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The Implementation of AI Technology in Mathematics Education to Enhance Students' Learning Independence and Critical Thinking Skills

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Abstract: The application of artificial intelligence (AI) technology in mathematics education demonstrates significant potential in enhancing students' learning independence and critical thinking skills. Various innovative approaches, such as problem-based learning, brain-based learning, and ethnomathematics, have proven effective in fostering independent and reflective learning characters. On the other hand, the integration of AI through intelligent systems—such as intelligent tutoring systems, gamification, and adaptive learning platforms—has enriched the mathematics learning experience in a more personalized and interactive manner. AI also plays a role in improving student engagement, conceptual understanding, and creativity in problem-solving. However, challenges such as technological gaps, misconceptions about AI, and infrastructure limitations remain obstacles to its implementation. Findings suggest that although the effectiveness of AI in enhancing students' cognitive and affective aspects has been identified, systematic studies that link AI with the development of students' learning character in the context of mathematics remain limited. Therefore, further in-depth and practical research is needed to develop AI-based mathematics learning designs that can shape students to be independent, critical, and adaptive in facing 21st-century challenges.

Keywords: Artificial Intelligence, Mathematics Education, Learning Independence, Critical Thinking, Pedagogical Innovation.

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A. INTRODUCTION

Mathematics as a Subject that Enhances Student Thinking and Independence Mathematics plays a crucial role in developing students' logical, analytical, and systematic thinking skills, which significantly contribute to academic performance (Sukendraa & Sumandya, 2020; Fauzan et al., 2024). Mastery of mathematical concepts is not only essential in academic contexts but also highly relevant in daily life and various other fields of study. With the rapid development of information and communication technology in the digital era, expectations for improving the quality of mathematics education are growing. This demand arises in response to the need to create a generation with 21st-century competencies, such as problem-solving skills, critical thinking, and independence in the learning process (Qulsum, 2022). Therefore, the approach to mathematics education is required to be innovative, adaptive to changes, and contextual with the ever-evolving global challenges.

In the educational context, mathematics learning, whether through conventional or modern approaches, still faces various complex challenges. One of the prominent issues is the low motivation of students to learn mathematics (Ayyubi et al., 2024), which is often perceived

as a difficult and less engaging subject. The abstract nature of mathematics also poses difficulties for students in understanding the concepts presented, especially when the teaching strategies used are not relevant to real-life situations and do not actively engage students (Widayanti & Nur'aini, 2020). In practice, many teaching approaches remain teacher-centered, where the teacher becomes the focal point of classroom activities, while students' active participation tends to be limited. This situation hinders the development of student learning independence and critical thinking, two essential competencies for facing the challenges of 21st-century education. Therefore, there is a need for more participatory, contextual learning innovations supported by technology to address these obstacles more effectively (Nofmiyati et al., 2023).

The rapid development in the field of information and communication technology has driven significant changes in various aspects of life, including in the education sector (Permana et al., 2024). Educational technology plays a key role as the primary driver enabling the transformation of the learning process, making it more flexible, interactive, and responsive to the needs of individual learners (Oktafia et al., n.d.). Technological innovations, such as digital learning platforms, interactive applications, and AI-based learning systems, open up new opportunities for delivering content more effectively and contextually. In the context of mathematics education, the adoption of technology becomes critical given the subject's need for understanding abstract and logical concepts. Technology can facilitate the visualization of mathematical concepts, provide instant feedback, and adapt content to students' skill levels, thus overcoming common obstacles in traditional learning methods (Efendi & Sholeh, 2023). Therefore, the use of educational technology is a strategic step in addressing challenges in mathematics education and supporting the achievement of more meaningful learning goals (Inayah, 2024).

AI technology is transforming the educational landscape by enabling personalized learning experiences tailored to each student's needs. Key applications such as adaptive learning systems, educational chatbots, and learning analytics facilitate these adjustments, allowing educators to enhance student engagement and teaching effectiveness. This technology uses data to create personalized learning profiles, adjusting content and instructional methods to optimize student outcomes (Katiyar et al., 2024).

Artificial Intelligence (AI) has significant potential to improve the quality of education through personalized learning experiences and the development of critical thinking skills (Widodo et al., 2024). This technology allows for the adjustment of learning material according to the needs and abilities of individual students, creating a more effective and directed learning approach (Almujab, 2023). Furthermore, AI can expand access to education, especially for students in remote areas or those with special needs, and assist in automating administrative tasks, allowing teachers to focus more on teaching activities (Sugiarto et al., 2023). The use of AI also supports the development of interactive learning content and enables in-depth data analysis for curriculum improvement. Various AI-based platforms such as Canva, ChatGPT, and Quizizz have been widely utilized by students to support the learning process (Arisanti et al., 2025). However, over-reliance on this technology could lead to new challenges, such as reduced social interaction and dependency on automated systems. Despite these challenges, the implementation of AI in education promises a transformation towards a more adaptive and responsive learning environment in the digital age (Nur et al., 2024).

Although several studies have previously addressed essential aspects of mathematics education, such as the relationship between mathematical concepts, learning independence, and mathematical critical thinking dispositions, there remains a gap in research specifically exploring the influence of artificial intelligence (AI) on mathematics learning

(Muhammadiyah et al., 2024). One study indicated that AI implementation improved critical thinking skills in students by 53.2%; however, this research was limited to education technology students and did not explicitly examine mathematics learning. Other studies have focused on self-efficacy in mathematics and critical thinking in online learning contexts, but they have not linked these aspects directly to AI utilization. Therefore, there is a need for a systematic literature review to map research trends, summarize key findings, and identify research gaps related to the role of AI in fostering learning independence and critical thinking skills in mathematics education.

Previous research has shown the significant potential of artificial intelligence (AI) technology in supporting educational transformation, particularly through personalized learning, the development of critical thinking skills, and increased learning process efficiency. Adaptive learning systems, educational chatbots, and learning analytics are concrete examples of AI applications that are widely utilized to accommodate individual students' abilities and needs. However, despite the widespread research on AI applications in general education contexts, studies specifically examining AI's contribution to mathematics education, especially in relation to fostering students' learning independence and critical thinking, remain limited. One study recorded a 53.2% improvement in critical thinking as a result of AI implementation, but it focused on technology education students rather than mathematics education at the primary or secondary school level. Additionally, other studies emphasized self-efficacy and cognitive abilities in online learning, without directly linking AI as an intervention variable. This disconnection in research focus has created a gap in understanding how AI can be effectively implemented in mathematics education to foster independent and critical thinking students. Therefore, this research is designed to address this gap by conducting a systematic literature review on relevant studies. The main goal is to identify, classify, and analyze various scientific findings related to the implementation of AI technology in mathematics education and to evaluate the extent to which this technology contributes to enhancing students' learning independence and critical thinking skills. The results of this study are expected to provide comprehensive theoretical and practical insights for educators, researchers, and educational technology developers in designing more adaptive and transformative mathematics learning strategies in the digital era.

B. METHOD

This study aims to systematically review various scholarly literatures discussing the implementation of artificial intelligence (AI) technology in mathematics education, with a primary focus on its contribution to enhancing students' learning autonomy and critical thinking abilities. The research method employed is qualitative, using a systematic literature review (SLR) approach, designed to identify, evaluate, and synthesize findings from previous studies in a structured and transparent manner. The literature search strategy involved searching various leading academic databases such as Scopus, Web of Science, ERIC, Google Scholar, and ScienceDirect using a combination of keywords such as: "artificial intelligence," "AI in education," "mathematics learning," "student autonomy," "critical thinking," and "AI and mathematics education." The search process was limited to publications from the past ten years (2015–2025), written in English and Indonesian, and published in indexed journals or relevant academic proceedings.

Inclusion criteria for this study include articles that explicitly discuss the use of AI technology in the context of mathematics learning, link AI implementation with aspects of student autonomy or critical thinking, and contain empirical data or literature reviews that can be qualitatively assessed. Exclusion criteria include non-peer-reviewed sources, studies that discuss AI technology in general without relevance to mathematics learning, articles that

are not fully accessible or written in languages other than English, and publications from outside the last decade. The selection process involved screening titles and abstracts to assess their relevance to the research topic. Full-text articles that met the inclusion criteria were selected for detailed review. Relevant data, including authorship, publication year, research methodology, key findings, and conclusions, were systematically extracted from each chosen article. The data extraction was carefully carried out to ensure accuracy and completeness. The extracted data were then synthesized and analyzed to identify trends, patterns, and gaps in the existing research, providing insights into the discussion and conclusions of the systematic literature review. Based on this explanation, the research procedure is illustrated in Figure 1.

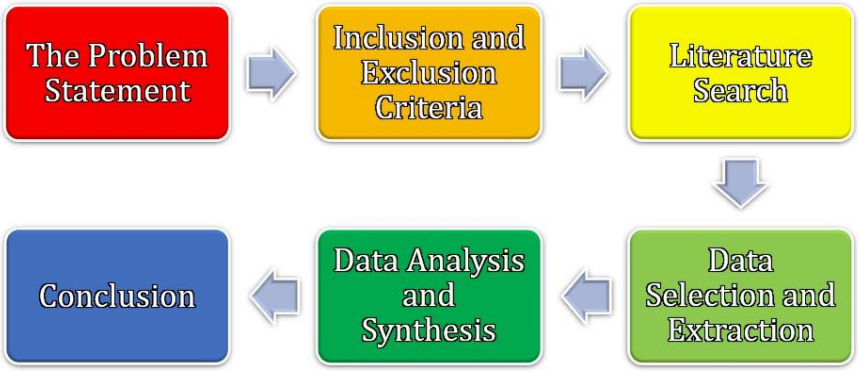

Figure 1. Research Procedure

C. RESULTS AND DISCUSSION

Based on the findings from 50 journal articles, 36 relevant research studies have been identified that can explain the focus and objectives of this research. We have formulated several aspects that need to be explained, including: (1) Mathematics as a learning tool that enhances students' thinking and learning independence; (2) Artificial Intelligence as a tool to facilitate mathematics learning; (3) The influence of Artificial Intelligence in mathematics learning; (4) Mathematics learning integrated with Artificial Intelligence can foster students' independence and critical thinking attitudes; and (5) The effectiveness of Artificial Intelligence in mathematics learning in developing students' independence and critical thinking attitudes.

Tabel 1. Research Variables

No	Research Focus/Area	Authors	Key Insights/Main Research Variables
1	Learning Independence and Critical Thinking in Mathematics Education	RM et al. (2024); Fauzan et al. (2024); Mahmudi et al. (2025); Sundayana (2016); Kusuma Dewi & Rahayu Utami (2016); Hendriana (2014); Nurfadilah & Hakim (2019)	Problem-based mathematics learning, brain-based learning, and humanistic approaches can enhance students' independence and critical thinking skills.
2	AI as a Support Tool for Mathematics Learning (Personalized & Interactive)	Alhalafi & Alshammari (2024); Tulak et al. (2024); Castillo Del Pezo et al. (2024); A. K. Umam (2024);	AI facilitates personalized learning, gamification, robotics, and AR; increases motivation and learning outcomes; challenges include

No	Research Focus/Area	Authors	Key Insights/Main Research Variables
		Harahap & Siswadi (2024); Saputro & Nurrahmi (2023)	technological gaps and misconceptions about AI.
3	Intelligent Systems and AI Platforms in Mathematics Education	Zhang et al. (2021); Ashton et al. (2024); Kharismawati et al. (2024); Kim et al. (2024); Ismahani (2025); A. Umam et al. (2023); Dahliani (2023)	Intelligent tutoring systems, AI-based LMS, and Canva significantly improve concept understanding, collaboration, and student engagement.
4	Integration of AI with Critical and Reflective Pedagogical Strategies	Suseno et al. (2023); Efendi et al. (2024); Latifatul Husna et al. (2023); Rizky & Adi (2023); Sri Annisa & Mailani (2023); Ismiati et al. (2021); Opinion et al. (2018)	AI supports constructivist approaches such as problem posing, ethnomathematics, and RME that enhance students' independence and critical thinking.
5	Effectiveness of AI on Independence, Critical Thinking, and Creativity in Mathematics Learning	Oktavianus et al. (2023); Avise & Ayala (2010); Hendriyanto et al. (2024); Lestari et al. (2021); Abdul & Elfin (2024); Afifah & Kusuma (2021); Prsetya et al. (2023)	AI is effective in personalizing learning, motivating students, and improving creativity, engagement, and algorithmic problem-solving; challenges include infrastructure and access issues.

Tabel 1 summarizes the research findings in the field of The Implementation of AI Technology in Mathematics Education to Enhance Students' Learning Independence and Critical Thinking Skills. Divided into five main focuses, it highlights various complementary approaches to enhancing students' learning independence and critical thinking skills in mathematics education. Various learning models, such as problem-based learning, brain-based learning, and humanistic approaches, have been proven to stimulate students to be more independent and think critically. On the other hand, Artificial Intelligence (AI) has emerged as an important tool in supporting mathematics learning, offering personalization, gamification, robotics, and augmented reality (AR) that can enhance student motivation and learning outcomes. AI also supports the use of intelligent platforms and AI-based tutoring systems, allowing students to gain a deeper understanding of concepts and increasing their engagement in learning. Furthermore, the integration of AI with pedagogical strategies such as problem posing, ethnomathematics, and realistic mathematics education (RME) approaches can foster students' independence and critical thinking abilities. However, despite AI's proven effectiveness in enhancing creativity, engagement, and algorithmic problem-solving, challenges related to infrastructure, accessibility, and misconceptions about AI remain barriers that need attention. Overall, this research reveals the great potential of AI in enriching the mathematics learning experience and supporting the development of independent and critically thinking student character.

1. Mathematics as a Learning Tool to Enhance Students' Thinking and Independence

Mathematics plays a crucial role in enhancing intelligence and fostering students' independence. The integration of logical mathematical intelligence and learning independence has been shown to significantly influence academic performance, with logical mathematical intelligence contributing 30.04% and learning independence contributing 29.99% to student achievement (RM et al., 2024). Logical mathematical intelligence plays a key role in enhancing critical thinking and problem-solving abilities, which are directly related to mathematics learning outcomes. On the other hand, learning independence encourages students to learn autonomously and responsibly, which is associated with better academic performance and character development (Fauzan et al., 2024). Teaching strategies such as Problem-Based Learning (PBL) have been proven effective in cultivating students' independence through increased confidence, motivation, and responsibility in the learning process (Mahmudi et al., 2025). Additionally, blended learning models have shown better results in improving critical thinking and independence compared to traditional teaching methods. Despite the importance of mathematics education in shaping intelligence and independence, challenges such as low student engagement and limited resources may hinder the achievement of learning goals. Therefore, continuous improvement in teaching strategies and the creation of a supportive learning environment are essential to optimize the benefits of mathematics education.

Mathematics education plays a critical role in developing students' cognitive abilities while fostering learning independence. Research shows that mathematical problem-solving abilities and learning independence are often underdeveloped in middle school students (Sundayana, 2016). To address this, educators can apply teaching strategies aligned with students' learning styles and encourage independent learning (Kusuma Dewi & Rahayu Utami, 2016). Brain-based learning models have proven effective in enhancing students' creative mathematical thinking while also promoting learning independence. Additionally, the humanistic approach to mathematics education plays a role in fostering important character traits such as self-confidence, critical thinking, and responsibility (Hendriana, 2014). By encouraging students to actively solve mathematical problems and present their solutions independently, teachers can cultivate independence and confidence in mathematics learning (Nurfadilah & Hakim, 2019). These strategies collectively contribute to strengthening students' mathematical competencies and personal development.

These findings indicate that mathematics education is not only focused on computational skills or algorithms but also serves as a medium for developing students' cognitive and affective capacities. Logical mathematical intelligence facilitates critical and systematic thinking, while learning independence is a crucial prerequisite for long-term learning success. Innovative teaching strategies have been proven to foster students' self-confidence, responsibility, and internal motivation, all of which are essential elements in building learning independence. Overall, the literature consistently supports the central role of mathematics in developing students' intellectual and personal growth. However, challenges remain, including low student engagement and limited learning resources. Furthermore, most research still focuses on cognitive outcomes, while students' affective aspects and character development have not been extensively studied or integrated. On the other hand, there is a lack of studies that explicitly connect cutting-edge technology-based teaching strategies, such as AI, with the enhancement of mathematical character and students' learning independence.

2. Artificial Intelligence as a Tool to Facilitate Mathematics Learning

Artificial Intelligence (AI) plays a transformative role in facilitating mathematics learning by enhancing educational personalization, increasing student engagement, and providing real-time feedback. The integration of AI technologies such as intelligent tutoring systems and

generative models enables a learning experience tailored to individual students' needs, optimizing their understanding of complex mathematical concepts (Alhalafi & Alshammari, 2024). AI can also analyze students' learning styles and adjust learning content to be more relevant and effective, thereby promoting active participation and deeper understanding of mathematical principles (Tulak et al., 2024). Additionally, student engagement in learning is enhanced through interactive problem-solving environments, including the use of robotics and gamification, which have been shown to increase students' interest and motivation in exploring mathematical concepts. AI also provides immediate feedback, enabling students to quickly identify and correct mistakes, which supports mastery of mathematical skills while helping educators monitor students' learning progress more effectively (Castillo Del Pezo et al., 2024). However, the implementation of AI in mathematics education still faces several challenges, such as the technological gap and data privacy issues, which need to be addressed to ensure fair access and ethical use of this technology in various educational contexts.

Recent studies highlight the great potential of Artificial Intelligence (AI) in improving the quality of mathematics education. The integration of AI and Augmented Reality (AR) technologies has proven to improve the quality of mathematics instruction, although the preparation time required still poses a challenge (A. K. Umam, 2024). Various AI-based tools such as intelligent learning software and adaptive tutoring systems provide significant support for mathematics education students in enhancing academic performance and learning motivation (Harahap & Siswadi, 2024). Research also indicates that AI-based digital learning, using platforms like Canva, can improve mathematics test scores while also increasing student engagement in the learning process. Furthermore, AI-based learning media have been proven effective in enhancing motivation for mathematics learning, with the majority of participants showing positive responses to their learning experiences (Saputro & Nurrahmi, 2023). However, some students have unrealistic expectations or misconceptions about AI systems, which can limit their effectiveness. Overall, these findings show that AI has great potential to facilitate and enrich mathematics learning, provided it is implemented wisely and strategically.

From the existing research findings, it can be seen that AI functions as a highly effective tool in transforming the dynamics of mathematics learning, providing a more personalized and interactive experience for students. AI's ability to adapt learning content to individual learning styles and provide real-time feedback significantly supports the development of students' cognitive skills and problem-solving abilities. Additionally, the use of technologies like gamification, robotics, and AR shows that mathematics learning can become more engaging and motivating for students. This aligns with the concept that mathematics learning is not just about memorizing formulas and concepts but also about honing students' critical thinking and independence in problem-solving. However, challenges related to AI implementation, such as the technological gap and data privacy issues, indicate that this technology needs to be applied carefully and strategically. Furthermore, unrealistic expectations of AI in mathematics education can hinder the optimization of this technology, especially if students do not fully understand how AI functions in the learning process. Overall, AI shows great potential in facilitating and enriching mathematics learning. AI-based tools can encourage the development of students' independence by giving them more control over their learning process, allowing them to correct mistakes and understand concepts deeply. The application of this technology in mathematics also supports the development of critical thinking skills, as students are confronted with problem-solving situations that require reflection and in-depth analysis. However, it is important to note that although research findings indicate that AI can enhance student engagement and understanding, challenges related to technological gaps, data privacy, and students' understanding of this technology

must be addressed to ensure fair and effective implementation. Some studies suggest that unrealistic expectations about AI may reduce its effectiveness in supporting mathematics learning.

3. The Influence of Artificial Intelligence in Mathematics Learning

The integration of Artificial Intelligence (AI) into mathematics education has revolutionized educational methods by enhancing personalization and student engagement. AI technology allows for the presentation of tailored learning experiences, enabling educators to more effectively meet the individual needs of each student. One form of personalization is the AI system's ability to adjust content and learning speed based on each student's proficiency level, creating a more engaging learning environment (Zhang et al., 2021). Additionally, tools such as intelligent tutoring systems provide customized feedback, which is essential for mastering mathematical concepts (Ashton et al., 2024). In terms of collaboration, AI-based Learning Management Systems (LMS) have significantly improved collaborative learning outcomes, as research has shown that students using AI-based LMS score higher in science literacy compared to traditional methods (Kharismawati et al., 2024). These systems also encourage student interaction, strengthening problem-solving skills in mathematics through collaborative tasks (Kim et al., 2024). However, the application of AI in education also raises ethical challenges, such as data privacy issues and potential algorithmic biases that could exacerbate existing inequalities. Therefore, it is crucial to ensure that AI acts as a facilitator, not a replacement for educators, so that the human element in teaching remains intact. Although AI offers significant opportunities for improving mathematics learning, a thoughtful and ethical approach is necessary to ensure fair and effective educational practices.

Recent studies demonstrate that Artificial Intelligence (AI) has a significant influence on mathematics learning. AI technologies, including intelligent learning software and adaptive tutoring systems, have been proven to enhance students' academic performance and their understanding of mathematical concepts. Integrating AI into mathematics education has also been shown to increase students' motivation and engagement in the learning process (Ismahani, 2025). Furthermore, teachers report that using AI-based tools and Augmented Reality (AR) substantially improves the quality of mathematics instruction, although challenges such as preparation time and limited resources remain (A. Umam et al., 2023). A study using digital AI-based tools such as Canva demonstrated improved mathematics learning outcomes for seventh-grade students, with test scores and student engagement increasing significantly over two cycles (Dahliani, 2023). Overall, these findings show that AI technology offers promising opportunities to improve mathematics learning, although considerations of accessibility and realistic expectations for its implementation must be taken into account.

These findings suggest that mathematics learning integrated with AI not only functions as an academic aid but also as a catalyst for developing a more reflective and independent mindset. Through adaptive feedback and personalized content, students are challenged to develop their own learning strategies, analyze mistakes independently, and form a deeper conceptual understanding. Moreover, collaboration within AI-based LMS strengthens the social and cognitive aspects crucial in problem-solving-based learning. While research results show the positive potential of AI in mathematics education, several important issues must be addressed. Ethical concerns such as data privacy, algorithmic bias, and the digital divide cannot be ignored. Additionally, limitations in resources and teacher readiness also hinder the widespread and effective implementation of AI technology. Therefore, the success of AI implementation depends on a thoughtful and ethical approach, supported by appropriate

policies and professional training for educators. Through this approach, AI can become a facilitator that supports students' development of mathematical thinking, independence, and critical problem-solving skills, while maintaining the essential human aspects of education.

4. Mathematics Learning Combined with Artificial Intelligence Can Foster Student Independence and Critical Thinking Attitudes

The integration of mathematics learning with Artificial Intelligence (AI) technology can significantly enhance students' learning independence and critical thinking skills. Research indicates that logical-mathematical intelligence and learning independence are crucial factors in improving mathematics learning outcomes (Suseno et al., 2023). AI enables personalized learning content according to each student's needs, fostering independent learning and more autonomous exploration of mathematical concepts. Furthermore, the use of AI-based tools like ChatGPT facilitates problem-solving activities that require critical thinking skills, allowing students to deeply engage with mathematical concepts (Efendi et al., 2024). The application of AI in collaborative learning also encourages students to analyze and evaluate solutions critically, ultimately strengthening their problem-solving skills (Latifatul Husna et al., 2023). Although the benefits of AI in fostering independence and critical thinking are evident, concerns remain regarding over-reliance on technology and its impact on traditional teaching methods. Therefore, a balance between integrating AI and foundational teaching practices is necessary to create holistic education.

Research indicates that innovative approaches in mathematics education can enhance students' critical thinking and independence. Problem-posing-based learning improves students' understanding of mathematical concepts and critical thinking skills in eighth-grade students compared to conventional methods (Rizky & Adi, 2023). Similarly, the integration of Quizizz with Problem-Based Learning and ethnomathematics improves critical thinking and learning independence in elementary school students (Sri Annisa & Mailani, 2023). In junior high school students, the Metacognitive Scaffolding approach has shown potential in developing critical thinking skills in mathematics (Ismiati et al., 2021). Additionally, the Realistic Mathematics Education approach has shown better results in enhancing critical thinking and students' self-confidence in junior high school compared to traditional teaching methods (Opinion et al., 2018). Collectively, these studies highlight the potential of innovative teaching strategies, integrated technology, and context-aware pedagogy in fostering critical thinking and independence across various educational levels.

Effective mathematics learning in the 21st century requires the integration of technology and pedagogical strategies that encourage active participation, metacognitive reflection, and in-depth exploration of concepts. AI, as an adaptive technology, can play the role of a facilitator in creating responsive and personalized learning spaces. This aligns with the principles underlying the success of pedagogical approaches. Critically, empirically tested innovative approaches share characteristics with the benefits offered by AI. All these methods emphasize the development of students' self-potential independently and with higher-level thinking. While research on AI in mathematics education is still in its exploratory stages, its trend is already leading towards achieving outcomes similar to those of proven pedagogical approaches. This suggests that AI is not just a passive tool but can be developed as an active pedagogical medium aligned with constructivist learning principles.

5. The Effectiveness of Artificial Intelligence in Mathematics Education in Fostering Student Independence and Critical Thinking Attitudes

The integration of Artificial Intelligence (AI) in mathematics education demonstrates significant potential in fostering students' independence and critical thinking skills. Through

personalized learning approaches, AI adjusts the material according to individual learning styles, allowing students to learn at their own pace and gain a deeper understanding of mathematical concepts (Oktavianus et al., 2023). Research indicates that the use of AI-based platforms increases problem-solving ability by 30% and understanding of abstract concepts by 25% compared to conventional methods (Avise & Ayala, 2010). Moreover, AI contributes to the development of critical thinking skills by encouraging algorithmic problem-solving and analytical approaches in addressing mathematical challenges (Hendriyanto et al., 2024). AI also enhances student motivation and engagement through instant feedback and tailored explanations, creating a more interactive and engaging learning environment. However, the effectiveness of AI faces challenges such as technological access gaps and the potential reduction of the teacher's role, which need to be addressed to ensure AI implementation is fair and optimal in educational settings (Prsetya et al., 2023).

Recent studies have explored the effectiveness of Artificial Intelligence (AI) application in mathematics education, particularly in fostering students' learning independence and critical thinking attitudes. The use of AI-based learning tools has been shown to improve learning independence, critical thinking skills, creativity, and problem-solving abilities in students (Lestari et al., 2021). Specifically in the context of mathematics, the integration of AI technology enhances student motivation and understanding of the learning material (Abdul & Elfin, 2024). Research using AI-based digital tools like Canva also demonstrates significant improvements in mathematics learning outcomes and student engagement in the learning process. Furthermore, other research emphasizes the importance of mathematical self-efficacy and critical thinking skills in online mathematics learning, where self-efficacy drives motivation and learning independence, while critical thinking contributes to improved cognitive abilities (Afifah & Kusuma, 2021). These findings collectively indicate that AI integration in mathematics education positively impacts the development of students' learning character, although its implementation still faces several challenges.

These findings suggest that AI is not merely a technological tool but can serve as a catalyst for independent learning and critical thinking. AI creates an adaptive learning environment, enabling students to manage their learning autonomously while still receiving relevant guidance and feedback. Data-driven content and learning pace adjustments support a deeper understanding of mathematical concepts. Moreover, AI stimulates high-level cognitive processes by presenting analytical challenges that require creative problem-solving. Although AI has proven effective in improving learning outcomes and students' metacognitive competencies, its effectiveness is not without challenges. The technology access gap, school infrastructure readiness, and teachers' ability to manage AI platforms are obstacles that need to be addressed. Additionally, there are concerns that AI may reduce the teacher's role as a humanistic learning facilitator if not wisely integrated. Therefore, the success of AI implementation depends on the synergy between technology, pedagogy, and humanistic approaches in education.

D. CONCLUSIONS AND SUGGESTIONS

The application of Artificial Intelligence (AI) technology in mathematics education has demonstrated significant effectiveness in fostering students' learning independence and critical thinking skills. AI enables personalized learning, encouraging students to study independently, grasp concepts deeply, and actively engage in high-level thinking processes through solving mathematical problems. Findings from various studies indicate that AI can substantially enhance self-efficacy, learning motivation, problem-solving skills, and students' cognitive engagement. However, AI implementation has not yet been fully integrated into

instructional strategies explicitly designed to develop students' cognitive and affective character. Research gaps remain due to the lack of systematic studies evaluating the specific role and effectiveness of various AI applications in the context of mathematics education. Therefore, there is a need to develop AI-based pedagogical models that not only focus on academic outcomes but also support the transformation of students into independent, reflective, and critical learners in the digital era.

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