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The influence of artificial intelligence on critical thinking ability in mathematics: A systematic literature review

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ABSTRACT

Artificial intelligence (AI) is rapidly expanding in mathematics education; however, its impact on students' critical thinking skills remains not fully understood. As AI integration in learning increases, evaluating how this technology influences students' cognitive abilities is essential. This study aims to explore the impact of AI on critical thinking skills in mathematics learning through a Systematic Literature Review. Following the PRISMA protocol, the Systematic Literature Review (SLR) approach was used to collect and analyze relevant studies. The reviewed studies consisted of Scopus-indexed articles published in the last ten years, resulting in eight articles selected for further analysis. The findings indicate that AI use can positively contribute to students' critical thinking development, particularly in supporting interactive learning. However, there are also negative effects when students become overly reliant on technology, leading them to solve problems procedurally without a deep conceptual understanding. This study concludes that AI can effectively enhance students' critical thinking skills in mathematics, provided it is implemented with appropriate strategies. The findings have implications for developing hybrid learning models that integrate AI with traditional teaching approaches to achieve optimal learning outcomes.

Pengaruh kecerdasan buatan terhadap kemampuan berpikir kritis dalam matematika: Sebuah tinjauan pustaka sistematis

Kata Kunci:

AI, kecerdasan buatan, berpikir kritis, matematika, tinjauan literatur

ABSTRAK

Penggunaan kecerdasan buatan (AI) dalam pendidikan matematika berkembang pesat, tetapi dampaknya terhadap kemampuan berpikir kritis siswa masih belum sepenuhnya dipahami. Seiring dengan meningkatnya integrasi AI dalam pembelajaran, penting untuk mengevaluasi bagaimana teknologi ini mempengaruhi aspek kognitif siswa. Penelitian ini bertujuan untuk mengeksplorasi pengaruh AI terhadap kemampuan berpikir kritis dalam pembelajaran matematika melalui Tinjauan Literatur Sistematis. Pendekatan Systematic Literature Review (SLR) dengan protokol PRISMA digunakan untuk mengumpulkan dan menganalisis penelitian yang relevan. Studi yang ditinjau adalah artikel yang terindeks Scopus dalam 10 tahun terakhir, menghasilkan 8 artikel yang dianalisis lebih lanjut. Hasil penelitian menunjukkan bahwa penggunaan AI, terutama dalam mendukung pembelajaran interaktif, dapat berkontribusi positif terhadap perkembangan kemampuan berpikir kritis siswa. Namun, terdapat juga dampak negatif ketika siswa menjadi terlalu bergantung pada teknologi, sehingga hanya mampu menyelesaikan soal secara prosedural

tanpa pemahaman konseptual yang mendalam. Penelitian ini menyimpulkan bahwa AI dapat menjadi alat yang efektif untuk meningkatkan kemampuan berpikir kritis siswa dalam matematika, asalkan diimplementasikan dengan strategi yang tepat. Hasil penelitian ini memiliki implikasi bagi pengembangan model pembelajaran hybrid yang mengintegrasikan AI dengan pendekatan pengajaran tradisional guna mencapai hasil pembelajaran yang lebih optimal.

Contribution to the literature

This research contributes to:

- Identifying AI's potential to enhance critical thinking and its risks of fostering procedural dependency.
- Synthesizing findings from the last decade, offering a comprehensive understanding of AI's impact on students' analytical and problem-solving skills in mathematics.
- Highlighting the need for balanced pedagogical strategies and recommending hybrid learning models that combine AI tools with traditional teaching to maximize critical thinking development.
- Emphasizing the ethical and practical considerations for integrating AI into educational contexts provides a foundation for further research into personalized and critical learning approaches.

1. INTRODUCTION

Information and communication technology development has changed how we interact and learn. Artificial Intelligence (AI), a branch of computer science that focuses on developing systems that can mimic human intelligence, offers great potential to overhaul traditional education methods [1]. AI can serve as a tool that adapts learning materials according to students' individual needs, thus enabling customization in the learning process [2]. This adaptation can lead to more effective and engaging learning experiences. Ultimately, AI has the ability to personalize educational pathways for each learner.

One of the most important subjects in school is Mathematics, as it has applications in various fields, such as natural sciences, economics, social sciences, medicine, computing, banking, and many more [3] [4]. Despite its importance, students worldwide struggle with mathematical concepts, as evidenced by results from international assessments, such as the Programme for International Student Assessment (PISA) and national maturity exams in several countries, including Bulgaria [5]. According to the 2018 PISA report, only 23.4% of students in OECD countries achieved proficiency level 4 or above in mathematics, indicating a widespread challenge in developing higher-order mathematical thinking skills [6]. Furthermore, many students struggle with problem-solving, logical reasoning, and conceptual understanding, essential components of critical thinking in mathematics [7], [8]. This persistent difficulty highlights the need for improved teaching methodologies and resources. Consequently, educators are continuously seeking effective strategies to enhance students' mathematical abilities.

AI offers promising solutions to these challenges by diagnosing learning difficulties and providing personalized feedback to improve mathematical understanding [9]. AI-driven tools, such as intelligent tutoring systems and automated assessment platforms, have demonstrated the potential to enhance problem-solving skills and foster engagement

through gamification and visualization techniques, particularly in topics such as functional analysis and geometry [10], [11]. Ultimately, the goal is to create more adaptive and effective learning experiences. These technologies aim to bridge the gap between traditional teaching methods and the individual needs of students.

Despite numerous studies on AI in education, few comprehensively analyze its role in fostering mathematical critical thinking. A recent review of publications from Science Direct, Scopus, SpringerLink, ProQuest, and EBSCOhost (2017–2021) identified over 900 articles related to AI in education. However, only 20 explicitly addressed the use of AI in mathematics education, with even fewer focusing on its impact on critical thinking [12]. This indicates a significant research gap, as most studies prioritize technological implementation over pedagogical strategies integrating AI to enhance higher-order thinking skills [13]. Furthermore, there is a lack of consensus on how AI influences students' logical reasoning and problem-solving processes in mathematical contexts [14]. AI also has the potential to assist educators in managing classrooms and analyzing student progress more effectively [13]. AI-driven analytics can help identify students who require additional support, enabling teachers to design more targeted instructional strategies [14]–[16]. However, limited empirical research examines how AI-based interventions can be systematically leveraged to develop students' critical thinking skills in mathematics beyond rote memorization and procedural fluency [17].

Given these gaps, this study adopts a Systematic Literature Review (SLR) approach to synthesize existing research and provide a holistic analysis of AI's impact on mathematical critical thinking. The SLR method is particularly suited for this study as it allows for a structured and comprehensive examination of published literature, ensuring that relevant studies are systematically identified, analyzed, and synthesized based on predefined criteria [18]. By employing this approach, the study aims to bridge the gap in understanding how AI can be strategically integrated into mathematics education to foster critical thinking, thereby contributing to theoretical and practical advancements in the field. Additionally, existing studies focus on technological implementation rather than pedagogical implications, leaving a gap in understanding how AI can be strategically integrated to develop critical thinking skills in mathematics [19]. This study aims to bridge these gaps by systematically reviewing existing literature to provide a comprehensive analysis of the impact of AI on students' mathematical critical thinking skills.

2. METHOD

The method used in this research was a Systematic Literature Review (SLR). SLR is a method of collecting appropriate data on a specific topic that meets predetermined eligibility criteria [20]. It aimed to analyze the collected journal articles using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). After receiving ethics approval, the research was conducted. PRISMA consists of four stages: identification, screening, eligibility, and inclusion. This technique was chosen because it can help the researchers to synthesize important journal publications. Specifically, it provides a structured and transparent approach to reviewing existing research. By following the PRISMA guidelines, researchers can conduct an accurate search to find AI practices in mathematics education. This ensures that the review is comprehensive and minimizes bias. Figure 1 below is a PRISMA diagram for this research. The diagram visually represents the flow of information through the different phases of the review process. Ultimately, this methodology allows for a robust and reliable analysis of the current state of research.

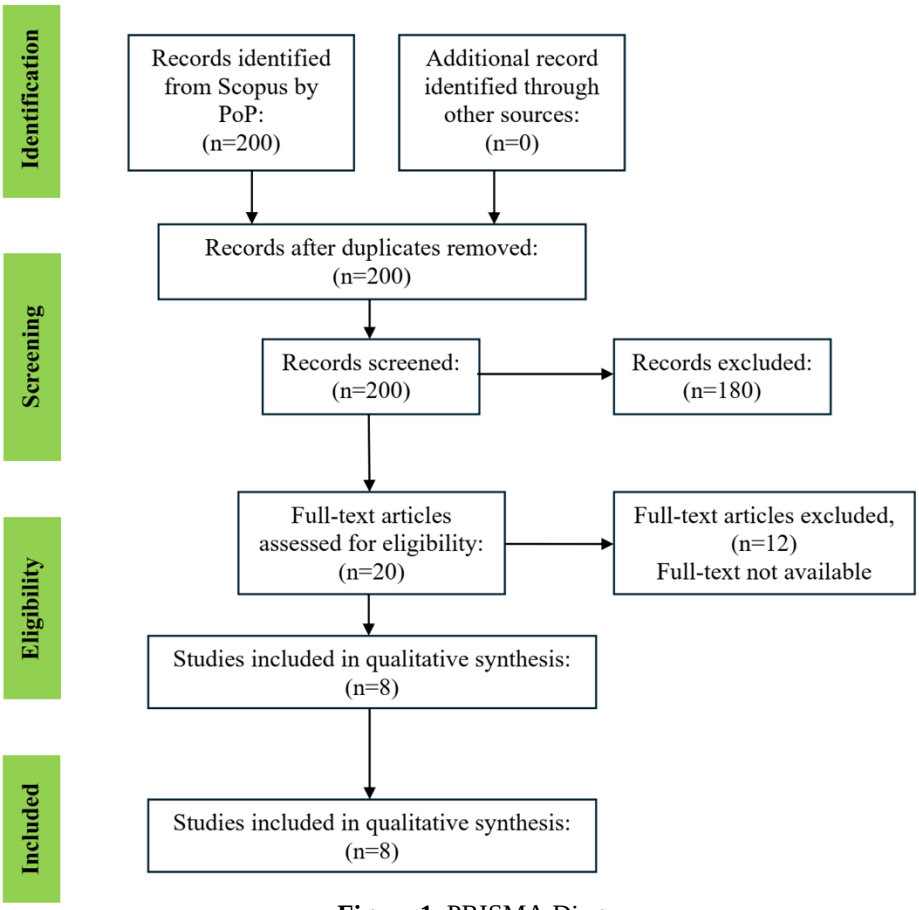

Figure 1. PRISMA Diagram

2.1 Identification

A search was conducted on Harzing's Publish or Perish with Scopus as the source. Scopus is one of the most widely recognized academic indexing databases. It is often preferred over other indexing services due to its comprehensive coverage, quality control, and analytical tools [21]. The researchers found two main search terms based on our underlying research topic: AI and mathematics education. Therefore, the researchers expanded the search terms and strategy to explore as many potentially relevant studies as possible. To search, the keywords used were "AI" OR 'artificial intelligence' AND 'mathematics education' OR 'thinking' OR 'learning' OR 'instruction'. As a result, 200 journal articles were classified at this process stage. This methodology aimed to ensure a broad and inclusive retrieval of relevant academic literature.

2.2 Screening

The researchers used various inclusion and exclusion criteria in this approach. No systematic review articles, books, book chapters, or conference proceedings were included in the literature selection. Furthermore, the researchers concentrated only on English-language journal articles, so there was less chance of complicated or uncertain translations required. Then, the researchers looked at articles published within the last 10 years. After the screening stage, 180 papers were identified as not meeting the research criteria, leaving only 20 articles. This rigorous selection process aimed to ensure the relevance and quality of the final dataset.

2.3 Eligibility

The eligibility stage resulted in incomplete articles. First, journal articles that did not meet the criteria of best practices in AI in mathematics were rejected. Then, to ensure that all 20 articles fit the study selection criteria and objectives, each article's title, abstract, methodology, results, and discussion were thoroughly reviewed. At this stage, 12 articles were rejected because they did not fully describe AI in mathematics education or the full-text paper was unavailable. As a result, 8 articles were selected for publication in the final stage of the review process.

2.4 Inclusion and Exclusion Criteria

After collecting all results from all identified sources, the researchers used selection criteria, such as time, document type, language, and subject area, to filter out articles that were not relevant to our study. When selecting articles for inclusion and exclusion, the inclusion and exclusion criteria should be clearly defined to ensure that the selected studies are relevant to the main research objectives. Table 1 shows this review study's inclusion and exclusion criteria and the research findings. It was determined that 8 relevant articles and full-text articles from these publications were obtained.

Table 1. Criteria for Inclusion and Exclusion

Criteria	Inclusion	Exclusion
Title and body of the article	Appropriate and appropriate titles for research requirements	Not following the study requirements and having an irrelevant title
Year of publication	Publications from 2020 to 2024	Publication outside the specified range
Types of publications	Journal publications	Publications in Proceedings, Books
Language	English	Other
Areas of study of articles	Education	In addition to education
Accessibility	Full-text articles or open-access	Article preview and require payment
Index	Scopus	In addition to Scopus

3. RESULTS AND DISCUSSION

Table 2 presents eight papers that meet the criteria to be analyzed in this SLR research.

Table 2. Eligible Articles for Analysis

No	Title
1	Imagining the thinking machine: Technological myths and the rise of artificial intelligence [22]
2	Designing educational technologies in the age of AI: A learning sciences-driven approach [23]
3	Effects of artificial Intelligence–Enabled personalized recommendations on learners' learning engagement, motivation, and outcomes in a flipped classroom [24]
4	AI for education: Knowledge and its assessment in AI-enabled learning ecologies [25]
5	A comprehensive AI policy education framework for university teaching and learning [26]
6	Leadership is needed for ethical ChatGPT: Character, assessment, and learning using AI [27]
7	Deep learning goes to school: toward a relational understanding of AI in education [28]
8	The impact of AI on learner–instructor interaction in online learning [29]

Table 2 presents the eight selected articles that align with the study's research objectives and criteria. The analysis of these articles reveals key themes regarding the role of AI in enhancing mathematical critical thinking skills. Specifically, the findings indicate that AI-based tools contribute to improved problem-solving abilities, logical reasoning, and

conceptual understanding. Additionally, the reviewed studies highlight the potential of AI to personalize learning experiences, adapting to students' individual needs and learning paces. However, challenges like the lack of pedagogical frameworks for AI integration and ethical considerations in AI-driven education were also identified. These insights provide a foundation for drawing meaningful conclusions and formulating recommendations for future research on optimizing AI's role in mathematics education.

Based on the paper that met the criteria for analysis, some studies showed that the use of AI in education has the potential to encourage students' critical thinking studies [25], [26] [29]. AI in education can encourage students to think more analytically and engage in complex epistemic performance rather than relying solely on procedural solutions. Assessment with AI can provide personalized formative feedback that focuses on thought processes and products rather than just standardized outcomes. This can support more recursive, collaborative, and reflexive learning than traditional assessment methods [25]. Later, in Seo *et al.* research [29], the use of AI in online learning seems to have the potential to encourage students to rely more on procedural solutions provided by AI rather than developing their own analytical and creative problem-solving skills. The study showed that both students and instructors were concerned that excessive AI-powered support could overly "standardize" the learning process and limit opportunities for exploration, discovery, and the development of higher-order thinking skills.

However, the research of Cecilia *et al.* [26] offers a different opinion. The study showed that the use of AI in university teaching and learning has the potential to encourage more analytical thinking and lead to overreliance on procedural solutions. While AI can provide personalized feedback and support to help students identify areas for improvement, the study expressed concern that over-reliance on AI could negatively impact the quality of education and students' critical thinking and writing skills. Essentially, the study highlights a potential trade-off between the benefits of AI-assisted learning and the preservation of essential cognitive skills.

Other research does not address how AI affects critical thinking skills but provides some insight into how controversial AI is in education [22]. AI is highly controversial, with debates surrounding its feasibility and implications dating back to its early history. Then research, Luckin and Cukurova [23] discuss the importance of learning science research for designing and evaluating educational technologies that use AI and propose a framework for developing and adopting AI-based educational technologies through interdisciplinary collaboration. Research Cope *et al.* [25] examined the effects of an AI-powered personalized video recommendation system on student engagement, motivation, and learning outcomes in a flipped classroom for a systems programming course, and found that the system significantly improved the learning performance and engagement of students with moderate levels of motivation. Research Crawford *et al.* [27] discussed the emergence of AI chatbots and the opportunities and challenges it presents for higher education. The research states that teachers play a major role in character development in students to utilize AI for good and not for abuse.

Integrating AI in educational settings has sparked significant debate regarding its impact on students' cognitive processes, particularly whether AI encourages analytical thinking or promotes reliance on procedural solutions [30], [31]. AI tools have been shown to provide immediate feedback and in-depth analytical assessment, which can increase students' emotional engagement and motivation in the learning environment [32]. This immediate feedback is critical as it allows students to reflect on their work and encourages a deeper understanding of the subject matter, thus promoting analytical thinking [33]. In addition, AI's ability to personalize the learning experience can facilitate collaboration

between students and intelligent systems, enhancing creativity and innovation [33]. This suggests that AI can encourage students to think more critically and analytically if used appropriately.

However, significant concerns exist regarding the potential for over-reliance on AI technology. Some research suggests that while AI can improve academic writing and motivation, it also raises the issue of dependency, where students may rely too much on AI for solutions rather than engaging in independent critical thinking [34], [35]. The challenge lies in balancing the use of AI tools with the need for students to develop their problem-solving skills independently. In addition, the pedagogical implications of AI in education highlight the need for educators to guide students in using AI as a tool rather than a crutch. Research shows that while AI can improve problem-solving skills, it is important for educators to address gaps in student understanding that AI cannot bridge [36]. This is particularly relevant in mathematics, where conceptual understanding is critical. Therefore, the role of educators becomes crucial in fostering an environment where AI is used to enhance learning without compromising students' analytical abilities [37], [38].

In addition, findings from Zou's research suggest that although students recognize the importance of developing critical thinking skills, the use of AI-generated content aids may create a paradox where students may not engage deeply with the material, leading to a decrease in critical thinking ability [19], [39]. This is in line with the idea that AI should augment rather than replace human cognitive functions, as emphasized by Kim *et al.*, who advocate for educational designs that encourage collaboration between students and AI [11], [40], [41]. If AI is considered a crutch, students may not develop the skills necessary to analyze, evaluate, and synthesize information independently [42].

Despite its potential, challenges remain in adopting AI in mathematics education. Future research should explore specific pedagogical frameworks that maximize AI's impact on higher-order thinking skills. Additionally, empirical studies are needed to assess long-term learning outcomes and the scalability of AI-driven interventions in diverse educational settings. Investigating the role of teachers in AI-integrated classrooms and identifying best practices for blending AI with traditional teaching methods will be crucial for optimizing its educational benefits. Overall, this study confirms that AI has the potential to enhance critical thinking in mathematics education. However, its successful implementation requires a comprehensive approach integrating technological, pedagogical, and ethical considerations. Future research and educational policies should focus on strategies that leverage AI's capabilities and ensure its responsible and effective use in fostering deeper mathematical understanding.

4. CONCLUSION

This study highlights the significant role of AI in enhancing students' critical thinking skills in mathematics. The findings indicate that AI serves as a tool for assisting learning and fosters analytical reasoning, problem-solving, and logical argumentation. AI-based interventions in mathematics education help students transition from rote and algorithmic learning to a deeper, more critical understanding of mathematical concepts. Additionally, AI supports personalized learning by adapting to individual learning styles and paces, enhancing student engagement and motivation. The implications of these findings suggest that well-defined pedagogical strategies should guide the integration of AI in mathematics education. While AI offers numerous benefits, its effectiveness depends on thoughtful implementation that emphasizes the development of critical thinking rather than mere automation of learning tasks. Educators must balance technological advancements with

meaningful instructional design to ensure AI-driven learning environments encourage deep cognitive engagement. Furthermore, ethical considerations, such as data privacy and algorithmic bias, should be carefully addressed in AI-based educational applications. This research has implications for developing hybrid learning models that integrate AI with traditional teaching approaches to achieve optimal learning outcomes.

AUTHOR CONTRIBUTION STATEMENT

MZA contributed to the article's writing, research methods analysis, data collection and processing, data analysis implementation, and results preparation and discussion sections. IZ contributed to providing direction and guidance in topic development, assisting in writing and editing, and providing input on relevant references and literature. HA contributed to providing direction and guidance in topic development and assisting in writing and editing.

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