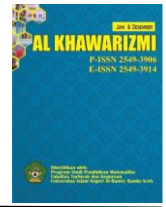
Al Khawarizmi, Vol. 10, No. 1, June 2026 (14-35)

Al Khawarizmi
Jurnal Pendidikan dan Pembelajaran Matematika

journal homepage: https://jurnal.ar-raniry.ac.id/index.php/alkhawarizmi



THE IMPACT OF ARTIFICIAL INTELLIGENCE ON MATHEMATICS EDUCATION: A SYSTEMATIC LITERATURE REVIEW

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Artikel info

Artikel history:
Received 12 May 2026
Received in revised form 18 May 2026
Accepted 16 June 2026
Available online 30 June 2026

Kata Kunci:
Artificial Intelligence, Mathematics Education, ChatGPT, Systematic Literature Review, Adaptive Learning

Abstrak

This study evaluates the impact of Artificial Intelligence (AI) in mathematics education through a systematic literature review. Thirty studies published between 2020 and 2026 were analyzed to identify types of AI used, educational contexts, mathematical concepts addressed, research methods, as well as student learning outcomes and teacher practices. The findings suggest that AI has the potential to support student performance, engagement, perception, and teacher practices in mathematics education, although the strength of evidence varies across study designs, contexts, and AI tools. Limitations such as small sample sizes and short intervention durations suggest areas for future research. These findings provide comprehensive insights into the role of AI in mathematics education and practical implications for pedagogy and research.

INTRODUCTION

Artificial Intelligence (AI) has emerged as a transformative force in contemporary education, particularly in mathematics, a domain characterized by abstract reasoning, symbolic representation, procedural complexity, and conceptual challenges (Voskoglou & Salem, 2020; Engelbrecht & Borba, 2024; Park & Doo, 2024). Mathematics learning requires more than the ability to apply formulas or follow procedures. Students are expected to understand concepts, interpret representations, reason logically, solve unfamiliar problems, and communicate mathematical ideas with clarity. Yet, in many classrooms, students may be able to complete routine calculations while still struggling to explain why a method works, how one concept is connected to another, or how mathematical knowledge can be transferred to new situations. This condition makes mathematics education a meaningful context for examining the role of AI-supported learning.

The integration of AI into mathematics education is part of a longer history of technology-enhanced mathematics learning. Digital tools such as computer algebra systems, dynamic geometry software, virtual manipulatives, and online learning platforms have reshaped how mathematical ideas are represented, explored, and discussed. However, the current development of AI introduces new possibilities because AI-supported systems can generate explanations, provide feedback, adapt learning paths, detect errors, analyze students' responses, and assist teachers in instructional planning. Earlier discussions on artificial and traditional learning in mathematics emphasized that AI may enrich the learning process, but it should not be positioned as a simple replacement for teachers' pedagogical judgment (Voskoglou & Salem, 2020). This reminder remains important today as generative AI, intelligent tutoring systems, adaptive platforms, mathematical solvers, and AI chatbots become increasingly accessible to students and teachers.

AI technologies in mathematics education have been implemented through diverse forms, including intelligent tutoring systems, adaptive learning platforms, AI chatbots, generative AI visualization tools, mathematical solvers, and learning analytics dashboards (Mohamed et al., 2022; Son, 2024; Wardat et al., 2023; Schorcht et al., 2024; Tsakeni et al., 2025). These tools are not pedagogically identical. Intelligent tutoring systems and adaptive platforms are commonly used to support individualized feedback, guided practice, and learning diagnosis. AI chatbots and large language model-based tools can support dialogue, explanation, problem-solving assistance, and simulated interaction. Generative image tools may help visualize mathematical ideas, while learning analytics can support teachers in monitoring students' progress and making instructional decisions. Therefore, AI in mathematics education should be understood as a broad technological ecosystem rather than a single intervention.

Several empirical studies suggest that AI-supported mathematics learning may improve students' problem-solving accuracy, conceptual understanding, motivation, engagement, and attitudes, although these effects remain dependent on tool design, instructional context, teacher mediation, and intervention duration (Alvarez, 2024; Torres-Peña et al., 2024; Susilawati et al., 2025; Tashtoush et al., 2025). For example, AI-powered tutors and calculus-oriented AI tools have been used to support students' mathematical performance and conceptual clarity, while AI-supported realistic mathematics education and gamification have been associated with improvements in motivation and problem-solving skills. Nevertheless, these findings should be interpreted carefully. AI does not automatically create meaningful mathematics learning. Its contribution depends on whether it is embedded in sound pedagogical design, connected to mathematical reasoning, and mediated by teachers who can evaluate the quality of AI-generated responses.

Teacher readiness is therefore a central condition for meaningful AI integration in mathematics education. Recent studies show that mathematics teachers and pre-service teachers require not only technical familiarity with AI, but also AI literacy, AI-TPACK readiness, prompt-design competence, critical evaluation skills, and ethical awareness to use AI-generated outputs pedagogically and responsibly (Pörn et al., 2024; İnci Kuzu, 2026; Mailizar et al., 2026; Kul et al., 2026; Xie & Luo, 2026). This issue is especially important because AI-generated mathematical explanations may appear fluent and convincing while still containing conceptual errors, incomplete reasoning, or misleading procedures. Without adequate teacher mediation, students may become overly dependent on automated answers and lose opportunities to develop independent mathematical thinking.

Beyond teacher readiness, issues of equity, inclusion, and evidence quality also require attention. AI-supported interventions may offer personalized and adaptive learning opportunities for students with different learning needs, including students with learning disabilities. However, the evidence remains uneven, and positive findings should be interpreted with caution when studies have limited samples, short intervention periods, weak follow-up, or moderate to high risk of bias (Paglialunga & Melogno, 2025). In addition, access to infrastructure, digital devices, stable internet connection, and teacher support may influence who benefits from AI-supported mathematics learning. If these contextual factors are ignored, AI may reproduce existing educational inequalities rather than reduce them.

Although previous reviews have mapped AI in mathematics education and intelligent tutoring systems, the literature remains fragmented across AI tools, educational levels, mathematical topics, research designs, and implementation contexts (Mohamed et al., 2022; del Olmo-Muñoz et al., 2023). Moreover, recent studies suggest that teacher-focused AI research, inclusive AI-supported mathematics learning, and evidence on long-term conceptual development remain limited and methodologically uneven (Li et al., 2025; Paglialunga & Melogno, 2025). The rapid growth of research after 2020, especially following the wider public use of generative AI, creates a need for an updated and focused synthesis that can clarify how AI is being used, what outcomes are reported, and what gaps remain in the field.

Therefore, this study conducts a systematic literature review of studies on AI in mathematics education published between 2020 and 2026. This review aims to: (1) identify the types of AI technologies applied in mathematics education; (2) examine the educational levels and learning contexts in which AI has been studied; (3) synthesize evidence related to students' learning outcomes, engagement, perceptions, and teachers' pedagogical practices; and (4) identify methodological, practical, and ethical challenges in the existing literature. By addressing these aims, this review seeks to provide a balanced synthesis of AI in mathematics education, avoiding overly general claims while emphasizing the conditions under which AI may contribute meaningfully to mathematics teaching and learning.

METHODS

Research Design

This study employed a systematic literature review (SLR) design to synthesize empirical and analytically relevant studies on the use and impact of artificial intelligence (AI) in mathematics education. The review was guided by the PRISMA 2020 framework to ensure that the identification, screening, eligibility assessment, and inclusion of studies were conducted in a transparent and traceable manner (Page et al., 2021). The review focused on publications from 2020 to 2026, a period marked by rapid development in AI-supported educational technologies, including generative AI, AI chatbots, intelligent tutoring systems, adaptive learning platforms, learning analytics, and machine learning-based applications.

The literature search was conducted using the WATASE UAKE application as a supporting tool for article tracking and screening management. The source of records was limited to Scopus-indexed publications. Scopus was selected because it provides broad coverage of peer-reviewed international literature in education, mathematics education, educational technology, computer science, and interdisciplinary research related to AI-supported learning. To maintain methodological consistency, no register or additional database was included in the final search process.

The search strategy combined two main concepts: artificial intelligence and mathematics education. The search terms included AI-related keywords and mathematics education-related keywords connected with Boolean operators. The general search structure was: ("artificial intelligence" OR "AI" OR "intelligent tutoring system" OR "adaptive learning" OR "AI chatbot" OR "learning analytics" OR "generative AI" OR "machine learning" OR "robotics") AND ("mathematics education" OR "mathematics learning" OR "mathematics teaching" OR "mathematics instruction" OR "math education" OR "math learning"). The search was limited to studies published between 2020 and 2026.

The identification stage produced 204 records from Scopus. Before screening, 38 duplicate records were removed. A further 21 records were marked as ineligible based on the preliminary screening criteria, 45 records were removed for other reasons, such as unsuitable document type or insufficient alignment with the review focus, and 10 records were excluded because they did not provide abstracts for screening. After this stage, 90 records remained for title and abstract screening.

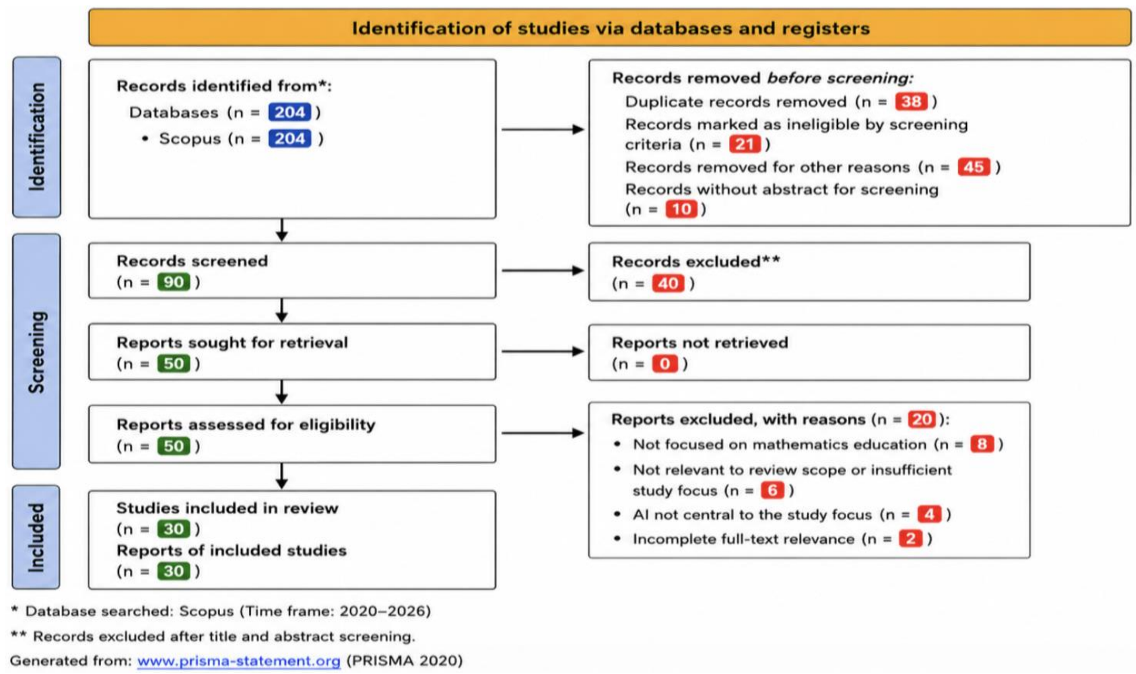

Figure 1.
PRISMA flow diagram of the study

During title and abstract screening, 40 records were excluded because they did not sufficiently address AI in mathematics education or did not match the focus of the review. This process resulted in 50 reports sought for retrieval. All 50 reports were successfully retrieved and assessed for eligibility. At the full-text eligibility stage, 20 reports were excluded for specific reasons: eight were not focused on mathematics education, six were not relevant to the review scope or had insufficient study focus, four did not place AI as the central focus of the study, and two had incomplete full-text relevance to the review questions. Finally, 30 studies were included in the systematic review.

The inclusion criteria were as follows. Studies were included when they provided empirical evidence or analytically relevant insight related to AI-supported mathematics education. In addition, the studies had to focus on AI or AI-supported tools in mathematics education, be published between 2020 and 2026, be indexed in Scopus, provide clear relevance to mathematics teaching, learning, assessment, teacher readiness, or educational implementation, and contain sufficient information for extraction and synthesis. Studies were excluded when they focused on non-mathematics contexts, treated AI only as a peripheral issue, lacked full-text relevance, or did not provide sufficient relevance or analyzable evidence for the review questions.

Data were extracted from the 30 included studies using a structured extraction form. The extracted information included author(s), year of publication, country or research context, journal quartile, type of AI tool used, mathematical concept addressed, research design, data collection technique, data analysis technique, educational level, sample or participants, theoretical framework, and key findings. This extraction process allowed the review to connect each claim in the results section with the characteristics of the included studies.

The methodological quality and relevance of the included studies were assessed through several considerations: clarity of research objective, appropriateness of research design, connection between AI tools and mathematics education, transparency of data collection and analysis, relevance of participants or context, and clarity of reported findings. Because the included studies varied in design and scope, the appraisal was used to guide interpretation rather than to produce statistical weighting.

A narrative synthesis was used because the included studies were heterogeneous in terms of AI tools, educational levels, mathematical concepts, research designs, and reported outcomes. Quantitative information was summarized descriptively, including publication year, country, educational level, types of AI tools, mathematical concepts, and methodological approaches. Qualitative information was synthesized thematically to identify recurring patterns, gaps, challenges, and implications for AI-supported mathematics education. The synthesis avoided broad causal claims and focused instead on patterns of evidence, contextual variation, and conditions under which AI may support mathematics teaching and learning.

RESULTS

Characteristics of the Included Studies

Before presenting the thematic and descriptive synthesis, the characteristics of the 30 included studies are summarized in Table 1. This table provides a comprehensive overview of key information from each study, including the authors and year of publication, research context, educational level, specific AI tools employed, mathematical concepts addressed, research design, participants or data sources, and main findings. The inclusion of Table 1 serves to make the review corpus more transparent and auditable. By presenting these details in a structured format, readers can easily trace how the synthesis conclusions were derived from the original studies. This level of transparency enhances the methodological rigor of the systematic literature review and allows for critical appraisal of the evidence base underlying the reported results.

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Table 1.
Characteristics of the Included Studies

No.	Author(s) (Year)	Country / Research Context	Type of AI	Mathematical Concept	Research Design	Educational Level	Main Finding
1	Voskoglou & Salem (2020)	Greece & Egypt	General AI, machine learning, social robots	Algebra, trigonometry, problem solving	Conceptual review	Higher education and general education	AI is unlikely to replace teachers, but it can serve as a useful instructional support tool.
2	Chiang, (2021)	Taiwan	Machine learning, deep learning	STEM, learning efficiency	Descriptive quantitative study	Higher education (Civil Engineering students)	The DEA-Mahalanobis approach was effective for measuring AI-supported learning efficiency.
3	Tamborg et al. (2022)	Denmark & England	Machine learning, image recognition	Probability, statistics, geometry	Literature review	Primary and secondary education (K-9)	Integrating computational thinking and mathematics is important for developing critical AI awareness.
4	Lee & Yeo (2022)	United States	AI chatbot (IBM Watson)	Fractions, part-whole understanding	Design-based research	Higher education (preservice elementary teachers)	The chatbot simulated students' misconceptions and supported preservice teachers' practice in responsive mathematics teaching.
5	Engelbrecht & Borba, (2024)	South Africa & Brazil	Computer algebra systems, ChatGPT, general AI	Algebra, geometry, calculus	Narrative review	All educational levels	AI reshapes mathematics learning spaces, but digital inequality remains a major challenge.
6	Jančařík et al. (2023)	Czech Republic	AI chatbot for tutoring	Percentages, volume of cubes	Descriptive quantitative study	Secondary education	The chatbot was useful for tutoring, and response-time analysis helped detect random or careless answers.
7	Wardat et al. (2023)	United Arab Emirates	ChatGPT	Geometry, linear equations, calculus	Qualitative case study	Higher education and general education	ChatGPT showed limitations in geometry and generated several misconceptions.
8	Bagno et al. (2024)	Israel	ChatGPT	Linear algebra, eigenvalues, vector spaces	Experimental study with session analysis	Higher education	ChatGPT was not yet suitable as an independent instructor because of frequent logical errors.
9	Botana et al., (2024)	Spain	ChatGPT, GeoGebra Discovery	Euclidean geometry	Comparative conceptual study	Secondary and higher education	ChatGPT failed in several geometry cases, while GeoGebra Discovery was more reliable.
10	Alvarez, (2024)	Philippines	MathGPT, Flexi 2.0	Differential calculus	Quasi-experimental study	Higher education (preservice elementary teachers)	Both AI tools improved learning outcomes, with Flexi 2.0 showing stronger effects.
11	Alhazzani (2024)	Saudi Arabia	ChatGPT	School mathematics topics	Descriptive quantitative study	Secondary education	The ChatGPT-based framework was feasible for developing creative mathematics teaching skills.
12	Pörn et al. (2024)	Finland	General AI tools	K-12 mathematics	Mixed-methods study	Primary and secondary education	Digitally skilled teachers showed openness toward AI, but their attitudes remained ambivalent.
13	Torres-Peña et al. (2024)	Colombia	ChatGPT, MathGPT, Gemini, Wolfram Alpha	Differential calculus	Qualitative descriptive study	Higher education	AI helped verify solutions but struggled to detect procedural errors.
14	Schorcht et al. (2024)	Germany	DALL-E, MidJourney, Leonardo.Ai	Geometric sequences, irrational numbers	Exploratory qualitative study	Primary and secondary education	MidJourney produced the best visual outputs, but AI struggled to translate abstract mathematical structures.
15	Filiz & Gür (2025)	Turkey	ChatGPT	Mathematical problem solving	Mixed-methods study	Higher education (preservice elementary teachers)	ChatGPT improved metacognitive awareness and problem-solving strategies.

16	Wang et al. (2025)	Singapore	AI-based RoBERTa model	K-12 mathematics	Quantitative study using sequence mining	Primary and secondary education	Tutoring interactions were dominated by instructional moves, while high school students showed more active participation.
17	Akosah, (2025)	Ghana	AI-assisted collaborative learning tools	Collaborative problem solving	Qualitative phenomenological study	Higher education (preservice elementary teachers)	Preservice teachers reported positive perceptions, although technical issues and group dynamics remained challenging.
18	Gómez Niño et al., (2026)	Colombia & Chile	Conceptual AI for feedback and personalization	Inclusive K-12 mathematics	Conceptual analysis	Primary and secondary education	Teachers' conceptions shaped AI adoption and inclusive learning outcomes.
19	Kuzmenko, 2025)	Russia	YandexGPT, ChatGPT, neural networks	General school mathematics	Quantitative survey	Mathematics teachers	About 70% of teachers were ready to use AI, although limited knowledge and resources remained barriers.
20	Tashtoush et al. (2025)	Jordan	Wolfram Alpha, Microsoft Math Solver	Mathematical critical thinking	Quasi-experimental study	Secondary education	AI significantly improved students' critical thinking and positive attitudes toward mathematics.
21	Susilawati et al. (2025)	Indonesia	AI scaffolding using LLM-based tiered hints	Problem solving, fractions, geometry	Mixed-methods study	Secondary education	The integration of realistic mathematics education, AI, and gamification improved motivation and problem-solving skills.
22	Kuzu (2026)	Turkey	ChatGPT, general AI literacy tools	Teachers' perceptions of AI integration	Mixed-methods study	Mathematics teachers	Teachers' AI literacy was above average, and their AI-related anxiety was low.
23	Atuahene & Boateng (2026)	Ghana	ChatGPT	General mathematics instruction	Descriptive survey	Senior high school	Teachers showed high awareness of ChatGPT, but time, training, and internet access remained key challenges.
24	Besas et al., (2026)	Philippines	ChatGPT	Problem solving, mathematical reasoning	Mixed-methods study	Junior high school	Self-directed learning was the dominant predictor of mathematics performance, while ChatGPT use showed a weak correlation.
25	Polydoros et al. (2026)	Greece & France	Intelligent tutoring systems, affective computing, virtual reality	Arithmetic, fractions, algebra, geometry	Conceptual review	Primary and secondary education	AI can support students with learning difficulties when designed ethically and inclusively.
26	Mailizar et al. (2026)	Indonesia	ChatGPT, Gemini, Copilot	Mathematics lesson planning	Mixed-methods study	Higher education (preservice elementary teachers)	Generative AI functioned as a peer mentor and improved preservice teachers' TPACK.
27	Al-Mutawah, (2026)	Bahrain	Intelligent tutoring systems, chatbots, assessment tools	General mathematics learning	Quantitative survey	Mathematics teachers	Teachers had positive perceptions of AI, with younger teachers reporting higher perceptions.
28	Xie & Luo (2026)	China	Generative AI, intelligent tutoring systems	Geometry, algebra, abstract mathematics	Quantitative scale development study	Higher education (preservice elementary teachers)	Preservice teachers' AI-TPACK readiness was still at an early or medium level.
29	Yeribatuah & Boateng, (2026)	Ghana	Adaptive learning, intelligent tutoring systems, gamification	Problem solving, conceptual understanding	Quantitative survey using SEM	Senior high school	AI had a significant positive effect on students' mathematics interest, performance, and perception.
30	Kul et al. (2026)	Turkey	ChatGPT, DALL-E, MidJourney, Wolfram Alpha	Fractions, geometry, algebra	Multi-method study	Higher education (preservice elementary teachers)	A 14-hour training program improved TPACK, and TPACK predicted 61% of generative AI acceptance.

Based on the characteristics summarized in Table 1, the included studies were analyzed descriptively and thematically according to publication year, geographical distribution, educational level, types of AI tools, mathematical concepts addressed, methodological approaches, and reported gaps or limitations

Distribution of Studies by Year (2020–2026)

The distribution of the 30 included studies shows that research on artificial intelligence in mathematics education increased considerably during the 2020–2026 period. Only one study was published in 2020 and one study in 2021. The number increased slightly to two studies in 2022 and two studies in 2023. A sharper rise appeared in 2024, with eight studies included in the review, followed by six studies in 2025. The highest number of studies was recorded in 2026, with ten studies. This pattern indicates that scholarly attention to AI in mathematics education has grown rapidly in recent years, particularly after the wider adoption of AI-supported learning tools, adaptive systems, AI chatbots, and generative AI in educational contexts.

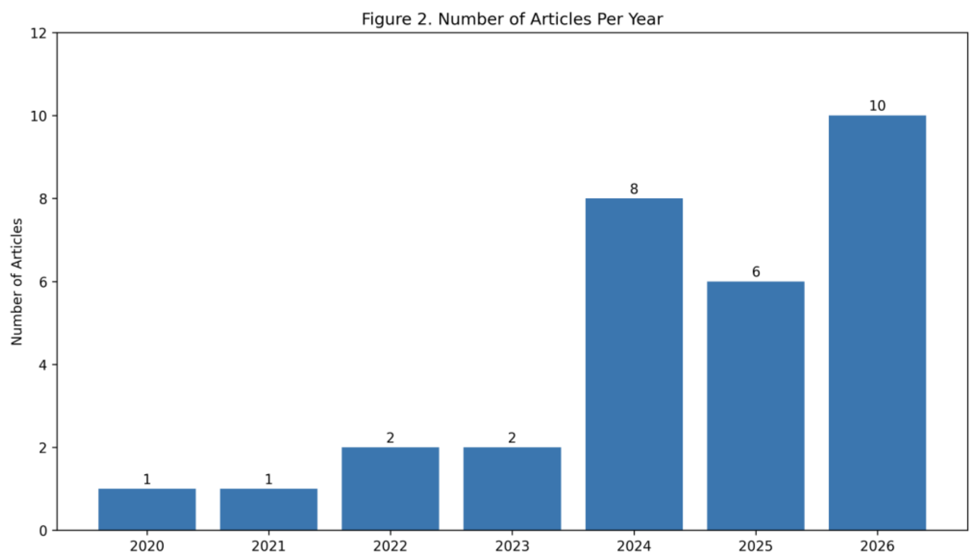

Figure 2. Number of Articles Per Year

Distribution of Studies by Country

The geographical distribution of the 30 included studies indicates that research on artificial intelligence in mathematics education has been conducted across diverse national and cross-national contexts. The studies spanned Asia, Europe, Africa, the Middle East, North America, and South America, confirming that AI-supported mathematics education has become an international research concern. However, the distribution was not even across countries. Several nations, including Turkey, Ghana, Indonesia, the Philippines, Spain, and Colombia, contributed multiple studies, while many other countries had limited or no representation. This uneven pattern suggests disparities in research capacity, technological infrastructure, and policy support for AI integration in mathematics education across

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different regions. Such imbalances highlight the need for more inclusive and globally representative research efforts in the future.

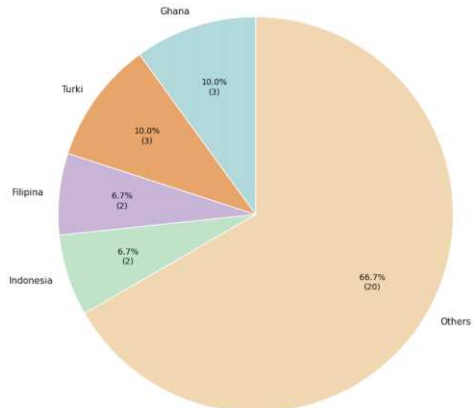

Figure 3.
Distribution of Studies by Country/Research Context

Turkey and Ghana were the most frequently represented research contexts, with three studies each. Indonesia and the Philippines followed with two studies each. Other single-country contexts appeared once, including Taiwan, the United States, the United Arab Emirates, Israel, Spain, Saudi Arabia, Finland, Colombia, Germany, Singapore, Russia, Jordan, Bahrain, China, and the Czech Republic. In addition, several studies involved cross-national contexts, namely Greece and Egypt, Denmark and England, South Africa and Brazil, Colombia and Chile, and Greece and France.

This pattern suggests that AI in mathematics education is being explored in both digitally advanced and developing educational settings. Studies from countries such as the United States, Finland, Germany, Spain, Singapore, China, and Israel reflect the growing use of AI-supported mathematics learning in technologically mature or research-intensive contexts. Meanwhile, studies from Ghana, Indonesia, the Philippines, Jordan, Bahrain, Colombia, South Africa, and similar contexts show that AI integration is also gaining attention in educational environments where issues such as digital infrastructure, teacher readiness, and equitable access may strongly influence implementation.

Overall, the geographical distribution shows that the research landscape is international but still fragmented. The relatively small number of studies from each country indicates that the evidence should be interpreted as an emerging global picture rather than a fully balanced representation of AI implementation in mathematics education across regions.

Educational Level

In terms of educational level, the 30 included studies covered a broad range of learning contexts. Primary and secondary education formed the largest category, with 13 studies. This category included studies conducted in K-12, K-9, junior secondary, senior secondary, and specific grade-level contexts. Higher education was represented by 10 studies, including studies involving university students and preservice teacher education programs. Three studies focused specifically on mathematics teachers, while four studies involved mixed or cross-level contexts, such as general education, primary-to-higher education, or secondary-to-higher education settings.

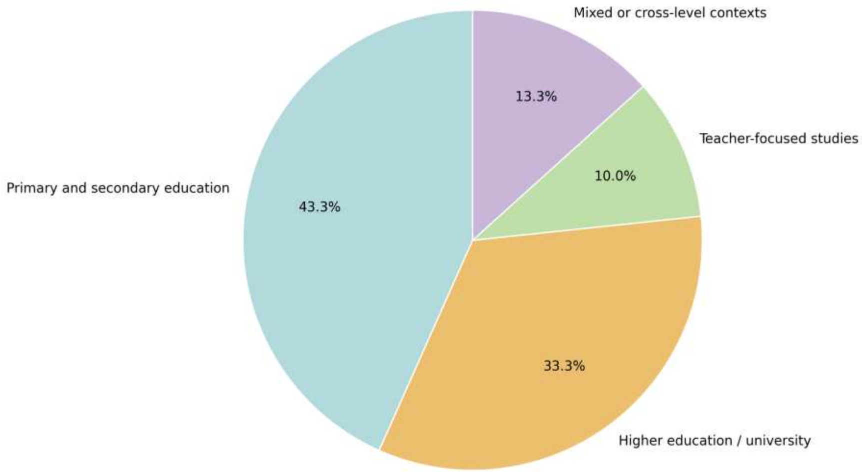

Figure 4.
Distribution of Studies by Educational Level

The dominance of primary and secondary education indicates that AI in mathematics education is often examined in school-based learning environments. This is understandable because students at these levels frequently encounter difficulties in mathematical concepts, procedural fluency, problem solving, and learning motivation. AI tools such as intelligent tutoring systems, adaptive platforms, chatbots, robotics, and learning analytics are therefore commonly positioned as forms of support for individualized learning, feedback, and engagement in school mathematics.

The presence of higher education studies shows that AI is also being examined in more advanced mathematical learning and in teacher preparation contexts. In this setting, AI may support conceptual explanation, problem-solving guidance, visualization, assessment, and preservice teachers' pedagogical development. Meanwhile, teacher-focused studies highlight the importance of professional readiness, because the effectiveness of AI in mathematics classrooms depends not only on the availability of technology but also on teachers' ability to select, interpret, and integrate AI tools into meaningful instruction.

Overall, the distribution by educational level shows that AI in mathematics education has been studied across multiple learning stages, with the strongest attention given to primary and secondary education. However, the limited number of teacher-focused and mixed-level studies suggests the need for more research on teacher readiness, classroom implementation, and continuity of AI-supported mathematics learning across educational levels.

Types of AI Tools Used

Because several studies reported more than one AI tool, this section used multi-response coding. Therefore, one study could be assigned to more than one AI tool category when multiple tools were explicitly reported. The most frequently represented categories were AI chatbots and conversational agents, followed by generative AI and large language model-based tools. AI chatbots and conversational agents included tools such as ChatGPT, MathGPT, Gemini, Microsoft Copilot, and other chatbot-based systems. Generative AI and large language model-based tools were mainly used to support mathematical explanation, problem-solving guidance, conceptual visualization, prompt-based learning, tutoring interaction, and critical analysis of AI-generated mathematical responses. The dominance of these categories reflects the rapid expansion of conversational and generative AI in mathematics education, especially after the wider public use of ChatGPT and related tools.

Intelligent tutoring systems (ITS) appeared in six studies and represented the third most frequent category. These systems were commonly used to provide individualized learning support, tutoring interaction, adaptive feedback, and guided mathematical practice. Their presence indicates that AI in mathematics education is not limited to open-ended generative tools, but also includes structured systems designed to support students' learning pathways and problem-solving processes. Mathematical solvers and computer algebra systems appeared in five studies, including tools such as Wolfram Alpha, GeoGebra Discovery, Microsoft Math Solver, and related computer algebra environments. These tools were mainly used to support symbolic computation, algebraic verification, geometric exploration, and step-by-step mathematical reasoning.

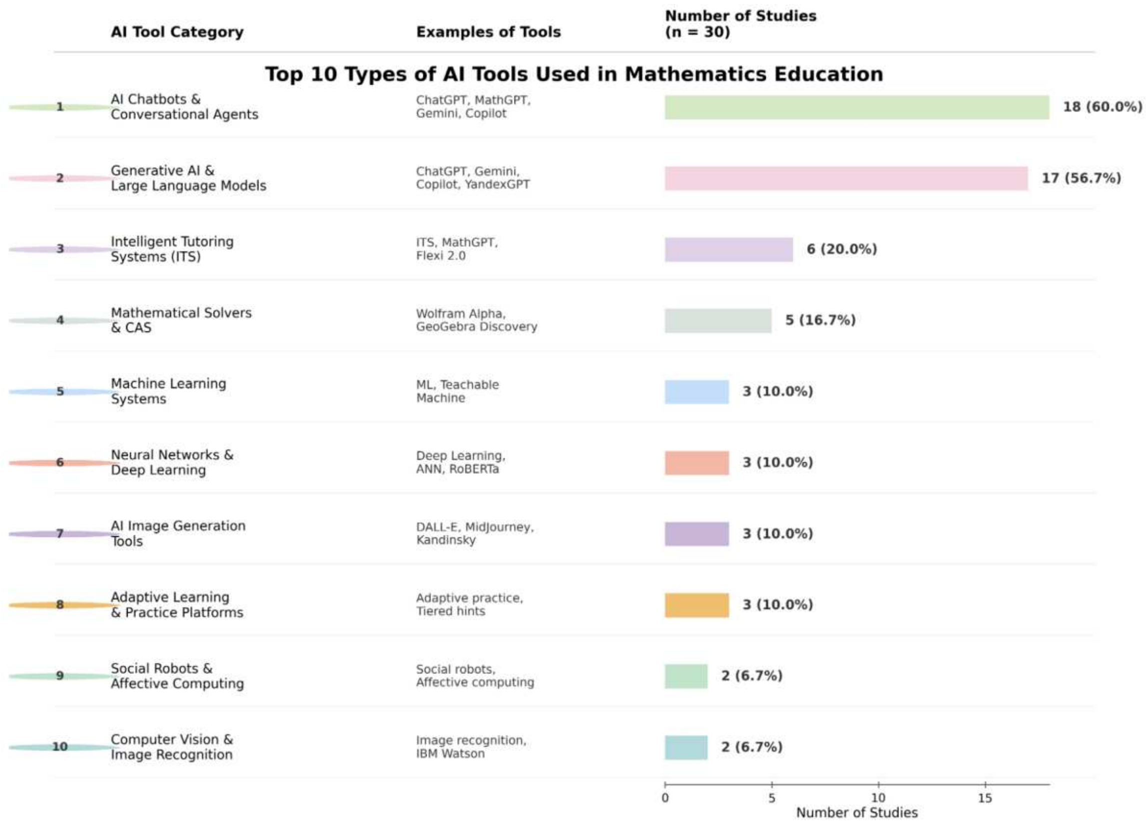

Figure 5.
Top 10 Types Of AI tools Used in Mathematics Education

Machine learning systems, neural networks and deep learning tools, AI image-generation tools, and adaptive learning or practice platforms each appeared in three studies. Machine learning and NLP-based analytics were used to analyze learning efficiency, identify patterns, annotate mathematical dialogue, or support computational thinking. Neural networks and deep learning tools were associated with automated analysis, prediction, and representation of learning-related data. AI image-generation tools, such as DALL-E, MidJourney, Leonardo.Ai, and Kandinsky, were used to support mathematical visualization and exploratory representation. Adaptive learning and practice platforms were used to provide tiered hints, individualized practice, gamified learning experiences, and feedback adjusted to students' learning needs.

Social robots and affective computing appeared in two studies, as did computer vision and image recognition tools. These categories indicate that AI-supported mathematics education is gradually expanding beyond text-based assistance and symbolic computation. Social robots and affective computing were mainly linked to interactive learning, engagement, and affective support, while computer vision and image recognition tools were used to interpret visual or handwritten mathematical inputs. Although these categories appeared less frequently, they show that AI in mathematics education is becoming increasingly multimodal, combining conversation, visualization, automation, recognition, and adaptive interaction.

Finally, one study focused on AI-assisted collaborative learning tools. This indicates that the use of AI to support collaborative mathematical learning is still relatively limited in the reviewed corpus. Most studies remain centered on individual tutoring, generative assistance, adaptive support, or tool-based mathematical problem solving rather than group-based AI-supported learning.

Overall, the distribution of AI tools shows that recent research on AI in mathematics education is strongly shaped by generative AI and chatbot-based technologies. However, the reviewed studies also demonstrate that AI in mathematics education is not limited to ChatGPT or large language models. It includes a wider technological landscape, such as machine learning, intelligent tutoring systems, adaptive platforms, computer algebra systems, dynamic geometry tools, mathematical solvers, learning analytics, and collaborative AI-supported environments. This diversity suggests that AI integration in mathematics education should be understood as a broad and evolving field rather than a single type of technology.

Mathematical Concepts Addressed

The mathematical concepts addressed in the 30 included studies were diverse, ranging from specific mathematical topics to broader mathematical competencies and teacher-related pedagogical domains. Because several studies covered more than one mathematical topic, the concepts were coded using a multi-response approach. This means that one study could be assigned to more than one conceptual category when it explicitly addressed multiple areas of mathematics.

Geometry was the most frequently addressed mathematical concept, followed by problem solving, algebra, and teacher pedagogy/general mathematics. This category appeared in studies that did not focus on a single mathematical topic, but examined AI in relation to mathematics teaching, teacher perception, lesson planning, AI literacy, AI-TPACK, and general mathematics learning. These studies show that current research is not only concerned with how AI helps students solve mathematical problems, but also with how teachers and preservice teachers understand, evaluate, and integrate AI into mathematics instruction.

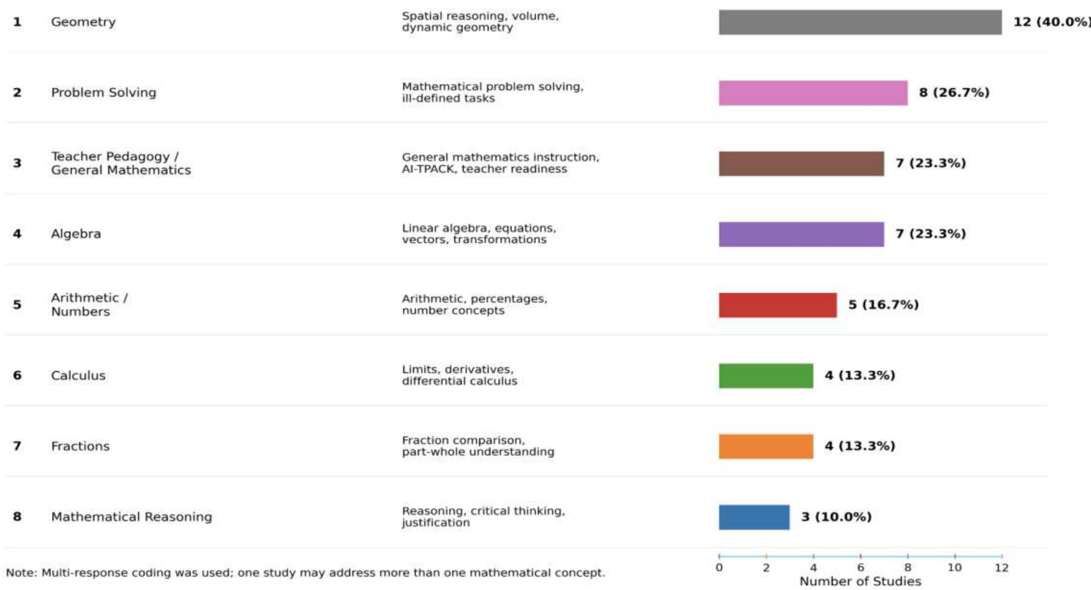

Figure 6.
Mathematical Concepts Addressed in the Included Studies

Problem solving, mathematical reasoning, critical thinking, and conceptual understanding also emerged as dominant themes. Several studies examined AI as a tool for supporting students' ability to reason through mathematical tasks, solve well-defined and ill-defined problems, engage in collaborative problem solving, or develop critical thinking in mathematics. This emphasis suggests that AI in mathematics education is increasingly being positioned not merely as a tool for producing answers, but as a learning support system for strengthening reasoning processes and conceptual engagement.

Specific mathematical topics were also represented in the reviewed studies. Geometry appeared in various forms, including Euclidean geometry, volume of cubes, dynamic geometry, geometric visualization, and spatial reasoning. Algebra and linear algebra were also frequently addressed, including systems of equations, linear equations, eigenvalues, vector spaces, transformations, and algebraic problem solving. These findings indicate that AI tools are often used in mathematical areas that require representation, symbolic manipulation, visualization, and step-by-step reasoning.

Fractions, arithmetic, percentages, and number-related concepts formed another important group. These topics appeared in studies involving part-whole understanding, comparison of fractions, arithmetic operations, percentages, irrational numbers, and number-based problem solving. The presence of these topics is important because they are foundational concepts in school mathematics and often become sources of persistent misconceptions among learners.

Calculus and other advanced mathematical topics were mainly found in higher education contexts. These included differential calculus, derivatives, limits, rates of change, analytic geometry, and calculus-related problem solving. AI tools in these studies were commonly used to support explanation, verification of solutions, symbolic computation, and feedback in more advanced mathematical learning.

A smaller number of studies addressed probability, statistics, computational thinking, data logic, mathematical aesthetics, infinity, continuity, and mathematical visualization. Although these topics appeared less frequently, they show the expanding scope of AI use in mathematics education. AI is not only being used for routine procedural tasks, but also for exploratory, representational, and interdisciplinary mathematical learning.

Overall, the distribution of mathematical concepts indicates that AI in mathematics education has been applied across both foundational and advanced domains. The evidence shows strong attention to general mathematics instruction, problem solving, reasoning, geometry, algebra, fractions, and calculus. However, the distribution also suggests that many studies still focus on broad instructional use rather than deep analysis of specific mathematical content. Future research should therefore examine more carefully how AI supports students' understanding of particular mathematical concepts, especially in relation to misconceptions, representation, proof, abstraction, and long-term conceptual development.

Methodological Approaches

The 30 included studies employed diverse research designs and methodological approaches. This diversity reflects the developing nature of research on artificial intelligence in mathematics education, where AI is examined not only through classroom intervention studies, but also through surveys, mixed-methods designs, qualitative inquiry, tool-based analysis, design-based research, and conceptual or narrative studies.

Quantitative non-experimental designs formed the largest methodological group, with nine studies. These studies commonly used surveys, structured questionnaires, scale development, descriptive statistics, correlational analysis, regression, SEM, CFA, EFA, ANOVA, or learning analytics to examine teachers' perceptions, students' attitudes, AI readiness, learning efficiency, or relationships among variables. This indicates that a considerable portion of the reviewed literature focuses on measuring perceptions, readiness, acceptance, and predictive relationships rather than directly testing AI-based instructional interventions.

Mixed-methods and multi-method designs were used in seven studies. These studies combined quantitative data, such as questionnaires, pre-post measures, performance scores, or scale-based instruments, with qualitative data from interviews, open-ended responses, observations, or focus group discussions. The use of mixed methods is important in AI-related mathematics education research because it allows researchers to examine not only whether AI is associated with improved outcomes, but also how students and teachers experience, interpret, and respond to AI-supported learning environments.

Conceptual, narrative, review-based, or comparative analytical designs appeared in six studies. These studies did not always involve direct classroom participants, but they contributed to the corpus by examining AI-related frameworks, theoretical arguments, literature-based evidence, or comparisons between AI-supported mathematical tools. Although these studies provide useful conceptual insight, their inclusion should be interpreted carefully because they do not offer the same type of empirical evidence as intervention, survey, or classroom-based studies.

Qualitative designs were represented in four studies. These studies used approaches such as case study, phenomenology, qualitative descriptive analysis, and exploratory qualitative inquiry. Data were commonly collected through interviews, observations, interaction records, prompt outputs, or user-experience scenarios. These studies provided deeper insight into how students, teachers, or preservice teachers interacted with AI tools, how they perceived AI-generated responses, and what kinds of challenges emerged during AI-supported mathematical learning.

Experimental and quasi-experimental designs were used in three studies. These studies examined the effects of AI-supported tools on learning outcomes such as mathematics achievement, critical thinking, attitudes, or problem-solving performance. Although the number of experimental studies was relatively limited, this category provides more direct evidence regarding the possible contribution of AI interventions to mathematics learning. However, the small number of experimental designs also indicates that stronger causal evidence remains limited within the reviewed corpus.

One study employed a design-based research approach. This study focused on the iterative design and analysis of an AI-based chatbot as a learning environment for supporting mathematics teacher preparation. Design-based research is valuable in this field because AI-supported mathematics learning often requires continuous refinement of tool design, pedagogical structure, learner interaction, and classroom usability.

In terms of data collection methods, questionnaires and survey instruments were the most frequently used, especially in studies examining AI readiness, teacher perception, student attitudes, self-directed learning, TPACK, AI-TPACK, or technology acceptance. Interviews, focus group discussions, and open-ended responses were used to capture participants' experiences and perceptions in greater depth. Several studies relied on prompt engineering, AI-generated outputs, chatbot interaction data, learning logs, or online tutoring datasets, showing that AI research in mathematics education increasingly uses digital trace data and tool-based evidence alongside conventional educational research instruments.

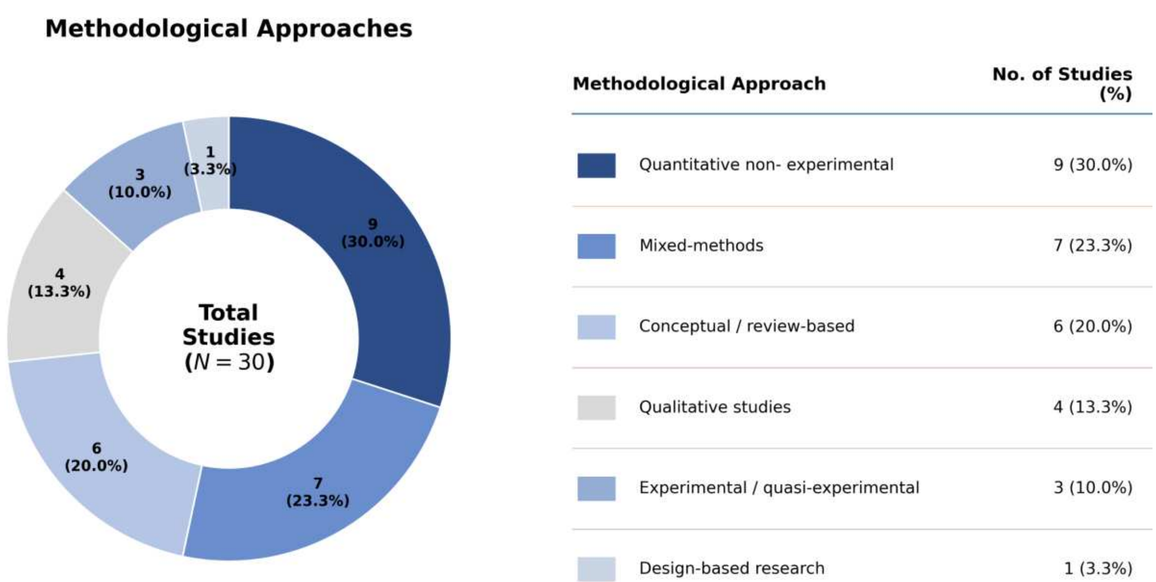

Figure 7.
Methodological Approaches of the Included Studies

The data analysis techniques were also varied. Quantitative studies commonly used descriptive statistics, t-tests, ANOVA, MANCOVA, regression, correlation, SEM, CFA, EFA, and path analysis. Qualitative studies generally used thematic analysis, content analysis, narrative analysis, or interpretive analysis of AI-generated responses and participant experiences. Some studies applied more specialized methods, such as DEA with Mahalanobis distance, lag sequential analysis, sequence mining, algebraic geometry methods, and aesthetic analysis of AI-generated mathematical visualizations.

Overall, the methodological distribution shows that research on AI in mathematics education is methodologically broad but still uneven. Survey-based and mixed-methods studies are relatively prominent, while experimental and design-based studies remain limited. This suggests that the field has developed a strong interest in perceptions, readiness, acceptance, and exploratory use of AI, but still needs more rigorous intervention studies, longitudinal designs, and classroom-based evaluations to establish stronger evidence regarding the sustained impact of AI on mathematics learning.

Gaps and Limitations

The synthesis of the 30 included studies reveals several gaps and limitations in the current body of research on artificial intelligence in mathematics education. Although the reviewed studies show growing interest in AI-supported mathematics learning, the evidence remains uneven in terms of research design, educational context, mathematical focus, and depth of analysis.

The first major gap concerns the limited number of rigorous intervention studies. Many studies examined perceptions, readiness, acceptance, or general experiences with AI, while fewer studies tested the direct effect of AI tools on students' mathematics learning through experimental, quasi-experimental, or longitudinal designs. As a result, the available evidence is stronger in describing how students and teachers perceive AI than in demonstrating how AI changes mathematical understanding, problem-solving ability, or long-term achievement.

The second gap relates to the short duration of many studies. Several studies captured immediate responses to AI tools, short-term performance, or initial user experience. However, mathematics learning often requires gradual conceptual development, repeated practice, and sustained reasoning. Because of this, short-term findings may not fully explain whether AI-supported learning produces durable improvement in students' conceptual understanding, procedural fluency, mathematical reasoning, or independent problem-solving skills.

The third limitation concerns the dominance of broad AI use rather than deep analysis of specific mathematical concepts. Many studies discussed AI in general mathematics learning, teacher readiness, or pedagogical integration, but fewer studies examined how AI supports students' understanding of particular mathematical ideas such as algebraic structure, geometric proof, proportional reasoning, calculus concepts, or statistical thinking. This limits the ability of the review to explain which mathematical topics benefit most from AI and which topics remain difficult for AI-supported instruction.

Another important gap is related to teacher readiness and pedagogical integration. Several studies acknowledged that teachers and preservice teachers need AI literacy, digital competence, and pedagogical judgment to use AI meaningfully. However, only a limited number of studies examined how teachers actually design, implement, monitor, and evaluate

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AI-supported mathematics instruction in real classrooms. This indicates that future research should move beyond general teacher perception and examine concrete classroom practices, instructional decision-making, and teacher–AI–student interaction.

The reviewed literature also shows a gap in equity-oriented research. Although AI is often presented as a tool for personalization and access, only a small number of studies directly examined how socioeconomic background, digital access, school infrastructure, language, disability, or regional inequality affects the use of AI in mathematics education. This is a critical issue because AI may support learners who already have strong digital access, while students in under-resourced contexts may experience limited benefit or even further exclusion.

A further limitation concerns the reliability and transparency of AI-generated mathematical responses. Generative AI tools and chatbots can support explanation, visualization, and problem-solving guidance, but several studies indicate that these tools may produce incorrect, incomplete, or misleading mathematical reasoning. This creates a serious pedagogical concern because students may accept AI-generated solutions without sufficient verification. Future studies need to evaluate not only whether students like using AI, but also whether AI responses are mathematically accurate, conceptually meaningful, and pedagogically appropriate.

The existing studies also provide limited evidence on students' cognitive dependence on AI. While AI can provide instant support, hints, and explanations, there is a risk that students may rely too heavily on AI-generated answers and reduce their own mathematical effort. Few studies have examined how AI affects students' productive struggle, independent reasoning, metacognition, or ability to justify mathematical solutions without technological assistance.

Finally, the geographical and contextual distribution of studies remains fragmented. Although the included studies represent various countries and educational levels, the number of studies from each context is still small. This makes it difficult to generalize findings across different education systems, curriculum structures, technological infrastructures, and cultural settings. More comparative and context-sensitive studies are needed to understand how AI implementation in mathematics education differs across regions and school systems.

Overall, the gaps and limitations indicate that research on AI in mathematics education is developing rapidly but still requires stronger methodological rigor and deeper pedagogical analysis. Future studies should prioritize longitudinal and classroom-based designs, larger and more diverse samples, concept-specific mathematical investigations, teacher-centered implementation studies, equity-focused analysis, and careful evaluation of the accuracy and educational value of AI-generated mathematical responses.

Discussion

This systematic literature review shows that research on artificial intelligence in mathematics education has grown rapidly, particularly from 2024 onward. This growth reflects a wider transformation in educational technology, especially after the increasing use of generative AI, AI chatbots, intelligent tutoring systems, adaptive learning platforms, machine learning applications, mathematical solvers, and AI-supported assessment tools. However, the findings of this review also suggest that the expansion of AI research should not be interpreted too quickly as evidence of consistent educational improvement. The reviewed studies differ substantially in research design, educational context, AI tool, mathematical content, and measured outcomes. Therefore, the central question is not simply whether AI improves mathematics education, but how AI is used, for whom it is useful, under what conditions it works, and what pedagogical risks accompany its use.

The geographical distribution of the reviewed studies indicates that AI in mathematics education is being explored across Asia, Europe, Africa, the Middle East, North America, and South America. This pattern suggests that AI-supported mathematics learning is no longer confined to a small group of highly developed education systems. Nevertheless, most countries were represented by only a limited number of studies, making broad generalization difficult. Context remains decisive. Infrastructure, internet access, institutional readiness, curriculum policy, socioeconomic background, and teacher capacity may shape whether AI becomes a meaningful learning support or merely another unevenly distributed digital resource. This finding is consistent with del Olmo-Muñoz et al. (2023), who showed that socioeconomic conditions can influence students' participation in technology- and AI-supported mathematics learning even when access to technology is formally provided. Thus, equity should not be treated as a secondary issue, but as a central condition for interpreting the impact of AI in mathematics education.

In relation to educational level, the reviewed studies were concentrated mainly in primary and secondary education, followed by higher education, teacher-focused studies, and mixed-level contexts. This emphasis on school mathematics is understandable because students at these levels often encounter difficulties in conceptual understanding, procedural fluency, mathematical reasoning, and motivation. AI tools are frequently positioned as supports for hints, feedback, visualization, individualized practice, and problem-solving assistance. However, the relatively smaller number of teacher-focused studies remains an important gap. AI cannot improve mathematics classrooms by itself. Teachers are still needed to evaluate AI-generated responses, connect them with mathematical concepts, design meaningful prompts, identify misconceptions, and prevent students from accepting automated answers uncritically. Studies on AI literacy, AI anxiety, and AI-TPACK confirm that successful AI integration depends on teachers' pedagogical judgment, confidence, and critical awareness (İnci Kuzu, 2026; Xie & Luo, 2026).

One of the clearest findings of this review is the dominance of AI chatbots, generative AI, and large language model-based tools. ChatGPT, Gemini, Microsoft Copilot, MathGPT, and similar tools appeared frequently because they can generate explanations, examples, feedback, and step-by-step assistance. Yet the reviewed evidence also shows that AI in mathematics education is not a single technology. It includes intelligent tutoring systems, adaptive learning platforms, neural networks, machine learning systems, computer algebra systems, dynamic geometry tools, mathematical solvers, image generation tools, social robots, computer vision, and learning analytics. Each tool has a different pedagogical function. Intelligent tutoring systems may support individualized feedback and practice, but Son (2024) cautions that many ITS studies still function at the level of augmentation rather than full transformation. Mathematical solvers and dynamic geometry tools may support verification, representation, and exploration, while generative AI may support dialogue, explanation, and task adaptation. Therefore, future studies should avoid using "AI" as a broad and vague label. Researchers need to explain what type of AI is used, what mathematical purpose it serves, and how it changes students' learning activity.

The mathematical concepts addressed in the reviewed studies were also varied, including geometry, problem solving, algebra, arithmetic, fractions, calculus, mathematical reasoning, and general mathematics pedagogy. Geometry appeared most frequently, followed by problem solving and algebra. This pattern suggests that AI is often applied in mathematical areas requiring visualization, symbolic manipulation, representation, feedback, and step-by-step reasoning. However, many studies still discuss AI at a general instructional level rather than examining how it supports students' understanding of specific concepts. This is a limitation because mathematics learning is content-sensitive. AI support for geometry may not work in the same way as AI support for algebra, fractions, calculus, or word problems. For example, Wardat et al. (2023) found that ChatGPT showed limitations in geometry and misconception correction, while Torres-Peña et al. (2024) emphasized the importance of well-designed prompts and iterative AI interaction in calculus learning. Future research should therefore examine concept-specific learning processes, including misconceptions, representations, proof, reasoning patterns, and long-term conceptual development.

Methodologically, the current evidence remains uneven. Quantitative non-experimental studies and mixed-methods designs were common, while experimental, quasi-experimental, longitudinal, and design-based studies were less frequent. As a result, much of the existing literature is stronger in describing perceptions, readiness, acceptance, and early implementation experiences than in establishing causal effects on mathematics achievement. This finding supports the need to soften claims about AI's impact. Paglialunga and Melogno (2025), for instance, found positive outcomes in AI-based interventions for students with learning disabilities, but also warned that many studies had moderate to serious risk of bias. Similarly, positive findings on AI-supported problem solving, motivation, or critical thinking should be interpreted as promising but context-dependent rather than universally conclusive.

Finally, this review highlights important concerns about overreliance, ethics, inclusion, and human mediation. Mathematics learning requires productive struggle, justification, verification, and independent reasoning. If students use AI mainly to obtain quick answers, they may lose opportunities to develop mathematical understanding. AI-supported mathematics education should therefore be designed to encourage students to question, compare, explain, justify, and reflect.. In inclusive mathematics education, AI may help students with learning difficulties through personalization and affect-aware support, but it must remain human-centered, transparent, and ethically governed (Polydoros et al., 2026). Overall, AI has meaningful potential in mathematics education, yet its value depends on pedagogical design, teacher mediation, mathematical reliability, ethical implementation, and equitable access.

CONCLUSION

This systematic literature review examined 30 studies on artificial intelligence in mathematics education published between 2020 and 2026. The findings show that research in this area has grown rapidly, especially from 2024 onward, alongside the increasing use of generative AI, AI chatbots, large language models, adaptive learning systems, intelligent tutoring systems, automated solvers, robotics, and learning analytics in educational settings. The reviewed studies indicate that AI has been applied across diverse geographical contexts and educational levels, with the strongest attention given to primary and secondary education. AI tools were commonly used to support mathematical explanation, feedback, visualization, problem solving, engagement, teacher readiness, and pedagogical practice. The mathematical topics addressed were also varied, including general mathematics instruction, reasoning, geometry, algebra, fractions, arithmetic, calculus, and conceptual understanding. However, the evidence remains methodologically uneven. Many studies focused on perceptions, readiness, acceptance, or short-term experiences, while experimental, longitudinal, and concept-specific studies were still limited. Therefore, the impact of AI on mathematics education should be interpreted carefully and contextually, rather than as a universal positive effect. Overall, AI shows promising potential to support mathematics teaching and learning, but its value depends on pedagogical design, teacher readiness, accuracy of AI-generated responses, student digital literacy, infrastructure, ethical use, and equitable access. Future research should prioritize stronger intervention designs, long-term classroom studies, deeper analysis of specific mathematical concepts, teacher agency, and the responsible use of AI in mathematics education.

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