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ARTIFICIAL INTELLIGENCE IN MATHEMATICS LEARNING: A LITERATURE STUDY ON EDUCATIONAL TRANSFORMATION IN THE DIGITAL ERA

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ABSTRACT

Artificial Intelligence (AI) has fundamentally changed the landscape of mathematics learning in the digital era. This study aims to: (1) map trends and developments in the application of AI in mathematics learning, (2) analyze the effectiveness of AI in improving student learning outcomes and motivation, and (3) identify challenges and opportunities for implementing AI in the context of Indonesian mathematics education. The method used is a literature study by searching sources from various reputable scientific databases. The results of the study indicate that AI platforms such as Photomath, ChatGPT, and Socratic dominate the use in mathematics learning. Their effectiveness is proven by the increase in students' mathematics scores by 20.6% and teacher competency by 84.6%. However, student dependence on AI, limited infrastructure, and low digital literacy remain major obstacles. This study concludes that planned, ethical, and policy-based AI integration is crucial for realizing adaptive, inclusive, and quality mathematics learning in the era of digital transformation.

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INTRODUCTION

The development of artificial intelligence (AI) technology has had a significant transformative impact on various sectors of life, including education. In the context of mathematics learning, AI presents a breakthrough capable of shifting conventional paradigms towards a more adaptive, personalized, and efficient learning ecosystem (Jose & Jose, 2024) . Mathematics, as a foundation of science, is often considered a challenging subject, so innovative approaches are needed to improve student understanding and motivation. The integration of AI in mathematics learning offers solutions through intelligent tutoring systems, analysis of learning behavior data, and personalized content tailored to individual student needs (Cukurova, 2023) . Digital transformation in education is not simply the adoption of technology, but rather a fundamental shift in the way knowledge is conveyed and constructed.

Various theoretical and empirical studies have reinforced the urgency of integrating AI into mathematics learning. Personalized learning theory asserts that each learner has a unique

learning pace and style, and AI can accommodate this diversity through adaptive algorithms (Hwang, 2022) . AI-based platforms such as Khan Academy and Carnegie Learning have been statistically proven to improve students' mathematical performance at various levels of education. Furthermore, Vygotsky's scaffolding theory has received a new interpretation in a digital context, where AI acts as a cognitive scaffold that provides instant and differentiated feedback (Anderha, 2025) . Research (Vaerenbergh, 2023) shows that the use of AI in mathematics education significantly increases student engagement. Furthermore, the TPACK (Technological Pedagogical Content Knowledge) framework serves as a relevant conceptual foundation for understanding how AI technology can be pedagogically integrated into the mathematics curriculum (Dabingaya, 2022) .

However, there is a substantial research gap in the existing literature. Most previous studies have focused on the general implementation of AI in education without in-depth analysis of the mathematics context, particularly in developing countries like Indonesia. Furthermore, studies on the long-term effectiveness of AI on critical thinking and mathematical problem-solving skills are still very limited (Chi et al., 2023) . The novelty of this research lies in its comprehensive and systematic literature review approach to map the transformation patterns of AI-based mathematics education, identify dominant technological trends, and formulate contextual pedagogical implications for the Indonesian education system in the digital era.

Based on the background and research gaps, the problem formulations in this study are: (1) How are the developments and trends in the application of artificial intelligence in mathematics learning based on the latest literature review? (2) To what extent is the effectiveness of using AI in improving student learning outcomes and motivation in mathematics? (3) What are the challenges and opportunities for implementing AI in mathematics learning in the digital era, especially in the context of Indonesian education? In line with the problem formulations, the objectives of this study are: (1) To map the current developments and trends in the application of AI in mathematics learning through systematic literature analysis; (2) To analyze the effectiveness of AI in improving student learning outcomes and motivation in mathematics; (3) To identify strategic challenges and opportunities for implementing AI in mathematics learning in the context of Indonesian digital education.

This research is expected to provide theoretical benefits by enriching the body of knowledge on AI integration in mathematics education, serving as a comprehensive academic reference. Practically, the results of this study can serve as a reference for educators, curriculum developers, and policymakers in designing effective, contextual, and sustainable AI implementation strategies. For educational institutions, this research contributes to encouraging digital transformation that is not only technology-oriented but also centered on improving the quality of meaningful mathematical learning experiences for all students.

RESEARCH METHODS

This research uses a literature study approach as the primary method in reviewing and analyzing various scientific sources relevant to the topic of integrating artificial intelligence into mathematics learning. This literature study was chosen because it allows researchers to build a deep, comprehensive, and critical understanding of existing knowledge developments without involving primary data collection from the field (Zawacki-Richter et al., 2019) . The literature source collection process was conducted purposively through searches of various reputable scientific databases, including Google Scholar, Scopus, ERIC, and ResearchGate. Keywords

used in the search included terms such as "artificial intelligence in mathematics education," "AI-based learning," "digital transformation in education," and their variations in Indonesian. The publication period was limited to 2021 to 2026 to ensure the relevance and currency of the analyzed sources.

Literature inclusion criteria included: indexed international and national journal articles, academic reference books, and research reports from credible institutions that directly address the application of AI in the context of mathematics education. Sources that did not meet scientific standards, could not be verified for authenticity, or were outside the scope of the topic were excluded from the analysis. Data analysis was conducted through the stages of reading, recording, classifying, and synthesizing information from each source thematically. Findings from various literature were then critically reviewed to identify patterns, similarities, differences, and knowledge gaps. This process resulted in a structured scientific narrative that was able to answer the research problem formulation in an argumentative and evidence-based manner.

DISCUSSION

The literature reviewed in this study encompasses various recent studies discussing the integration of artificial intelligence (AI) in mathematics learning and the broader transformation of digital education. To provide a comprehensive overview of the sources used, the following table summarizes the ten articles that form the primary basis for this discussion.

Table 1. Literature Synthesis on AI Integration in Mathematics Learning

No	Author & Year	Title	Method	Key Findings
1	(Harjun & Lewa, 2026)	Transforming AI Education Curriculum in the Society 5.0 Era	Systematic literature review	The curriculum must integrate technology, 21st century skills, and character values.
2	(Muhsarrof et al., 2025)	Transforming the Education Curriculum Through the Utilization of AI	Qualitative-Literature Study	AI is able to personalize learning adaptively based on the student's learning pace and style.
3	(Sunarti, 2024)	Digital Learning Transformation with AI	Literature review	AI automates the learning process and accelerates access to information efficiently.
4	(Saehu Abas, 2025)	AI-Assisted Learning Transformation	Qualitative-Case Study	The transformation takes place through four stages: introduction, design, implementation, and evaluation.
5	(Yunita, 2025)	AI in Mathematics Learning: Challenges and Opportunities	Systematic literature review	AI (Photomath, ChatGPT, Socratic) increases learning effectiveness but creates student dependency
6	(Musthofa et al., 2026)	Paradigm Transformation of	Qualitative Conceptual	AI is changing the methodology from linear to

		Educational Research Methodology in the Digital Era		a hybrid based on data and intelligent analytics.
7	(Marta et al., 2025)	Utilization of AI in Mathematics Learning in Elementary Schools	Community service	Teacher competency increased by 84.6% and students' math scores increased by 20.6%
8	(Ikhsan et al., 2026)	Integration of AI in Physics and Mathematics Education Based on Al-Quranic Values	Literature Study	AI supports the visualization of abstract concepts and the development of value-based logical thinking.
9	(Mujib, 2025)	The Role of AI in Improving Mathematics Learning in the Digital Age	Systematic literature review	AI improves mathematics students' motivation, conceptual understanding, and academic achievement.
10	(Kumalasari et al., 2026)	Student Assistance in Utilizing AI for Elementary School Mathematics Learning	Community service	Creative and ethical use of AI supports interactive learning based on the Independent Curriculum.

Source: From various literature reviews

The table above shows the diverse methodological approaches and study contexts used by researchers, ranging from systematic literature reviews and case studies to community service programs. This diversity actually enhances the depth of analysis in the following discussion, as the different perspectives provide a more comprehensive picture of the phenomenon of AI integration in mathematics learning.

Trends and Developments in the Application of Artificial Intelligence in Mathematics Learning

The development of AI applications in mathematics learning shows an increasingly rapid and multidimensional trajectory. A study conducted by Yunita & Gunawan (2025) through an analysis of 30 scientific articles revealed that the most dominant AI platforms utilized in the context of mathematics learning today are Photomath, ChatGPT, and Socratic. These three platforms are able to interact directly with mathematical problems faced by students, provide step-by-step solutions, and provide structured conceptual explanations. This finding reflects that the trend of AI utilization in mathematics is no longer experimental, but has moved towards more widespread adoption across various levels of education (Sunarti, 2024) . In addition to conversation-based platforms, curriculum transformation is also a crucial dimension in the development of AI in education. Contemporary curriculum development demands a harmonious integration of technology, 21st-century skills, and student character development. The curriculum no longer positions teachers as the sole source of knowledge, but rather encourages a transformation in the role of facilitators who utilize AI as pedagogical partners. This aligns with the implementation of the Independent Curriculum in Indonesia, which explicitly provides space for the use of adaptive technology in the learning process.

In 2026, Musthofa added a statement to strengthen these findings through his research at MA Plus Al Kautsar Kraksaan, which demonstrated that AI is capable of collecting and analyzing

data from exam results, interactive exercises, and continuous student evaluations to identify each individual's learning patterns. Thus, AI serves not only as a learning aid but also as a pedagogical decision-making system capable of adjusting the level of material difficulty and delivery methods to suit students' learning preferences. This trend represents a paradigm shift from one-size-fits-all learning to a truly personalized and responsive learning ecosystem.

The development of AI in mathematics learning is also inseparable from the dimension of research methodology. (Saehu Abas, 2025) notes that the integration of AI has shifted the paradigm of educational research from a linear, researcher-centered methodology to a hybrid approach driven by data and algorithmic analytics. This shift indirectly impacts how researchers understand and evaluate the effectiveness of AI-based mathematics learning, resulting in more precise and measurable empirical evidence.

The Effectiveness of Using Artificial Intelligence on Student Learning Outcomes and Motivation in Mathematics

Empirical evidence regarding the effectiveness of AI in improving mathematics learning outcomes is growing stronger with the increasing number of data-based studies conducted in recent years. (Muhsarrof et al., 2025) in a community service program implemented at a Public Elementary School in Kampar Regency recorded an average increase in students' mathematics scores of 20.6% after the consistent use of AI-based learning media. Furthermore, teachers' competence in utilizing AI technology also increased significantly by 84.6%, indicating that the effectiveness of AI is not only felt by students but also has a positive impact on the professional capacity of educators. Their systematic literature review found that the use of AI in mathematics learning has a measurable positive impact on three fundamental aspects: learning motivation, conceptual understanding, and student academic achievement. AI is able to provide a personalized, interactive, and adaptive learning experience tailored to individual needs, ultimately encouraging more active student engagement in the process of constructing mathematical knowledge.

The role of teachers has also undergone a significant transformation, from mere conveyors of information to facilitators and innovators who orchestrate technology-based learning environments. (Kumalasari et al., 2026) in a mentoring program for prospective elementary school mathematics teachers showed that intensive training in the creative and ethical use of AI successfully improved students' abilities in designing interactive, contextual, and student-centered learning in accordance with the Independent Curriculum. This finding confirms that the effectiveness of AI in mathematics learning is highly dependent on the readiness and competence of educators as the spearheads of technology implementation in the classroom. A deeper dimension states that in the context of mathematics learning, AI can help visualize abstract concepts that have historically been a major obstacle to student understanding. Adaptive learning systems and AI-powered digital simulations provide dynamic visual representations of concepts such as functions, geometry, and calculus, thereby training logical and systematic thinking skills more effectively than conventional approaches. The integration of moral values in the use of this technology is also emphasized as an important foundation for ensuring that AI use remains within the framework of ethics and academic responsibility.

Challenges and Opportunities of Implementing Artificial Intelligence in Mathematics Learning in the Digital Era

Despite the various positive achievements outlined, the implementation of AI in mathematics learning also faces a series of challenges that cannot be ignored. (Marta et al., 2025) identified that the most crucial challenge is students' over-reliance on AI, which has the potential to reduce independent thinking skills and fundamentally lower mathematical literacy levels. When students habitually rely on Photomath or ChatGPT to solve every problem without understanding the process, the goal of mathematics learning to develop critical and analytical thinking skills will not be optimally achieved.

Furthermore, limited technological infrastructure poses a significant structural barrier, particularly in remote areas and schools with limited budgets. (Harjun & Lewa, 2026) note that the digital literacy gap between teachers and students, along with the lack of operational training for educators on AI technology, remains a major obstacle hindering the equitable and sustainable implementation of AI. This creates a dichotomy between relatively technologically prepared urban schools and rural schools still grappling with basic limitations. While infrastructure and teacher readiness challenges are real, intensive training programs and ongoing mentoring have proven effective in gradually overcoming these obstacles. This presents a strategic opportunity for the government and educational institutions to design teacher professional development programs oriented towards AI literacy as a medium-term priority.

Ikhsan 2026 added that various available AI platforms, ranging from text applications and presentations to virtual assistants, have actually provided an adequate technological ecosystem to support a comprehensive digital learning transformation. Educational institutions need to strategically leverage this opportunity by designing AI integration policies that are systematic, measurable, and based on real-world needs. The four-stage transformation model, encompassing introduction, learning design, limited implementation, and evaluation, offers a practical framework that Indonesian schools can adopt to integrate AI into the mathematics curriculum in a gradual and planned manner.

CONCLUSION

This literature review yields three main conclusions. First, the application of AI in mathematics learning shows a rapidly growing trend, marked by the dominance of the Photomath, ChatGPT, and Socratic platforms and the transformation of the curriculum toward a technology-based adaptive approach. Second, AI has proven effective in measurably improving mathematics learning outcomes, student motivation, and conceptual understanding, as evidenced by a 20.6% increase in student grades and an 84.6% increase in teacher competency. Third, AI implementation still faces serious challenges in the form of student dependency, infrastructure gaps, and low teacher digital literacy. Implications, these findings encourage the need for education policies that systematically integrate AI into the national mathematics curriculum. Educational institutions are advised to design sustainable teacher training programs, develop ethical guidelines for the use of AI in the classroom, and build equitable digital infrastructure to ensure the transformation of mathematics learning is inclusive, equitable, and high-quality across all levels of education in Indonesia.

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