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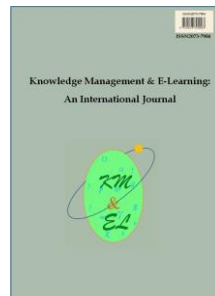
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Evaluating the impact of artificial intelligence in mathematics education: A systematic literature review

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Abstract: Artificial Intelligence (AI) as a representation of technological advancement, has been recognized for its potential to positively and negatively impact the educational sphere. In mathematics education, AI revolutionizes learning by offering students more flexible and adaptive learning experiences. This study aims to provide insights into the impact of AI integration in

mathematics education through a systematic literature review (SLR). The primary focus of this research includes trends in AI usage based on year, country, and education level, types of AI integration, and the impacts and challenges encountered in implementing AI in mathematics learning. The research data comprises empirical articles collected using the PRISMA approach, drawing from databases such as Scopus, ERIC, and SAGE over the past five years. This results in the analysis of 13 selected articles. The findings reveal dynamic trends in AI utilization, particularly in Indonesia and Australia. In Indonesia, AI is primarily used to expand access to online education, while in Australia, it is leveraged for personalized learning. AI is predominantly integrated at the middle school and university levels, with ChatGPT as the primary tool to assist students in understanding mathematical concepts. The benefits of AI include improvements in cognitive, affective, and teaching abilities. The challenges of AI identified include low user awareness, limited educator skills, cognitive impacts on students, and technological access disparities that exacerbate educational inequalities.

Keywords: Artificial intelligence; Educational technology; Mathematics education; Systematic literature review

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1. Introduction

Technological advancements in recent years have significantly impacted education (Ghory & Ghafory, 2021; Hammada, 2024; Raja & Nagasubramani, 2018). Technology integration in education has enabled more flexible and adaptive learning approaches for students to learn at their own pace and style (Ajani, 2024; Castro, 2019; Gligorea et al., 2023). Online platforms and adaptive learning software facilitate self-directed learning to enhance students' skills and academic performance (Kim et al., 2014; Muhaimin et al., 2023; Muhaimin & Juandi, 2023). Furthermore, studies show that these technologies enable more efficient information transmission between teachers and students and improving communication and resource access (Vasiljevic-Prodanovic et al., 2017). This ease of access promotes better collaboration and facilitates broader dissemination of learning resources (Ghory & Ghafory, 2021). In addition to supporting students' learning outcomes, technology benefits educators by simplifying the management of learning materials (Baek et al., 2008) to provide real-time feedback (Hooda et al., 2022; Omamo et al., 2022; Porter & Grippa, 2020) and enabling the development of more interactive and engaging teaching (Kholid et al., 2023; Muhaimin et al., 2025a; Pahmi et al., 2023). Technology has positively influenced education systems by advancing student progress, supporting teachers, and enhancing material management.

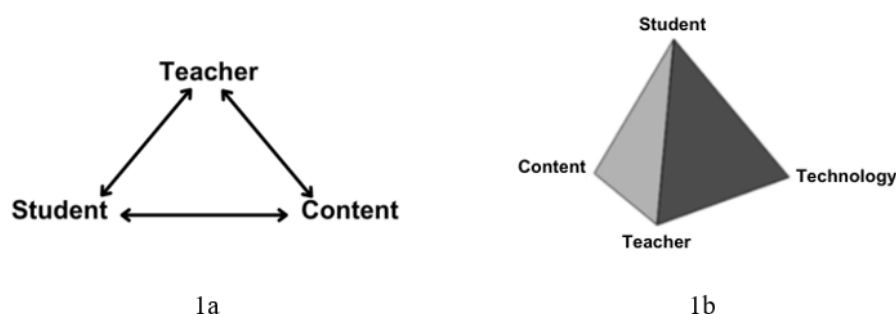


Fig. 1. The didactic triangle framework (1a) and tetrahedron framework (1b)

In traditional education, the learning process is characterized by the interaction between educators, learners, and content, a framework known as the didactic triangle theory (Goodchild & Sriraman, 2012; Straesser, 2007). This model emphasizes the importance of direct interaction among these three components, where educators are the primary link between content and learners (see Fig. 1a). However, with the advancement of technology, educational paradigms are transforming. The didactic triangle has evolved into the didactic tetrahedron (Olive et al., 2009; Ruthven, 2012), where technology appeared as a fourth independent element equivalent to educators, learners, and content (see Fig. 1b). In this model, technology functions as a supporting tool and an entity capable of independent and direct interaction with the other components (Liu & Buchbinder, 2024). Meanwhile, AI, as a cutting-edge representation of technology in education, exemplifies this transformation. Digital integration through AI has reshaped how students learn and how educators teach. AI is used to personalize learning experiences (Tiwari, 2023) and to provide instant feedback (Chan & Colloton, 2024) to assist teachers in designing more adaptive teaching strategies (Kim et al., 2022).

The presence of AI in mathematics education requires careful attention. While AI offers numerous benefits, its imprudent application could potentially cause inequalities in learning processes and reduce the effectiveness of students' knowledge construction

(Dasari et al., 2024). This concern arises because mathematics, as an a priori discipline, often involves abstract concepts and demands deep logical reasoning (Waxman, 2021). Understanding mathematical concepts requires a posteriori knowledge, which relies on concrete experiences and real-world understanding (Pritchard, 2018). AI systems often provide direct answers without adequately explaining the underlying logic or processes (Dasari et al., 2024). According to Plato's theory of knowledge construction, "*justified true belief*" is necessary, meaning information must be true and justified to be considered valid knowledge (Pritchard, 2018). Consequently, there is a risk that AI-driven knowledge construction may not facilitate epistemic justification, thus, in the end, hindering students' ability to develop a deep understanding (Dasari et al., 2025; Hendriyanto et al., 2024; Sahara et al., 2025; Suryadi, 2019).

This study conducted a comprehensive systematic literature review to evaluate the impact of AI integration in mathematics education. It explored how AI impacts student learning outcomes, knowledge construction, and challenges associated with its implementation. The novelty of this study lies in several key aspects. First, unlike Nurwahid & Ashar (2024), who focused only on potential uses of AI – such as personalization, assessment, tutoring, and game-based learning – this study offers a broader evaluation of the actual impact of AI. Meanwhile, our study analyses trends by publication year, country, and education level, and identifies the most commonly used types of AI. Moreover, our study also specifically examines the impacts and challenges of AI integration and provides practical recommendations for optimizing its use – an area that has not been explored in depth by previous studies. This study differs from Mohamed et al. (2022), who emphasized AI approaches, research distribution by country, methodology, publication trends, and emerging themes. Instead, the focus is on specific types of AI used in mathematics education, their impacts and challenges, and presents actionable strategies for effective implementation. This systematic review offers a comprehensive and focused investigation that directly answers the following research questions.

RQ1: What are the trends in AI usage in mathematics education (in terms of year, country, and educational level)?

RQ2: What types of AI integration are used in mathematics education?

RQ3: What are the benefits and challenges of AI integration in mathematics learning?

2. Method

2.1. Type of research

This study is a Systematic Literature Review (SLR) aimed at providing a comprehensive overview of the integration of AI in mathematics education. According to Moher et al. (2009), systematic reviews address formulated research questions through a series of steps that involve collecting, analysing, and evaluating data from relevant studies. This process includes identifying, selecting, and evaluating studies that align with the topic. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) approach is selected as a systematic method for reviewing and selecting articles. PRISMA was chosen as it offers a clear and structured procedure for selecting articles to be used as research data.

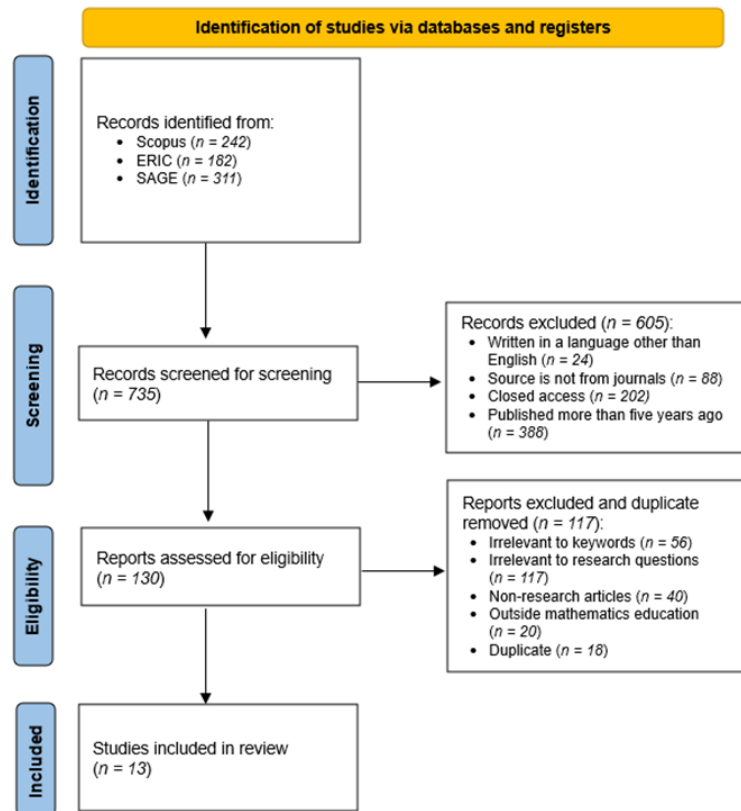


Fig. 2. PRISMA flowchart

2.2. Articles selection process

The article selection process in this study follows the PRISMA flow. According to Moher et al. (2009), PRISMA encompasses several selection stages: identification, screening, eligibility, and inclusion. These stages help ensure that the articles chosen are relevant to the research topic. Fig. 2 visualizes the systematic review process using PRISMA in this study.

2.2.1. Identification

This initial stage involves filtering articles, starting with the determination of relevant keywords and the search for articles in journal databases. The keywords used to search for articles are (“*Artificial Intelligence*” OR “*AI*”) AND (“*Mathematics Education*” OR “*Mathematics Learning*” OR “*Mathematics Teaching*”). The search was conducted using three main databases: Scopus, ERIC, and SAGE, which were chosen because these journal databases maintain high-quality article standards and focus on education. The search was conducted in the fields of “*article title, abstract, and keywords*” to ensure the retrieval of articles directly related to the research topic. The article review process was conducted in the ninth month of 2024. At this stage, a total of 735 articles were retrieved, with 242 articles from Scopus, 182 articles from ERIC, and 311 articles from SAGE.

2.2.2. Screening

After identifying the articles, the next step is establishing inclusion and exclusion criteria to select articles for research data. At this stage, the primary focus is on assessing the external aspects of the articles rather than their content. The inclusion criteria include articles written in English, sourced from journals, and available as open access. The focus on open-access articles was due to institutional access limitations, ensuring that all selected articles could be fully reviewed and transparently referenced. Additionally, the selected articles are limited to publications from the last five years, considering the significant increase in AI utilization during this period. The five-year publication window was chosen to reflect the rapid evolution of AI technologies and their recent applications in education. The inclusion and exclusion criteria at this stage are detailed in Table 1. Based on these criteria, 605 articles that did not meet the criteria were excluded, leaving 130 articles for this stage, with 50 from the Scopus database, 45 from the ERIC database, and 35 from the SAGE database.

2.2.3. Eligibility

After the screening stage, the selected articles were further examined in the eligibility phase, which focused on the substance of each study. This step ensured that only the most relevant and high-quality articles were included in the review. First, the focus was on keyword relevance. The researcher conducted a re-check of the screened articles to ensure that they truly belonged to the field of mathematics education and were closely related to the main topic, namely AI. Second, attention was given to the research questions. Each article was reviewed to determine whether it addressed the research questions formulated in this study, as these questions guided the direction and focus of the review. Third, the researcher ensured that only research-based articles were retained. Some articles passing the initial screening were found to be non-research papers, such as literature reviews, editorials, or conceptual papers, which were then excluded. Fourth, the eligibility process also emphasized the disciplinary scope, ensuring that all included studies were truly within the field of mathematics education. Since the screening process sometimes retrieved studies from other domains, a final cross-check was conducted to maintain accuracy. As a result, 130 articles passed the eligibility stage after excluding 117 articles, including duplicates and those not meeting the inclusion criteria. A more detailed description of the inclusion and exclusion criteria is presented in Table 1.

Table 1
Inclusion and exclusion criteria

Stage	Inclusion	Exclusion
Screening	Written in English	Written in languages other than English
	Source from journals	Source from proceedings
	Open access	Closed access
	Published within the last five years	Published more than five years ago
	Relevant to keywords	Irrelevant to keywords
Eligibility	Relevant to research questions	Irrelevant to research questions
	Research articles	Non-research articles
	Focused on mathematics education	Outside mathematics education

2.2.4. Included

At the eligibility stage, 13 articles were obtained and are presented in Table 2 as a summary before a more comprehensive analysis in the results and discussion sections. Table 2 also provides information tailored to the research questions or topics, offering an initial overview of the articles relevant to this study.

Table 2

Articles obtained from the PRISMA flow

Author (year)	Country	Level	Type of AI	Impact of AI
Egara and Mosimege (2024)	Nigeria	Junior high school	ChatGPT	Instruction
Getenet (2024)	Australia	University	ChatGPT	Problem-solving
Ramprakash et al. (2024)	India	University	ChatGPT	Problem-solving
Pörn et al. (2024)	Finland	Junior high school	ChatGPT	Motivation
Moral-Sánchez et al. (2023)	Spain	University	Chatbots	Motivation
Jančařík et al. (2023)	Czechia	Junior high school	Chatbots	Instruction
Qawaqneh et al. (2023)	Jordan	University	V-Labs	Problem-solving
Wardat et al. (2023)	United Arab Emirates	Senior high school	ChatGPT	Problem-solving
Soesanto et al. (2022)	Indonesia	Senior high school	ChatGPT	Problem-solving
Dasari et al. (2024)	Indonesia	University	ChatGPT	Problem-solving
Huang and Qiao (2024)	Australia	Junior high school	ChatGPT	Computational thinking
Pavlova (2024a)	Bulgaria	Junior high school	ChatGPT	Problem-solving
Guler et al. (2024)	Turkey	Junior high school	ChatGPT	Problem-solving

3. Results and discussion

3.1. Trend AI

3.1.1. Year of research

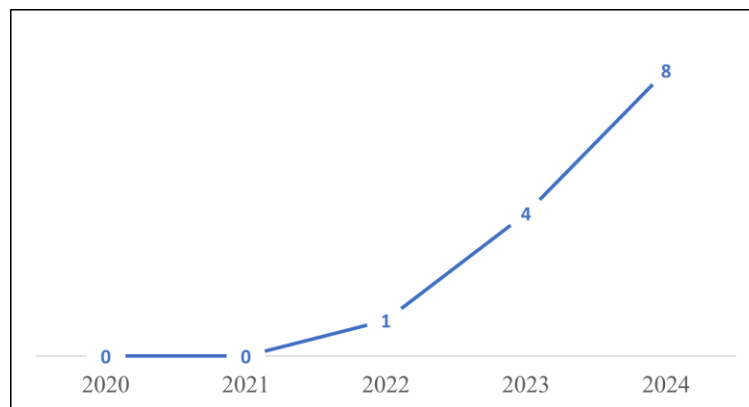


Fig. 3. PRISMA flowchart

Based on Fig. 3, research on the application of AI in mathematics education has shown a consistently increasing trend each year. From 2020 to 2021, no studies related to AI in

this field were found. However, starting in 2022, a significant rise occurred. In 2022, there was 1 study recorded (Soesanto et al., 2022), followed by 4 studies in 2023 (Jančařík et al., 2023; Moral-Sánchez et al., 2023; Qawaqneh et al., 2023). The peak occurred in 2024, with a surge to 8 studies (Dasari et al., 2024; Egara & Mosimege, 2024; Getenet, 2024; Guler et al., 2024; Huang & Qiao, 2024; Pavlova, 2024a; Pörn et al., 2024; Ramprakash et al., 2024), illustrating a dynamic growth and increasing relevance of AI in mathematics teaching.

The significant increase in research on AI applications in mathematics education, particularly from 2022 to 2024, can be attributed to the many positive outcomes of integrating this technological advancement. AI has begun to be recognized as a tool capable of accelerating learning processes, personalizing instructional materials, and enhancing classroom effectiveness (Guan et al., 2020; Harry & Sayudin, 2023; Nurjanah et al., 2024). This technology offers innovative solutions to traditional educational challenges, such as rigid teaching methods and difficulty in providing students with rapid, relevant feedback (Chen et al., 2023; Druga et al., 2022). During this period, the adoption of AI in education surged due to the need for more effective learning solutions. This spurred numerous studies and innovations on using AI in mathematics education (Cunška, 2022; Naidoo & Reddy, 2023), focusing on how this technology can improve student interaction and understanding amidst changing learning environments caused by the COVID-19 pandemic.

Before this, from 2019 to 2021, no studies specifically addressed the application of AI in mathematics education, as the technology had yet to develop fully. For example, ChatGPT, an AI chatbot developed by OpenAI, was launched in November 2022 (Goto & Katanoda, 2023; Haleem et al., 2022). After the launch of AI during this period, the educational sector began actively adopting this technology to enhance learning effectiveness and student understanding. Research findings from this period revealed that the implementation of AI in mathematics education showed positive results, encouraging further studies to explore its potential to create more interactive and adaptive education (Opesemowo, 2024). This marks a significant shift in how technology supports teaching and learning processes, particularly in mathematics, which requires logical reasoning and problem-solving skills.

3.1.2. Country of research

The trend of AI integration in mathematics education over the past five years demonstrates significant diversity across various countries, indicating the global expansion of AI applications in education. Indonesia (Dasari et al., 2024; Soesanto et al., 2022) and Australia (Getenet, 2024; Huang & Qiao, 2024) dominate with two studies. Other countries such as India (Ramprakash et al., 2024), Nigeria (Egara & Mosimege, 2024), the United Arab Emirates (Wardat et al., 2023), Jordan (Qawaqneh et al., 2023), Turkey (Çakıroğlu et al., 2024), Bulgaria (Pavlova, 2024b), Spain (Moral-Sánchez et al., 2023), the Czech Republic (Jančařík et al., 2023), and Finland (Pörn et al., 2024) contribute one study each (see Fig. 4). This geographic diversity reflects the global interest in AI's potential to enhance mathematics learning effectiveness across various educational contexts.



Fig. 4. Trends of AI research in mathematics education by country

The findings on the diverse trends of AI integration in mathematics education across countries reveal that this technology's application is not limited to one region but has spread globally. This diversity stems from factors such as the need for educational innovation and supportive government policies in each country. Technological advancements compel all sectors, including education (Adetunji & Moses, 2022), to adopt innovations to improve the effectiveness of learning activities (Kholid et al., 2023; Muhaimin et al., 2023; Serrano et al., 2019). In this context, AI has emerged as a tool capable of transforming teaching and learning methods (González-González, 2023). Educators and practitioners strive to create technology-based innovations to maximize learning processes. For example, a study by Jančarič et al. (2023) applied chatbots to assist mathematics teaching, demonstrating how technology can enhance teacher-student interactions. Additionally, tools like ChatGPT facilitate in-depth information retrieval, enabling students to access broader and deeper knowledge (Dasari et al., 2024; Gammoh, 2024). These innovations have become compelling research subjects in various countries, aiming to improve education through AI development.

The diverse adoption of AI across countries reflects varying educational challenges, enabling its implementation to be tailored to meet specific needs in different contexts. In developing systems like Indonesia, AI enhances accessibility and learning quality by overcoming resource limitations and providing broader access to quality materials and support (Hastungkara & Triastuti, 2020; Kadhim & Mousa, 2024). In developed nations such as Australia and Finland, AI supports personalized learning, allowing students to progress at their own pace and adapt to their learning styles (Huang & Qiao, 2024; Niemi, 2021). It also enables advanced data analysis, offering insights that help educators and policymakers design more effective strategies (Pedro et al., 2019; Sanusi et al., 2024). AI's application in education improves quality and adapts to each country's specific needs.

3.1.3. Educational levels

Based on Fig. 5, the integration of AI in mathematics education spans various educational levels, ranging from junior high school to university. Of the 13 reviewed articles, research on AI integration is most prominent at the junior high school level, accounting for six studies (Egara & Mosimege, 2024; Guler et al., 2024; Huang & Qiao, 2024; Jančařík et al., 2023; Pavlova, 2024b; Pörn et al., 2024). This is followed by university-level research with five studies (Dasari et al., 2024; Getenet, 2024; Moral-Sánchez et al., 2023; Qawaqneh et al., 2023; Ramprakash et al., 2024), while the senior high school level has only two studies (Soesanto et al., 2022; Wardat et al., 2023). Interestingly, no research was identified at the elementary school level, indicating that the primary focus of AI integration in mathematics education is currently on secondary and higher education levels.

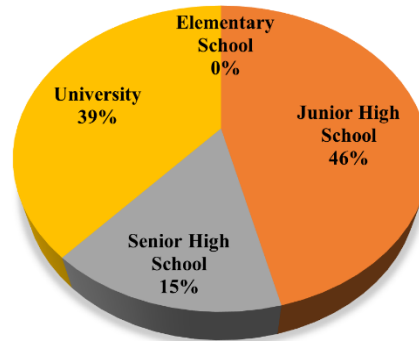


Fig. 5. Trends of AI research in mathematics education by educational level

The findings reveal that AI integration in mathematics education is most prevalent at the junior high school and university levels. At the junior high school level, students are introduced to more complex mathematical concepts, such as algebra and geometry, which require in-depth explanations and interactive exercises (Delvair, 2024). AI plays a crucial role in providing instant feedback and personalized learning, which helps students grasp the material better. For instance, technologies like ChatGPT allow students to ask questions and receive additional explanations beyond school hours, enabling them to complete assignments independently (Aktay et al., 2023; Hammer, 2024; Levine et al., 2024). At this stage, students are highly curious about new technologies (Muhaimin et al., 2025b), making them more open to exploring AI in learning contexts (Supardi & Hasanah, 2020). This makes junior high school the dominant level for AI use in mathematics education.

At the university level, AI is utilized for personalized learning and deeper data analysis. University students possess greater autonomy in learning (Serdyukova & Serdyukov, 2013), enabling AI to provide more individualized and in-depth learning experiences (Sun & Hoelscher, 2023). AI also offers flexible and relevant information for students seeking efficient and interactive learning solutions. For example, students frequently use ChatGPT to refine responses and strengthen argument justifications (Darmawansah et al., 2024; Ngo, 2023). Other AI tools, such as Elicit, help students find

accurate references (Whitfield & Hofmann, 2023), while QuillBot facilitates effective paraphrasing (Mohammad et al., 2023). Therefore, it is unsurprising that many studies on AI focus on university-level education, as its potential in higher education environments significantly supports independent learning, research, and advanced technology-driven innovation.

Meanwhile, the lack of research on AI integration at the elementary school level can be explained by the need for direct guidance from teachers for elementary students. At this educational level, students are still in the process of learning to read (Salmia, 2020), write (Lunenburg & Lunenburg, 2014), and understand basic concepts (Nahdi & Jatisunda, 2020), all of which require interaction and direct guidance from instructors. Although AI can provide feedback and personalized learning (Markauskaite et al., 2022), it still requires guidance or instructions from the user to function effectively (Guler et al., 2024; Pavlova, 2024b). This means that AI may be less effective at the elementary school level without intensive teacher guidance, which explains why research on AI at this stage is relatively limited. Furthermore, the focus of learning in primary education is more on developing social and emotional skills and building a solid cognitive foundation, which is better integrated with human interaction than with overly automated technology (Andersson, 2010).

3.2. AI integration

Our findings show three types of AI integration in mathematics education, as visualized in Fig. 6. First, ChatGPT emerges as the most frequently discussed technology, with ten studies reviewing its applications (Dasari et al., 2024; Egara & Mosimege, 2024; Getenet, 2024; Guler et al., 2024; Huang & Qiao, 2024; Pavlova, 2024b; Pörn et al., 2024; Ramprakash et al., 2024; Wardat et al., 2023). Second, chatbots are addressed in two studies (Jančařík et al., 2023; Moral-Sánchez et al., 2023), while virtual laboratories (V-Labs) appear in only one study (Qawaqneh et al., 2023). This diversity reflects the rapid technological advancements in the education sector, though it is possible that other AI types were not covered due to the limitations of the reviewed studies. This indicates that AI technology innovations continue to evolve, providing opportunities for further exploration in future research.

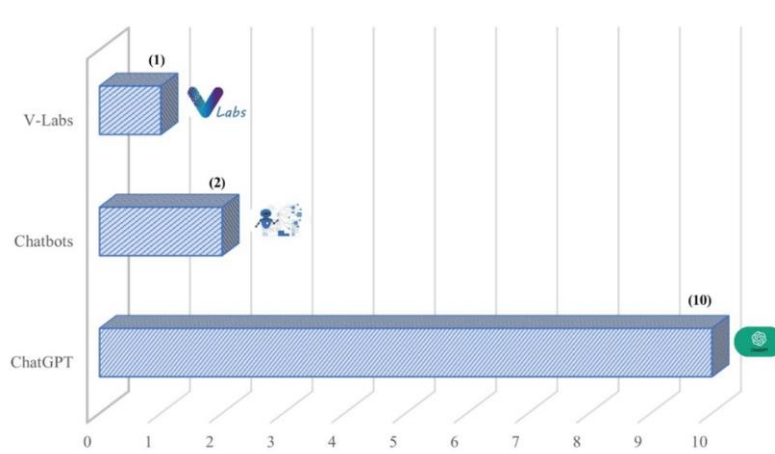


Fig. 6. Trends of AI research in mathematics education

ChatGPT dominates AI integration in mathematics education. Despite the challenges associated with its implementation, the flexibility and accessibility of ChatGPT allow users, including students and educators, to engage with this technology in various learning contexts (Javaid et al., 2023; Rahman & Watanobe, 2023; Zhu et al., 2023). Students can directly ask questions and receive detailed explanations of difficult mathematical concepts (Park & Manley, 2024), while educators use ChatGPT to support instruction (ElSayary, 2024) and provide real-time feedback (Silva & Janes, 2021). Moreover, ChatGPT's ability to deliver text-based responses and process diverse questions makes it an ideal tool for reinforcing students' understanding of the material (Tenakwah et al., 2025). It also serves as an effective self-learning tool, enabling students to interact with AI outside the classroom (Gammoh, 2024) and deepen their understanding of mathematical concepts more personally and interactively (Yu, 2023).

3.3. *Benefits of AI*

This topic highlights various benefits of integrating AI into mathematics education, encompassing cognitive, affective, and instructional aspects. As shown in Fig. 7, the greatest benefit lies in problem-solving abilities, with eight studies reporting improvements in these skills through AI implementation (Dasari et al., 2024; Getenet, 2024; Guler et al., 2024; Pavlova, 2024b; Ramprakash et al., 2024; Soesanto et al., 2022; Wardat et al., 2023). Motivation (Moral-Sánchez et al., 2023; Pörn et al., 2024) and teaching effectiveness (Egara & Mosimege, 2024; Jančařík et al., 2023) were also noted in two studies each, emphasizing AI's role in enhancing student motivation and supporting more effective instruction. Additionally, one study identified AI's benefit in developing computational thinking skills (Huang & Qiao, 2024), which bolsters students' logical and analytical abilities.

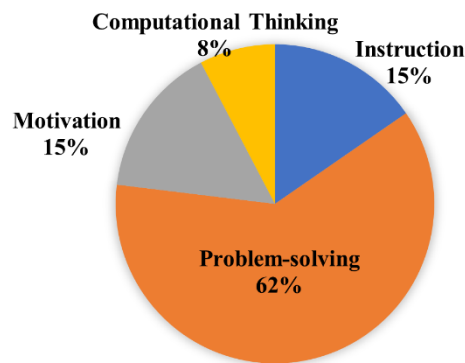


Fig. 7. Benefits of AI integration in mathematics education

The diversity of these benefits underscores AI's significant potential in supporting mathematics learning. The inherently problem-solving nature of mathematics provides an essential backdrop for understanding AI's role in education. With its fast and accurate responses, AI can help students grasp concepts and solve mathematical problems (Desmond et al., 2021). Features like instant feedback create a dynamic learning environment, allowing students to correct their mistakes immediately and explore new approaches (Alshahrani & Jameel Qureshi, 2024). The flexibility of AI in providing anytime access and adapting to students' difficulty levels further accelerates learning and enhances student engagement (Roshanaei et al., 2023).

AI creates interactive and responsive learning environments that motivate students to experiment, delve deeper, and discover better solutions. A widely used AI tool is ChatGPT (Gammoh, 2024; Dasari et al., 2024; Rahman & Watanobe, 2023), which provides quick and precise responses tailored to user input (George et al., 2023). ChatGPT not only helps solve mathematical problems but also plays a role in sharpening students' problem-solving skills (Getenet, 2024; Urban et al., 2024). Such AI integration enhances learning efficiency while making the experience more enjoyable and personalized, boosting students' learning motivation.

3.4. Challenges of AI

While AI offers numerous advantages, such as personalized learning, instant feedback, and support for educators, concerns remain regarding the reliability of its responses. Are the answers provided accurate? How do students construct knowledge from these responses? These challenges prompt consideration of the potential downsides of AI in education, including its negative effects. Dasari et al. (2024) note that students tend to uncritically accept AI-generated answers without questioning their accuracy or seeking further justification. This could lead to misconceptions if the AI provides inaccurate information. In such cases, students may become overly dependent on AI, neglecting the development of critical thinking skills necessary to evaluate the answers they receive. Findings by George et al. (2023) indicate that AI tools like ChatGPT often provide inconsistent answers. Pavlova (2024a) further highlights the need for clear and specific prompts to elicit expected responses from AI. Consequently, the role of educators is crucial in ensuring that students use AI technologies wisely. Teachers must guide students not to accept AI responses passively but to critically analyse and evaluate them. AI must remain a supportive tool rather than a replacement for deep learning processes involving thorough understanding and critical reflection.

It is also important to emphasize that technology independence must be supported in learning. The didactical tetrahedron theory situates technology as part of this independence Albano et al. (2018), implying that students can interact with technology without educator involvement. However, findings show that students still need teacher guidance when applying AI technology to ensure its wise use, maximizing the learning process. Dasari et al. (2024) revealed that classrooms relying solely on ChatGPT without teacher involvement did not enhance students' understanding and learning outcomes. Students using ChatGPT alone felt confused when directing their exploration and often received inconsistent responses to the same queries. In contrast, teachers guided by ChatGPT students demonstrated a more structured understanding, as teachers provided the necessary context and guidance for productive AI use. These findings align with the didactic triangle theory, which positions technology not as an independent entity (Goodchild & Sriraman, 2012; Straesser, 2007) but as a tool to extend students' cognition.

Furthermore, research by George et al. (2023) shows that AI like ChatGPT frequently generates inconsistent answers, while Pavlova (2024a) notes that AI requires very clear and specific instructions to produce accurate responses. These inconsistencies can hinder cognitive development, especially if students rely too heavily on AI. Thus, teachers play a critical role in ensuring that students accept AI responses passively and develop the ability to analyse and evaluate the information provided. With teacher guidance, AI remains an effective supporting tool without replacing the deep learning process involving critical reflection.

On another note, Egara and Mosimege (2024) highlight users' need for more awareness of AI's potential as a challenge to its integration into mathematics learning. Many educators and students do not fully understand how AI can enhance learning – most view AI development as potentially harmful when applied to education (Ivanov, 2023). However, with thoughtful use, AI as a technological representation can avoid hindering cognitive development and contribute to extending cognitive engagement with mathematics content (Pritchard, 2018).

This lack of awareness aligns with findings by Qawaqneh et al. (2023), which reveal that educators' limited experience with AI-based technology is a significant barrier. Many educators, particularly from older generations, need to become more accustomed to using educational technology, including AI (Uygun et al., 2024). This is due to limited exposure to technology in their youth and challenges in adapting to technological advancements later in life (Suryani, 2017). As a result, many educators in this group tend to stick to conventional teaching methods and doubt AI's potential to improve learning quality (Qawaqneh et al., 2023). This reluctance or discomfort in using AI affects its optimal utilization, preventing the full realization of its potential to support mathematics teaching.

Besides cognitive challenges, AI integration in learning also faces financial obstacles. Achieving more accurate and high-quality results often requires “*Pro*” or paid versions of AI tools (Deiana et al., 2023). This highlights inequalities in AI utilization, where only individuals or institutions with sufficient resources can access optimal AI technology, while others must settle for less effective versions. This disparity risks creating educational gaps, with students from under-resourced schools losing opportunities to benefit equally from AI technology. This situation hampers equitable access to educational technology and risks widening the quality gap in learning outcomes across institutions.

4. Conclusion

This study emphasizes the importance of integrating AI in mathematics education as a representation of the rapid advancement of technology. A systematic review of 13 relevant articles published within the past five years found that research on AI integration in mathematics education demonstrates a dynamic trend, particularly between 2022 and 2024. The studies are geographically distributed across countries such as Indonesia, Australia, India, the United Arab Emirates, Jordan, Turkey, Nigeria, Bulgaria, Spain, the Czech Republic, and Finland, with Indonesia and Australia being the most prominent contributors. In Indonesia, AI is widely utilized to expand access to education through online learning, whereas in Australia, AI is primarily used for personalized learning and data analysis, supporting tailored learning approaches that address individual student needs.

This study also reveals that AI integration is predominantly applied at the middle school and university levels. In middle schools, AI assists students in understanding complex mathematical concepts through interactive learning and prompt feedback. Meanwhile, AI supports self-directed learning and data analysis at universities, providing students with a more personalized and in-depth learning experience. The most dominant types of AI include ChatGPT, chatbots, and virtual labs (V-labs). ChatGPT stands out as the primary choice due to its flexibility in helping students and teachers grasp complex

mathematical concepts instantly and comprehensively, making it superior to other types of AI.

The impact of AI integration in mathematics education spans cognitive, affective, and instructional aspects. Cognitively, AI enhances students' problem-solving and computational thinking skills. Effectively, it boosts students' motivation to learn mathematics. However, this study also needs to cover several challenges in implementing AI, such as user awareness, educator skills, cognitive effects on students, and financial constraints. Low awareness among students and educators about AAI's potential and the lack of experience among educators in using AI-based technology are significant challenges. Additionally, the inconsistency of AI responses can disrupt students' knowledge of construction processes, leading to dependency that hinders the development of independent problem-solving skills. Financial barriers are also critical, as only well-resourced institutions can access advanced AI technologies, creating educational disparities.

5. Limitations and recommendations

The limitations of this study include the sources of data, the timeframe, and the scope of the field. Articles were collected from the Scopus, ERIC, and SAGE databases; however, future research could consider incorporating additional databases to enrich the references. Moreover, the study's timeframe was restricted to the past five years; subsequent research may expand or narrow this timeframe to align with the dynamics of AI development.

While this study complements previous reviews in terms of content, there remain significant opportunities to explore AI integration in education. While the scope of this study is limited to mathematics education, future research could investigate the application of AI in other disciplines, such as social sciences, natural sciences, and languages, to gain broader insights into the potential and challenges of AI in education.

Based on the findings, using AI in mathematics learning should be carried out prudently, avoiding situations where students rely solely on AI to solve every problem. Although AI offers convenience and speed in answering questions, students risk becoming over-reliant on AI without proper supervision, which could hinder the development of critical thinking, problem-solving skills, and a deep understanding of the material. Therefore, AI should be limited to being a supportive tool in learning, not a substitute for students' active and independent learning efforts.

The role of educators becomes crucial in guiding and supervising the use of AI. Teachers must actively ensure that AI is used productively by providing appropriate guidance on leveraging this technology to deepen students' understanding of mathematical concepts. Educators should help students understand that AI is a tool to accelerate learning, not an instant solution to every problem they encounter. Through wise supervision and intervention, educators can encourage students to develop critical thinking and problem-solving skills while ensuring that AI is used to support, not replace, the active and collaborative learning process.

Author Statement

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