data analysis to personalize learning for high school students. The system analyzes learning behaviors and knowledge gaps to propose appropriate learning pathways, enhancing learning efficiency and engagement. The system has shown significant progress in student performance after a few months of use (Thu, 2020). Barca (2025) investigated the impact of AI in secondary education through a literature review and a teacher survey, aiming to identify training needs. Their findings reveal that AI offers significant opportunities, such as personalized learning, optimized resource access, and reduced teacher workload, which are generally well-received by students. However, teachers are acutely aware of critical issues including technological dependence, data security risks, plagiarism, and the potential reduction of autonomous and creative thinking. A major concern highlighted is the specific training deficit among teachers and their limited familiarity with AI's latest technological advancements. Consequently, Barca concludes that a successful integration of AI in education necessitates a holistic approach that proactively addresses the training requirements of all stakeholders. For example, Khazanchi et al.'s (2025) study looked at the role of AI systems in improving the learning outcomes and engagement of eighth-grade students in rural schools. Specifically, the study used Edmentum Exact Path, an AI-based learning tool, as a support tool for teaching mathematics. AI in this context acts as a supplementary tool, providing personalized lessons and resources tailored to each student's individual needs, complementing the traditional teaching methods of teachers. Although the results showed that both the AI and control groups achieved significant improvements in mathematics achievement, the study could not confirm that AI was superior to the traditional method. More notably, AI showed the potential to positively impact students' affective engagement, helping them feel more interested and actively involved in the subject. However, no significant differences were observed in cognitive engagement between the two groups.

In higher education, the focus has been on training specialists in AI and integrating AI into advanced mathematics courses. For instance, new educational programs in AI have been introduced at the master's level, where students learn about applied intelligent systems (AIS) and intelligent decision support systems (Alzakwani et al., 2025; Eremeev et al., 2022; Fakhar et al., 2024; Galindo-Domínguez et al., 2024). These programs aim to equip students with practical skills in AI models and methods, preparing them for various professional roles. Furthermore, AI-powered adaptive learning has been explored in engineering mathematics education, where machine learning algorithms create personalized learning roadmaps for students, leading to improved learning outcomes. The use of AI in higher education also includes the development of hybrid AI-human tutoring systems, which combine the strengths of both AI and human instructors to provide comprehensive support to students (Cosentino et al., 2025; Thomas et al., 2023). Eremeev et al. (2022) highlighted the efforts of the NRU MPEI's department of applied mathematics and artificial intelligence in addressing the demand for highly qualified specialists in digital and information technologies, particularly AI. Beginning in the academic year 2021/2022, the university introduced a new master's degree program in applied mathematics and computer science with a specialization in AI. Through new academic disciplines such as AIS and intelligent decision support systems, students are gaining essential theoretical knowledge and practical skills in AI models and methods, enabling them to develop prototypes of modern AI systems for diverse applications. The study by Vintere et al. (2024) investigates the adoption and impact of AI-based platforms in undergraduate engineering mathematics education in Latvia and Estonia. While educators often view AI as a threat, the research highlights its potential to enhance creative and innovative thinking, particularly in mathematics, by enabling students to develop and improve mathematical and cognitive skills independently. The study aimed to identify commonly used AI platforms, gather user experiences from students and teachers, and perform a comparative analysis between the two countries to pinpoint challenges and considerations. The research identified various AI tools, including Photomath, Desmos, GeoGebra, and ChatGPT, and analyzed existing literature on their benefits. Empirical data was collected through student surveys and interviews with teaching staff. The findings reveal that Photomath, ChatGPT, and Symbolab are the most popular tools in both countries, with GeoGebra also prominent in Estonia and Desmos in Latvia. A study by Vintere et al. (2025) looked into how AI features are used in math learning, examining differences between countries, their effect on students' math skills, and why AI platforms are used. The research found no strong individual link between specific AI features and better math skills; however, a combination of these features collectively improved math proficiency. Instant feedback was the most valued AI feature, with Photomath highlighted as a leading platform offering it. The study stresses the need for a critical and strategic approach to integrating AI, recommending greater awareness of AI-generated results. Ultimately, for AI to significantly improve math learning, it must be paired with effective educational strategies. For example, the study by Torres-Peña et al. (2024) focused on integrating AI into calculus teaching, specifically the concepts of derivatives and rates of change. The main results showed that AI plays an important role in improving the effectiveness of mathematics education:

1. Enhanced conceptual understanding and computational skills: Students not only improved their accuracy in calculating derivatives but also developed a clear understanding of the difference between average and instantaneous rates of change. AI tools such as ChatGPT, MathGPT, Gemini, and Wolfram Alpha supported this by providing problem-solving exercises and verifying results.
2. Supported personalized and instantaneous learning: AI creates a dynamic and adaptive learning environment, providing immediate feedback and simulations, allowing students to interact continuously with their "virtual tutors". This promotes engagement and motivation.
3. Developing problem-solving skills: The study introduced an improved method of iteratively improving prompts and interactions with AI. This method helps improve the quality of feedback from AI, thereby improving students' problem-solving skills and ensuring a comprehensive understanding of mathematical concepts.

A recent study by Chohan and Khan (2024) introduced a groundbreaking educational tool called AI-MathBot, designed to address the challenges of teaching mathematical concepts, especially in the field of Calculus. This tool is a clear demonstration of the effective application of AI in the classroom. AI-MathBot has changed the way mathematics is learned in several important ways:

1. Personalized support: AI-MathBot provides personalized step-by-step solutions and guidance, focusing on core concepts such as finding the intersection of a linear equation. This allows students to learn at their own pace, effectively filling in knowledge gaps.
2. Ensuring consistency: By using generative AI like ChatGPT, the tool ensures that the solutions and teaching methods are always consistent with what teachers teach in class. This eliminates the confusion that often occurs when students refer to online materials that are not synchronized with the curriculum.
3. Create exercises and instant feedback: In addition to providing solutions, AI-MathBot is also capable of creating practice problems and tests with immediate feedback. This feature helps students consolidate knowledge and self-assess their abilities continuously and effectively, promoting active learning.

Besides the positive aspects, the integration of AI in mathematics education also presents several challenges and opportunities. One major challenge is the need for educators to adapt to new technologies and the potential ethical issues related to data privacy and algorithmic bias (Dias Rasteiro & Thiele, 2024; Opesemowo & Ndlovu, 2024). Teachers' training and familiarity with AI tools are crucial for effective implementation, as highlighted by the need for targeted training programs and structured curriculum integration (Jacobs et al., 2024; Ngoveni, 2025; Song et al., 2025; Tashtoush et al., 2024). The study by Ngoveni (2025) investigated the integration of AI tools in mathematics education within a South African open distance e-learning institution, revealing significant barriers to access such as unstable internet, limited device availability, and inadequate institutional support, particularly for students in rural areas. The research highlighted the critical need for improved digital infrastructure, targeted training, and clear ethical guidelines to effectively integrate AI into the curriculum and maximize its pedagogical benefits.

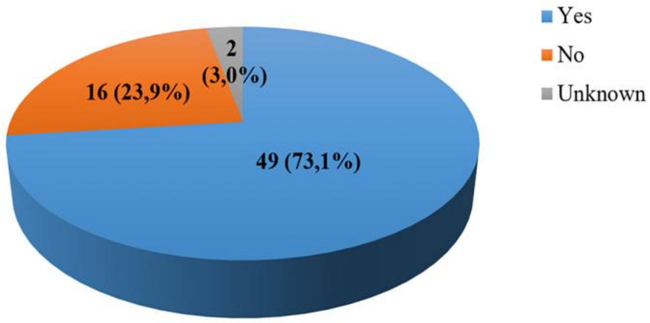

Figure 9. Distribution of AI in mathematics education by level of commercialization (Source: Authors' own elaboration)

Additionally, there is a risk of over-reliance on AI, which could undermine the development of creativity and problem-solving skills in students (Opesemowo & Ndlovu, 2024). However, the opportunities are substantial, including the potential for AI to address educational disparities, enhance personalized learning, and improve engagement and academic performance (Opesemowo & Adewuyi, 2024). To maximize these benefits, a balanced approach that leverages AI's potential while upholding core pedagogical principles is essential (Opesemowo & Ndlovu, 2024).

In terms of commercialization, AI applications also have clear differences. **Figure 9** clarifies this statement.

Figure 9 shows the level of commercialization of some AI tools. The levels are divided into three groups: "yes" (commercialized), "no" (not commercialized) and "unknown". The "yes" group accounts for the largest proportion, up to 73.1% with 49 tools. This number shows that the majority of educational AI tools are now on the market as commercial software. This reflects the strong development trend and great interest of technology businesses in the education sector. Meanwhile, the "no" group has 16 tools, accounting for 23.9%, representing tools that are not yet commercialized, which may still be being researched, tested or provided for free to the education community. This group shows that there are still efforts to develop AI tools for non-profit purposes. Finally, the "unknown" group accounts for a very small proportion (less than 5%), representing some tools whose commercialization status is unknown, possibly due to lack of data or recent development.

DISCUSSION AND RECOMMENDATION

The integration of AI in mathematics education is creating fundamental changes, not only in the tools used but also in the role of teachers and teaching methods. AI is considered a powerful and innovative tool that promises to revolutionize the way mathematics is taught and learned. One of the biggest changes is the shift in the role of teachers. Instead of being just knowledge transmitters in the traditional way, teachers are now becoming facilitators, coordinators and promoters of students' active learning. AI supports teachers in many tasks, from lesson planning, providing personalized support, to analyzing learning progress to detect knowledge gaps early. This helps teachers to interact more deeply with students in the classroom, especially when applying methods such as flipped classrooms. In addition, the development of AI tools in mathematics education is also very diverse. The most prominent group is the adaptive learning tools/ITS, with representatives such as Squirrel AI, MATHia, DreamBox. These tools focus on personalizing the learning process, adjusting the content and teaching speed to suit each student, especially effective at high school and university levels. In addition, AI chatbots such as ChatGPT are also showing strong popularity in supporting problem solving, answering questions and personalizing learning communication. The diversity of tools, from AR and VR applications such as GeoGebra AR to specialized deep learning tools, reflects a strong digital transformation trend in modern education. This shows that AI is becoming an indispensable part, serving many different educational goals, from consolidating basic knowledge to developing critical thinking.

The integration of AI in mathematics education has seen significant growth and diversification from 2015 to 2025. This period has been marked by the development of AI tools and their application across various educational levels, from K-12 to higher education. The use of AI in mathematics education has been driven by the need to enhance personalized learning, provide real-time feedback, and improve overall learning outcomes. Studies have shown that AI tools such as ChatGPT and generative AI platforms are increasingly being used to support personalized learning and adaptive learning systems, which cater to individual student needs and learning paces. Additionally, AI has been employed to automate assessment processes, develop new teaching methods, and create interactive learning environments that engage students more effectively.

The application of AI in mathematics education differs significantly between levels of education. At the primary and secondary levels, research focuses most on the use of tools such as ITS to personalize learning, provide instant feedback, and tailor assignments to each student. At the high school level, AI is used to optimize teaching resources and reduce the workload for teachers, with the support of chatbots and gamification applications to increase learning motivation. Meanwhile, at the university level, the application of AI goes beyond teaching to support research and develop critical thinking skills through platforms such as Photomath, GeoGebra, and ChatGPT, to prepare students for the demands of the 4IR.

Robust infrastructure changes are vital for integrating AI into mathematics education. However, over-reliance on technology can undermine students' ability to think creatively. Therefore, to maximize the benefits of AI, a balanced approach is needed, combining the potential of technology with core pedagogical principles, while focusing on teacher training and policy development. This necessitates schools and universities investing in modern network infrastructure and high-performance computing to meet AI application demands, including reliable internet and sufficient computational power. Furthermore, educational institutions must establish new data functions and roles for AI system management and data integrity. The development of AI-powered tools like ITS relies on robust infrastructure for continuous interaction and real-time feedback. Addressing these infrastructural needs creates a dynamic, adaptive learning environment, enhancing math outcomes and preparing students for an AI-centric future. Additionally, policies should mandate the inclusion of AI literacy in the curriculum, focusing on developing students' AI knowledge, skills, and attitudes. This can be achieved through modular AI literacy courses that are adaptable to local contexts and cultures, ensuring that all students, regardless of their background, have equitable access to AI education. Furthermore, ethical guidelines must be established to address data privacy, algorithmic biases, and the responsible use of AI in educational settings. These guidelines will help mitigate risks and ensure that AI integration promotes fairness and inclusivity.

Studies have shown that teachers' attitudes have a significant impact on their intention to use AI in teaching. Institutional support and resource availability are key factors that shape these attitudes and directly impact AI adoption in primary mathematics education (Li, 2025; Li & Manzari, 2025; Li & Noori, 2024). Effective AI integration requires systemic approaches, including policy changes, institutional support, and intensive training programs for both teachers and students (Zhuang & Zhang, 2025). Addressing digital inequality and improving technological infrastructure are critical to maximizing the benefits of AI in education (Li, 2025; Ngoveni, 2025). These findings reinforce the main results of this study, namely the importance of context and preconditions for promoting AI adoption.

In addition, studies have shown that integrating the technological pedagogical content knowledge framework improves teachers' ability to integrate AI into teaching. Professional development is necessary to improve teachers' technological competence and pedagogical strategies (Li, 2025; Li & Manzari, 2025). This supports the argument of this study that it is necessary to align AI implementation strategies with pedagogical approaches to improve the quality of mathematics education. This similarity suggests that successful technology integration depends not only on the technology itself but also on teachers' pedagogical abilities. AI tools such as ChatGPT and ITS have been shown to be useful in simplifying complex mathematical concepts and providing instant feedback, thereby enhancing student engagement and learning outcomes (Canonigo, 2024; Li et al., 2025; Opesemowo & Adewuyi, 2024; Ramprakash et al., 2024). These findings confirm the disruptive potential of AI in mathematics education and are consistent with the trends summarized in this study, which indicate the rise of AI tools to support learning.

Finally, AI integration also faces many challenges. Technological issues such as unstable internet connections and lack of suitable devices can hinder AI adoption, especially in disadvantaged areas (Canonigo, 2024; Ngoveni, 2025). Additionally, ethical concerns related to privacy and bias in AI systems are also significant barriers (Canonigo, 2024). These challenges are widely documented in the existing literature and stand in contrast to ideal expectations of seamless technology integration. Finally, the potential for AI to replace teachers is a major concern, causing resistance among educators. Research suggests that AI should complement rather than replace traditional teaching methods to alleviate these concerns (Canonigo, 2024). This argument rejects the notion that AI can completely transform education without human involvement and fits into the increasingly popular blended education models.

CONCLUSION

Based on the analysis of studies from 2015 to 2025, it can be seen that AI has been and is creating profound changes in the field of mathematics education. The discussion results have clarified four main aspects:

The development and application of AI in mathematics education shows an uneven distribution globally, reflecting the clear differences in the level of investment, interest and research development of countries and continents. China has emerged as the leading country in the number of research publications, affirming its prominent position in the field of educational technology. Asia is also the leading region in the total number of scientific articles on AI. Meanwhile, traditional educational powers such as the United States and the United Kingdom maintain a stable role and developing countries such as South Africa and India also show increasing interest. Although many other countries are still in the early stages with modest numbers of publications, their presence still reflects widespread global interest and shows the need to further promote this field through investment and international cooperation. The RQ1 is clarified.

With RQ2-Research on AI in mathematics education focuses on the development of adaptive and personalized learning systems, supported by advanced AI algorithms and technologies. The most frequently mentioned keywords such as "Adaptive Learning", "Learning Systems" and "Personalized Learning" indicate that the main focus of the research community is on creating flexible AI solutions that can adjust to the needs and abilities of individual students. This is supported by a strong interest in core AI foundations and methods such as "learning algorithms" and "deep learning". Although the keyword "mathematics education" appears, its relatively low frequency compared to the core terms of AI and learning systems suggests that mathematics education is considered a specific application context for broader AI research. This reflects the trend of applying existing AI technologies to address specific challenges in mathematics teaching and learning.

The diversity of AI tools and applications in mathematics education reflects the trend of strong and comprehensive digital transformation, from personalized learning to supporting the development of abstract thinking skills. AI tools are deployed globally with a variety of functions, from ITS that help personalize learning, to chatbots like ChatGPT that support math problem solving and communication. These tools are not only limited to replacing traditional methods but also have the ability to enhance and completely redefine the learning experience. In addition, technologies such as AR, VR, and learning analytics are also integrated to enhance student engagement and motivation. This description sheds light on RQ3.

With RQ4, through analysis, AI applications at all levels of education. This diversity shows that AI is being applied flexibly at all levels of education, from primary to postgraduate, not only to impart knowledge but also to develop critical thinking and other important skills. At the primary and secondary levels, AI mainly helps personalize learning and provide interactive learning methods. At the university level, AI is used to support research, develop critical thinking skills, and solve complex problems. An important additional point is the strong trend of commercialization of educational AI tools. The majority of the surveyed tools have been commercialized, indicating the great interest of technology companies in this field. This reflects the great economic potential of AI-based educational technology. However, besides commercial products, there is still a significant proportion of non-commercial tools, mainly serving research, testing purposes or being provided free of charge to the educational community. The presence of these tools shows that, despite the rapidly growing market, there are still efforts to develop AI for non-profit educational purposes.

Finaly, while AI offers many opportunities to improve mathematics education-such as personalizing learning, providing instant feedback, and automating administrative tasks-the integration of AI still faces significant challenges. AI has the potential to improve learning outcomes, especially at the secondary and higher education levels, but its adoption comes with risks. Ethical and data privacy concerns are a major issue, as the use of AI raises questions about the protection of personal information and the fairness of algorithms. Furthermore, teacher skill shortages and the risk of students becoming over-dependent on technology, which undermines creative thinking and problem-solving, are also challenges that need to be addressed. Finally, the uneven distribution of infrastructure and resources limits access to AI in many places. To maximize the benefits of AI, a balanced approach is needed that combines technology with core pedagogical principles while effectively addressing ethical and training issues.

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AI statement: The authors stated that an AI-based grammar checker (e.g., Grammarly) was used for proofreading. No content generation was performed by AI.

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APPENDIX A

Table A1. Summary table of 56 articles used for the study

No	Document title	Authors	Source	Year
1	Updating calculus teaching with AI: A classroom experience	Torres-Peña et al.	Education Sciences	2024
2	AI-generated content construction in digital exhibition halls and practical study of image processing algorithms in educational reforms	Ren	Journal of Combinatorial Mathematics and Combinatorial Computing	2025
3	Unlocking the opportunities through ChatGPT Tool towards ameliorating the education system	Javaid et al.	Bench Council Transactions on Benchmarks, Standards and Evaluations	2023
4	An era of ChatGPT as a significant futuristic support tool: A study on features, abilities, and challenges	Haleem et al.	Bench Council Transactions on Benchmarks, Standards and Evaluations	2022
5	Artificial intelligence in education: Mathematics teachers' perspectives, practices and challenges.	Tashtoush et al.	Iraqi Journal for Computer Science and Mathematics	2024
6	AI-based mathematics learning platforms in undergraduate engineering studies: Analyses of user experiences	Vintere et al.	Engineering for Rural Development	2024
7	Artificial intelligence (AI) in education: A case study on ChatGPT's influence on student learning behaviors	Nguyen et al.	Educational Process: International Journal	2024
8	Automated feedback on discourse moves: Teachers' perceived utility of a professional learning tool	Jacobs et al.	Educational Technology Research and Development	2024
9	Current practices and future direction of artificial intelligence in mathematics education: A systematic review	Awang et al.	International Electronic Journal of Mathematics Education	2025
10	Artificial intelligence in mathematics education: A systematic literature review	Bin Mohamed et al.	International Electronic Journal of Mathematics Education	2022
11	Pre-service teachers and ChatGPT in multistrategy problem-solving: Implications for mathematics teaching in primary schools	Getenet	International Electronic Journal of Mathematics Education	2024
12	Indonesian students' perceptions towards AI-based learning in mathematics	Soesanto et al.	Journal on Mathematics Education	2022
13	A meta-analysis of the effectiveness of intelligent tutoring systems on K-12 students' mathematical learning	Steenbergen-Hu and Cooper	Journal of Educational Psychology	2013
14	Unveiling the potential: A systematic review of ChatGPT in transforming mathematics teaching and learning	Almarashdi et al.	Eurasia Journal of Mathematics, Science and Technology Education	2024
15	Enhancing university teaching and learning through integration of artificial intelligence in information and communication technology	Alzakwani et al.	Edelweiss Applied Science and Technology	2025
16	The use of ChatGPT in addressing algebra anxiety and promoting confidence	Etcuban	International Electronic Journal of Mathematics Education	2025
17	AI artifacts in the mathematics didactical tetrahedron: A developed model	Mani and Zargeh	Eurasia Journal of Mathematics, Science and Technology Education	2025
18	AI in mathematics education: A bibliometric analysis of global trends and collaborations (2020-2024)	Hossein-Mohand et al.	Eurasia Journal of Mathematics, Science and Technology Education	2025
19	Enhancing students' learning experience in mathematics class through ChatGPT	Gouia-Zarrad and Gunn	International Electronic Journal of Mathematics Education	2024
20	Utilizing ChatGPT calculation errors to encourage students in adopting new exploration tools for self-learning and excelling in mathematics	Slobodsky et al.	International Conference on Math Education and Technology	2024
21	ChatGPT: A revolutionary tool for teaching and learning mathematics	Wardat et al.	Eurasia Journal of Mathematics, Science and Technology Education	2023
22	Artificial intelligence in mathematics education: The good, the bad, and the ugly	Opesemowo and Ndlovu	Journal of Pedagogical Research	2024
23	An artificial intelligence application in mathematics education: Evaluating ChatGPT's academic achievement in a mathematics exam	Korkmaz Guler et al.	Pedagogical Research	2024
24	Role of mathematics teachers in learner's diversity using AI tools	Cheng	Engineering Proceedings	2025
25	A systematic review of artificial intelligence in mathematics education: The emergence of 4IR	Opesemowo and Adewuyi	Eurasia Journal of Mathematics, Science and Technology Education	2024

Table A1 (Continued). Summary table of 56 articles used for the study

No	Document title	Authors	Source	Year
26	Bibliometrics analysis of research on argumentation in mathematics education	Kartika et al.	International Journal of Education in Mathematics, Science and Technology	2023
27	Bridging theory and practice: AI applications in learning and teaching in Pakistan's education system	Ullaha et al.	Jahan-e-Tahqeeq	2024
28	Retracted: Effectiveness of artificial intelligence (AI) in improving pupils' deep learning in primary school mathematics teaching in Fujian Province	Intelligence	Computational Intelligence and Neuroscience	2023
29	Intelligent tutoring systems in mathematics education: A systematic literature review using the substitution, augmentation, modification, redefinition model	Son	Computers	2024
30	The impact of ChatGPT on student learning/performing	Ayman et al.	The British University in Egypt	2023
31	Possibilities for using AI in mathematics education	Stefanova and Georgiev	Mathematics and Education in Mathematics,	2024
32	Exploring the integration of artificial intelligence-based ChatGPT into mathematics instruction: Perceptions, challenges, and implications for educators	Egara and Mosimege	Educational Science	2024
33	Enhancing mathematics education with ChatGPT-4 personalized problem-solving and consistent learning	Chohan and Khan	Proceedings of the 2nd International Conference on Computing and Data Analytics	2024
34	Artificial intelligence from teachers' perspectives and understanding: Moroccan study	Fakhar et al.	International Journal of Information and Education Technology	2024
35	Flipped dialogic learning method with ChatGPT: A case study	Pavlova	International Electronic Journal of Mathematics Education	2024
36	An analysis of the use of artificial intelligence in education in Spain: The in-service teacher's perspective	Galindo-Domínguez et al.	Journal of Digital Learning in Teacher Education	2024
37	Teachers and learners' perceptions about implementation of AI tools in elementary mathematics classes	Song et al.	SAGE Open	2025
38	Roles and research trends of artificial intelligence in mathematics education: A bibliometric mapping analysis and systematic review	Hwang and Tu	Mathematics	2021
39	Teachers' use of technology affordances to contextualize and dynamically enrich and extend mathematical problem-solving strategies	Santos-Trigo et al.	Mathematics	2021
40	Exploring latent topics and research trends in mathematics teachers' knowledge using topic modeling: A systematic review	Hwang and Cho	Mathematics	2021
41	Analysis of psychological factors influencing mathematical achievement and machine learning classification	Park et al.	Mathematics	2023
42	Preservice teachers' beliefs and intentions about integrating mathematics teaching and learning ICTs in their classrooms	Ndlovu et al.	ZDM	2020
43	Exploring the relationship between AI literacy, AI trust, AI dependency, and 21st century skills in preservice mathematics teachers	Zhang et al.	Scientific Reports	2025
44	Study on the impact of artificial intelligence on student learning outcomes	Sasikala and Ravichandran	Journal of Digital Learning and Education	2024
45	Efficacy of an adaptive learning system on course scores	Lim et al.	Systems	2023
46	Teaching artificial intelligence in secondary school: From development to practice	Levchenko et al.	RUDN Journal of Informatization in Education	2023
47	Thematic bibliometric analysis of 37 specialized journals in mathematical education research indexed in Scopus or Web of Science	Gaona and Arévalo-Meneses	Eurasia Journal of Mathematics, Science and Technology Education	2024

Table A1 (Continued). Summary table of 56 articles used for the study

No	Document title	Authors	Source	Year
48	Effectiveness of artificial intelligence (AI) in improving pupils' deep learning in primary school mathematics teaching in Fujian Province	Qiu et al.	Computational Intelligence and Neuroscience	2022
49	Artificial intelligence in mathematics education: A systematic review	Panqueban and Huincahue	Uniciencia	2024
50	The effectiveness of AI on K-12 students' mathematics learning: A systematic review and meta-analysis	Yi et al.	International Journal of Science and Mathematics Education	2025
51	ChatGPT's performance in university admissions tests in mathematics	Udias et al.	International Electronic Journal of Mathematics Education	2024
52	Exploring the integration of artificial intelligence in math education: Preservice teachers' experiences and reflections on problem-posing activities with ChatGPT	Kim et al.	School Science and Mathematics	2025
53	Pre-service mathematics teachers' perceptions of using GenAI for practicing teacher questioning: A semester-long study	Zhuang and Zhang	Eurasia Journal of Mathematics Science and Technology Education	2025
54	Exploring machine learning techniques for predictive analytics in computational mathematics	Chitre et al.	Panamerican Mathematical Journal	2024
55	Analysis of psychological factors influencing mathematical achievement and machine learning classification	Park et al.	Mathematics	2023
56	Roles and research trends of artificial intelligence in mathematics education	Kaushik et al.	Proceedings of the 2nd International Conference on Computational Methods in Science and Technology	2021