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AI in mathematics education: Potential ranging from automation to personalized learning

Alifia Kania Ramadhani[1)*], Iqbal Ramadani[2)]
[1) 2)] Mathematics Education, Sunan Kalijaga State Islamic University, Yogyakarta, Indonesia
*alifiakania333@gmail.com

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Abstract

The rapid development of artificial intelligence (AI) is reshaping many aspects of education, yet its meaningful contribution to mathematics instruction and student learning outcomes remains underexplored. Understanding how AI can enhance mathematical thinking, problem-solving, and personalized learning is critical in preparing students for future competencies. One of the challenges in learning mathematics is how to make it relevant to the times. One emerging approach was using artificial intelligence (AI) in mathematics education. Based on a literature review, this study aimed to explore and describe the potential of artificial intelligence (AI) in mathematics education. The method used was a literature review with a narrative design. Literature searches were conducted through reputable international sites such as Scopus, ScienceDirect, Springer, and World Scientific, with English keywords and years from 2015 to 2025. The collected literature was thematically analyzed to identify key themes such as AI usage trends, AI development potential, and implementation challenges. The results indicated that AI was increasingly used in mathematics education, particularly in various AI-assisted instructional tasks. Further potential in AI shows promise in personalizing learning and automating tasks, though challenges remain. In conclusion, AI is promising to transform mathematics education through adaptive, individualized, and data-informed learning approaches. However, its success depended on careful planning, teacher readiness, ethical frameworks, and alignment with educational goals and local contexts. These findings underscored the need for further research and context-specific development to ensure AI's effective and equitable integration into mathematics learning environments.

Keywords: Artificial intelligence, Mathematics education, Literature review, Learning innovation.

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INTRODUCTION

Technological transformation has driven various innovations that contribute to increased efficiency and productivity, one of which is through the development of artificial intelligence (AI). However, amid the benefits offered, there are also various concerns, among them is related to the low motivation to think independently. Deputy Minister of Higher Education, Science and Technology Stella Christie said that despite the Large Language Model (LLM) and other AI technologies, the responsibility for thinking and creating remains with humans. She also said that the presence of AI can be a push factor for us to be more productive and creative in

producing work (Loamy, 2024). In addition, UGM Faculty of Law Lecturer, Dina W. Kariodimedjo, PhD, stated that excessive use of ChatGPT can potentially trigger plagiarism that violates academic ethics and can provide answers that are not always accurate (Savitri, 2023). Nevertheless, with wise utilization, artificial intelligence or AI can make positive contributions in various fields, including education, research, and industry, by increasing efficiency, creativity, and access to wider information.

Along with its rapid development, there are many examples of AI development globally in various fields, including industry, healthcare, business, and education. In the pharmaceutical industry, for example, AI plays a role in optimizing production processes, accelerating drug discovery, and supporting data-driven marketing strategies (Dubey & Yadav, 2024). In the health sector, this technology can improve the accuracy of disease diagnosis through advanced medical visualization techniques (Eşer, Duman, Bayrakdar, & Çelik, 2023). Another example from the research by (Gonçalves, Spaniol, Rowland, & Rytter, 2025) in chatbot development, utilizing prompt engineering, students and faculty developed a chief operating bot (COB) that replicates the role of a chief operating officer (COO), using industry-specific documents to support exploratory question and answer sessions in a secure learning environment. The industrial and healthcare fields have widely utilized AI to improve efficiency and accuracy. Meanwhile, AI development in education is still applied to university-level learning oriented towards work readiness and has not been widely optimized to support learning processes at various levels.

Nevertheless, interest in artificial intelligence (AI) among students at other levels of education, especially secondary education, is beginning to emerge. An analysis of research conducted by (Hermila, Bouty, & Bau, 2024) shows that 83% of students found the learning experience enjoyable and felt helped when using ChatGPT, while 76% of them rated the content as appropriate for their learning needs. Interestingly, 68% of students also expressed interest in continuing to use ChatGPT in their learning process. These findings indicate the great potential for integrating AI-based technology into learning activities in a broader and more targeted manner. This is supported by the growing use of technology in various schools in Indonesia (Supianti, 2018). The availability of computer labs and internet access in many secondary schools also supports the readiness of infrastructure to support technology-based learning.

In addition, the utilization of AI in education still tends to be limited to models that have been commonly used, such as conversational AI, including chatbots and virtual assistants. There is research on the integration of digital transformation in the educational environment,

one of which highlights the importance of technology in improving character development (Nofridasari & Hidayati, 2023). AI chatbots or virtual assistants can be utilized to guide and answer student questions about subject matter flexibly, anytime, and anywhere (Fahrudin, Sollikhin, & Masruroh, 2024). The use of AI is expected to improve the efficiency and effectiveness of teachers' tasks, including in the preparation of teaching materials and learning evaluation (Pujiono, Prayogi, Shofiani, Yuliyanti, & Iskarim, 2024). However, while AI has shown benefits in supporting teachers' tasks and improving students' learning experience, the development of AI that can facilitate hands-on learning is still lacking.

In this context, it is important to take a closer look at the application of AI in subjects that have a strategic role in developing students' mindsets. One of the subjects that is considered as a good means to train, equip, and support the development of students' mindset is mathematics. In (Permendikbud Number 21 Year, 2016), it is stated that mathematics lessons aim to instil students' skills with logical, analytical, systematic, critical, and creative skills. Mathematics plays a role in helping students develop the ability to think logically and analytically, solve problems in a structured manner, and express ideas clearly and effectively (NCTM, 2000). Mathematics is a strategic subject for developing students' mindset because it emphasizes logic, analysis, and problem solving. Therefore, the application of AI in mathematics learning is very relevant to be studied more deeply.

This study is grounded in the TPACK (Technological Pedagogical Content Knowledge) framework (Mishra & Koehler, 2006), which highlights the importance of integrating technology in education through a balanced consideration of content knowledge, pedagogical strategies, and technological tools. In the context of mathematics education, AI offers opportunities to enrich teaching and learning by enabling adaptive feedback, fostering visualization of abstract mathematical concepts, and supporting differentiated instruction. Furthermore, the study adopts a constructivist learning perspective (Liu & Matthews, 2005; Schunk, 2012), which emphasizes that learners construct their own understanding through active engagement and interaction. AI-powered tools, when thoughtfully integrated, can create interactive and personalized learning environments that align with constructivist principles, supporting mathematical problem solving and critical thinking. These frameworks collectively guide the analysis of how AI can contribute meaningfully to mathematics education.

AI has great potential to support the process of developing students' thinking through various approaches, such as adaptive learning, instant feedback, problem recommendation systems tailored to students' abilities, and visualization tools for abstract concepts. Along with

technological advances, further exploration of AI development, implementation, and integration in education, especially in mathematics education, is becoming increasingly relevant. Although there have been many studies discussing the potential of artificial intelligence in education in general, studies specifically highlighting its application in mathematics learning are still limited (Akinwalere & Ivanov, 2022; Cope, Kalantzis, & Searsmith, 2021; Yulianti, Benardi, Permana, & Wijayanti, 2023). Therefore, this study focuses specifically on identifying and examining in greater depth how AI can be developed and implemented appropriately in the context of mathematics learning. The novelty of this study lies in its emphasis on the use of AI to support the development of students' thinking skills through approaches such as adaptive learning, instant feedback, ability-based question recommendation systems, and visualization of abstract concepts. This research is expected to contribute to enriching the literature on the potential of AI in mathematics education and the results of this research are expected to be a reference in developing a more effective mathematics learning system supported by AI.

RESEARCH METHODS

This study is qualitative research with literature review method and narrative review design. Narrative review was chosen as a form of literature review that focuses on summarizing and analysing various sources without following strict systematic procedures as in systematic reviews (Green, Johnson, & Adams, 2006). The literature review research procedure in this research is based on (Cresswell & Poth, 2023). Literature review steps as presented in Figure 1 with the following description.

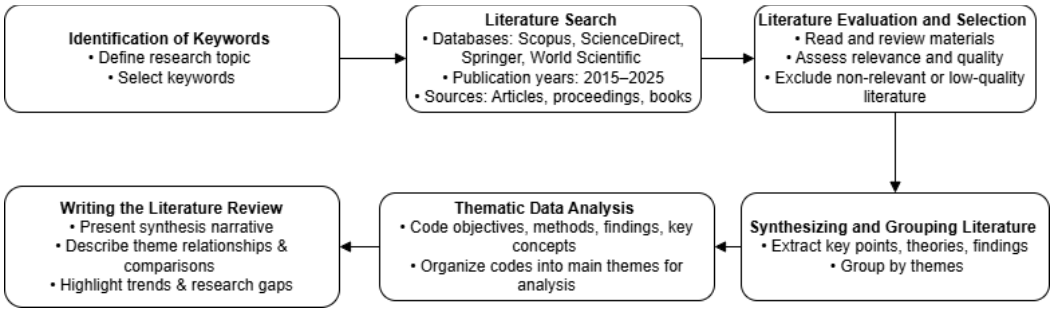

Figure 1. Research Procedure of the Study

Identification of keywords, the researcher will select study topics that are relevant to the research title, especially those related to artificial intelligence (AI) in mathematics education. At the initial stage, the researcher determines the main keywords that will be used in the literature search. The aim was to ensure that the literature searched was relevant to the research

topic, namely the development of artificial intelligence (AI) in mathematics education. The keywords used included “development”, “implementation”, “integration”, “mathematics education”, and “artificial intelligence”.

The literature search was conducted through reputable international websites such as Scopus, ScienceDirect, Springer, and World Scientific. The selection of international websites was based on the fact, that most of the articles relevant to the research topic came from these sources. The search was limited to articles, proceedings, and books published years between 2015-2025 to ensure that the literature reviewed reflected the most recent and relevant developments in the fields of artificial intelligence (AI) and mathematics education. AI technology is evolving rapidly, so recent articles are better able to illustrate innovations, implementations, and challenges.

Literature evaluation and selection, the researcher will read and review in depth each of the collected materials to understand the basic concepts and theories. The focus of the assessment is on the relevance to the topic of AI development in mathematics education, the quality and credibility of the sources, such as articles from reputable journals. In addition, literature that is not relevant to the research objectives will not be analysed further.

Synthesizing and grouping the literature, the literature that has passed the selection will be synthesized by noting important points, theories, concepts, approaches, and related findings. Then grouping the literature based on the theme or focus of the discussion, such as trends in the use of AI, the potential for AI development, and the challenges of AI development in mathematics education. This step was useful to see patterns and connections between studies and to prepare the ground for analysis and conclusions. The literature review referred to approximately 18 scientific articles relevant to the topic, which were selected based on their relevance to the research objectives.

Thematic data analysis, by identifying, categorizing, and interpreting the main themes that emerged from the literature reviewed. The thematic analysis stage began with a thorough reading of the literature to gain an initial understanding. Next, important sections, such as objectives, methods, findings, and key concepts from each article were coded. The codes were subsequently organized into pertinent themes that described in the previous step.

Writing the literature review, the results of the thematic analysis were then presented in the form of a synthesis narrative as outlined in the literature review section. This narrative describes the relationships between themes, comparisons between studies, and general trends in AI development in mathematics education. The author will present a critical summary of the

reviewed literature. Furthermore, it shows research gaps that can be used as a basis for further research.

RESULTS AND DISCUSSION

This section presents and discusses the findings of the study based on an analysis of 18 selected documents. A summary of these findings is provided in Table 1.

Table 1. Research Findings

No	Author(s), Year	Title	Document Type	Publication Title
1	(Hwang, Flavin, & Lee, 2023)	Exploring Research Trends of Technology Use in Mathematics Education: A Scoping Review Using Topic Modelling	Article	Education and Information Technologies
2	(al Darayseh & Mersin, 2025)	Integrating Generative AI into STEM Education: Insights from Science and Mathematics Teachers	Article	International Electronic Journal of Mathematics Education
3	(Djajasoepena et al., 2024)	Utilization of Artificial Intelligence to Support the Development of Teaching and Project Modules	Article	Journal of Community Services: Sustainability and Empowerment
4	(Flavin, Hwang, & Morales, 2025)	"Let's Ask the Robot!": Epistemic Stance Between Teacher Candidates Toward AI in Mathematics Lesson Planning	Article	Journal of Teacher Education
5	(Rizos, Foykas, & Georgakopoulos, 2024)	Enhancing Mathematics Education for Students with Special Educational Needs Through Generative AI: A Case Study in Greece	Article	Contemporary Educational Technology
6	(Smolić, Pavelić, Boras, Mekterović, & Jagušt, 2024)	LLM Generative AI and Students' Exam Code Evaluation: Qualitative and Quantitative Analysis	Proceeding	2024 47th MIPRO ICT and Electronics Convention (MIPRO)
7	(Park & Son, 2024)	Exploring the Functionality and Utilization Potential of ChatGPT-4o in Mathematics Education: Focusing on 7th-Grade Mathematics	Article	Korean School Mathematics Society
8	(Mishra, Oster, & Henriksen, 2024)	Generative AI, Teacher Knowledge, and Educational Research: Bridging Short and Long-Term Perspectives	Article	TechTrends
9	(Martínez, Garcia-Haro, Monje, & Balaguer, 2019)	Development of Applications for Humanoid Robots Using Multiple Platforms, Tools, and Cloud Data Sharing	Article	International Journal of Humanoid Robotics

No	Author(s), Year	Title	Document Type	Publication Title
10	(Fushimi et al., 2025)	Development of The Autonomous Lab System to Support Biotechnology Research	Article	Development of the autonomous lab system to support biotechnology research
11	(Sekara et al., 2024)	The Opportunities, Limitations, and Challenges in Using Machine Learning Technologies for Humanitarian Work and Development	Article	Advances in Complex Systems
12	(Bewersdorff et al., 2025)	Taking the Next Step with Generative Artificial Intelligence: The Transformative Role of Multimodal Large Language Models in Science Education	Article	Learning and Individual Differences
13	(Muawanah, Marini, & Sarifah, 2024)	The Interconnection Between Digital Literacy, Artificial Intelligence, and The Use of E-Learning Applications in Enhancing the Sustainability of Regional Language: Evidence from Indonesia	Article	Social Sciences & Humanities Open
14	(Laksana & Fiangga, 2022)	The Development of Web-Based Chatbot as a Mathematics Learning Media on System of Linear Equations in Three Variables	Article	MATHEdunesa
15	(Welleck, Liu, Lu, Hajishirzi, & Choi, 2022)	NATURALPROVER: Grounded Mathematical Proof Generation with Language Models	Proceeding	A 36th Conference on Neural Information Processing Systems (NeurIPS 2022)
16	(Wulff, Kubsch, & Krist, 2025)	Applying Machine Learning in Science Education Research: Chapter Natural Language Processing and Large Language Models	Book Chapter	Applying Machine Learning in Science Education Research
17	(Wahyudin, Riza, & Putro, 2018)	Development of Cyberblog-Based Intelligent Tutorial System to Improve Students Learning Ability Algorithm	Proceeding	Journal of Physics: Conference Series
18	(Daineko et al., 2024)	Development of the Software Agent «AIA» in The Framework of IITU MetaUniversity Design	Proceeding	Procedia Computer Science

The data were systematically coded and categorized into several key themes that reflect current practices and perspectives on the use of artificial intelligence (AI) in mathematics education. These themes include trends in the use of AI in mathematics education, the potential

for AI development in the field, and the challenges and barriers associated with its implementation. The following discussion elaborates on each of these themes.

Trends in the Use of AI in Mathematics Education

The development of artificial intelligence (AI) in education is showing an increasing trend, with various implementations starting to be seen in the context of mathematics learning (Hwang et al., 2023). The success of AI implementation in education is not only determined by the availability of technology, but also by the readiness and perception of educators as the main users. A study in Turkey showed that STEM teachers generally showed a positive attitude towards the use of AI in the teaching and learning process. However, there was a difference in the level of self-efficacy between male and female teachers in the use of technology, indicating a gender gap in comfort with AI (al Darayseh & Mersin, 2025). This finding is in line with the research of (Mishra et al., 2024) who confirmed that teachers' perceptions and digital competencies have a significant influence on the successful adoption of new technologies in the classroom. In the context of mathematics education, many current applications of AI focus on using readily available AI models to assist in the development of learning materials. This trend can be seen in the use of ChatGPT to develop learning modules and math lesson plans (Djajasoepena et al., 2024; Flavin et al., 2025). An interesting implementation was also seen in Greece, where ChatGPT 3.5 was used to create math worksheets tailored to the needs of students with special needs (Rizos et al., 2024).

In addition to material development, AI has also begun to be utilized in the evaluation of mathematics learning outcomes. Generative AI based on Large Language Models (LLM) has been used to assist automated assessment in education, although its ability to evaluate mathematical codes or expressions is still not fully accurate (Smolić et al., 2024). ChatGPT, for example, was able to provide fairly precise responses at the problem understanding and strategy exploration stages, but still showed inconsistencies at the execution and reflection stages, depending on the type and number of student errors (Lee, Shin, Park, Kim, & Lee, 2024). Other studies have shown ChatGPT can analyse student errors based on material characteristics and improve answer accuracy through prompt engineering, although its effectiveness is still limited to identical problems (Park & Son, 2024).

While these trends indicate the widespread adoption of AI in mathematics education, there are significant gaps that need to be addressed. Most implementations still focus on using generic AI models (such as ChatGPT) without modification or development specific to mathematics learning. These models, despite their impressive capabilities, have not been

optimized to meet specific needs in mathematics teaching and learning, such as visual representation of mathematical concepts, theorem proving, or in-depth analysis of students' mathematical reasoning.

Potential for AI Development in Mathematics Education

Based on recent research, the potential for AI development in mathematics education shows promising directions for improving the quality of learning. Several recent research articles have identified several development opportunities that can address gaps in current mathematics learning practices.

Personalization of Learning

The dominant potential is the development of AI-based adaptive learning systems in mathematics learning. As shown in several studies (Muawanah et al., 2024; Wulff et al., 2025), AI technology can customize learning content to the individual needs of students. AI can identify students' learning patterns, misconceptions, and level of mastery of certain mathematical concepts, and then present materials that suit their needs. This is particularly important in the often-hierarchical nature of mathematics learning, where understanding basic concepts is a prerequisite for more complex concepts.

Development of AI Models in Competency Improvement

Furthermore, the development of AI models specifically for problem solving and mathematical proof has great potential. (Welleck et al., 2022) has demonstrated through Natural Prover that AI can generate proofs for certain theorems and suggest relevant next steps. Such a model can be integrated with background references such as relevant theorems and definitions, making the resulting proofs more accurate and based on existing knowledge. This research provides a strong foundation for further development of more specific AI models that can be integrated in the context of mathematics learning.

The development of specialist chatbots on specific mathematics materials also has potential in developing students' cognitive and affective competencies. (Laksana & Fiangga, 2022) has demonstrated the implementation of a chatbot for the topic of linear equations that allows students to learn independently. Further development of this kind of chatbot to cover a wide range of math topics with more in-depth capabilities could provide more comprehensive learning support.

The focus on improving logical thinking is very much in line with the characteristics of mathematics learning, which demands reasoning, deduction, and inference. Research by (Wahyudin et al., 2018) explains that the development of cyberblogs based on intelligence

tutorial systems can improve student learning abilities in understanding algorithms. Based on this research, it can potentially be applied to mathematics learning, specifically in solving math problems in stages.

Support for Teachers

Another potential development is advanced algorithm-based learning optimization. (Fushimi et al., 2025) demonstrated the use of Bayesian optimization algorithms in scientific experiments, a concept that can be adapted for mathematics learning. This approach can be used to create an optimal math learning path based on student performance data, where the difficulty level and type of questions are adjusted according to student ability. Thus, AI can assist teachers in designing appropriate assessments that are based on student data analysis and tailored to the mathematics material being taught.

Integration in Learning

The integration of multimodal technologies in mathematics learning is another potential direction of development. (Bewersdorff et al., 2025) proposes a theoretical framework for multimodal AI integration that can integrate text, images, and interaction in learning. Given the nature of mathematics, which often relies on visual and symbolic representations, the development of AI that can explain mathematical concepts visually and textually will greatly assist students in understanding abstract concepts in mathematics learning.

Challenges and Barriers to AI in Mathematics Education

A review of the literature shows that the development and application of AI in mathematics education still faces several complex challenges and obstacles. These challenges can be categorized into several main aspects:

Technical and Infrastructure Constraints

Often AI-related media require adequate or supportive tools for learning to run smoothly. Studies such as (Martínez et al., 2019) and (Daineko et al., 2024) show that implementing advanced technologies (such as AI based on humanoid robots or VR/AR) requires expensive and complex technical infrastructure, which is not always available in primary and secondary education institutions. Reliance on middleware, cloud, and other technical resources is a barrier. This reliance makes it difficult for educational institutions that have limited access to stable internet networks or adequate hardware. In many regions, inadequate technology infrastructure makes access to cloud-based AI services suboptimal.

Ethical Issues and Privacy Risks in AI Implementation

Ethical issues and data security are important concerns. (Sekara et al., 2024) and (Wulff et al., 2025) warn that the use of AI without clear ethics could exacerbate educational disparities and risk students' privacy. There was discussion on how biases in the data as well as injustices embedded in the algorithm can exacerbate existing social and educational inequalities (Sekara et al., 2024). Moreover, the use of AI models developed and managed by private companies often lacks transparency, while student interaction data is often sent to the companies, raising privacy concerns as well as the potential for excessive private domination of the education sector (Wulff et al., 2025).

Concerns About the Dependability of AI Systems

In addition, many studies (Bewersdorff et al., 2025; Welleck et al., 2022) highlight the risk of student and teacher dependence on automated solutions, which can reduce human interaction and flexibility of thinking in mathematics learning. AI can help students diagram story problems and provide automated solution steps. However, suppose students follow the automated solution without understanding each step. In that case, they risk feeling passive and losing the ability to solve problems independently outside the context that the AI has programmed (Bewersdorff et al., 2025). As these systems are still in the development stage and the results produced need to be interpreted cautiously, over-reliance on them may hinder active human involvement in the learning process and reduce the quality of educational interaction (Welleck et al., 2022).

Limitations of AI in Handling Complex Mathematical Cognitive Problem

Current AI still has difficulties in understanding abstract concepts, thinking strategically, and guiding students personally in mathematical contexts. (Wulff et al., 2025) and (Welleck et al., 2022) indicated that AI's ability to provide intuitive reasoning, give step-by-step instructions, and adapt to students' learning styles remains limited. Challenges related to the length of the proof process and the accumulation of errors show that current AI models still struggle to maintain accuracy when faced with increasingly complex and lengthy evidence (Welleck et al., 2022). LLMs often face challenges in verifying each mathematical step in a structured manner, and tend to produce erroneous or inconsistent answers when tackling problems that are complex and require deep reasoning (Wulff et al., 2025).

CONCLUSIONS

This literature review has synthesized findings related to the potential of AI in mathematics education, such as key trends, opportunities for development, and several critical barriers that must be addressed for effective implementation. This literature review has explored the development, implementation, and integration of artificial intelligence (AI) in mathematics education. The findings highlight that AI holds strong potential in supporting personalized learning, developing mathematical problem-solving tools, and enhancing classroom practices through multimodal integration. However, challenges such as technical limitations, ethical concerns, and the gap in AI's ability to process abstract mathematical reasoning remain significant. Future development should prioritize context-specific models tailored to mathematical content, including visual representation, reasoning support, and adaptable scaffolding for learners to ensure the effective use of AI in mathematics learning. Collaborative efforts between educators, AI developers, and curriculum designers are crucial to align technological advances with pedagogical goals. This study is limited by its focus on literature from international journals, which may not fully capture Indonesia's unique educational contexts and technological readiness. Therefore, further research is recommended to examine local perspectives, including the readiness of Indonesian educators, infrastructure constraints, and culturally relevant applications of AI in math classrooms.

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