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The Role of Artificial Intelligence in Developing Critical Thinking among Science Students: A Systematic Literature Review

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Abstract

The use of artificial intelligence (AI) in learning encourages active student engagement and promotes creative, systematic, and logical thinking. This study aims to explore the role of AI in enhancing critical thinking among science students through a Systematic Literature Review (SLR). This literature review follows the PRISMA model, analyzing 18 articles from various databases such as Scopus, Web of Science (WoS), and Springer Link, the study identifies two main approaches: AI as a support tool in developing students' critical thinking and the use of AI in Problem-Based Learning. The findings indicate that AI has the potential to enhance student understanding, motivation, and engagement through broad access to information and interactive learning experiences. However, there are challenges such as over-reliance on technology, ethical issues, and inequality in access. Therefore, further research is needed to strategically integrate AI with traditional teaching methods to effectively and inclusively support the development of critical thinking.

Keywords: Artificial Intelligence (AI), Critical Thinking, Science Education, Interactive Learning, Systematic Literature Review (SLR)

Introduction

In this modern era, science education plays a crucial role in shaping future generations with high levels of knowledge and skills. One of the main challenges faced by educators is to educate and form students who not only master scientific concepts but are also capable of thinking critically and creatively. Critical thinking is recognized as an essential skill for students to face challenges in the workplace and social environments, including the ability to generate creative solutions to complex problems. Recently, artificial intelligence (AI) has emerged as one of the technological innovations with the potential to enrich knowledge and develop critical thinking skills among students.

Moreover, one of the main concepts of AI is the ability of computers and systems to mimic human intelligence in thinking, learning, and decision-making. Its use in education offers many benefits to students and teachers (Normadiah, 2023). On November 28, 2023, the Digital Education Policy (DPD) was launched by YB Puan Fadhlina Sidek, the Minister of

the Ministry of Education Malaysia (MOE), with the aim of producing digitally literate students. AI is a crucial component in aligning Malaysia with global standards to face the Fifth Industrial Revolution (5IR). UNESCO categorizes AI in education into three main areas: supporting learning, supporting teaching, and supporting institutional management.

Furthermore, AI has great potential to improve the quality of education, particularly in enhancing critical thinking among science students (Harmalawati, 2019). AI can provide fast, human-like feedback, allowing students to better understand learning materials and develop their critical thinking skills. It also creates adaptive learning environments tailored to individual needs and capabilities. However, over-reliance on AI can diminish students' ability to think critically and creatively if they depend on technology instead of thinking independently. Hence, it is crucial to evaluate both the positive and negative impacts of AI before implementing it comprehensively in the education system.

Purpose of Study

The purpose of this study is to explore the role of Artificial Intelligence (AI) in fostering critical thinking skills among science students. As the educational landscape continues to evolve in the digital era, the integration of AI technologies in teaching and learning has shown both potential and challenges (Zawacki Richter et., 2019). This study seeks to examine whether AI can effectively support the development of critical thinking as a core competency in 21st-century education among students in the field of science (Saavedra & Opfer, 2012).

To precise, this study aims to identify and analyses existing research finding on how AI tool, applications and platforms are being utilized to enhance critical thinking. Therefore, this study will highlight the key mechanism through which AI contributes to student's analytical reasoning, problem solving, decision making and self-awareness. Moreover, the study will assess both the positive and negative impacts of AI use in science education setting, offering a balanced perspective on its influence (Baker & Smith, 2019). In short, the findings of this review may guide the future research and educators of AI technologies in ways that genuinely enrich the cognitive development of learners.

Research Question

The formulation of the research questions in this study is guide by the PICo model, an acronym where "P" stands for "Population" or "Problem", "I" for "Interest" and Co refer to "Context" (Lockwood et., 2015; Mohamed Shaffril et al., 2021). These three elements were responsible to derive the research questions for this systematic literature review.

In the context of this study, the "Population" refers to science student, the "Interest" is how Artificial Intelligence (AI) influence the development critical thinking and the "Context" is science education within primary and secondary school setting. Based on these components, the following two research question were developed:

1. How Artificial Intelligence (AI) support the development of critical thinking among science students?
2. What are the positive and negative impacts of AI use on the development of critical thinking among science students?

These questions aim to guide the systematic review in exploring the educational value and implications of AI integration in science classrooms with particular focus on how such technologies influences student's higher- order thinking skills.

Methodology

Systematic Literature Review (SLR) is a qualitative study that involves structured steps to search, evaluate, and present information from various literature sources selected systematically. The information search method was conducted by accessing databases such as Scopus, Web of Science (WOS), and Springer Link to obtain high-quality sources relevant to the research needs. This study also used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram (Moher et al., 2019). PRISMA consists of four main phases that support clearer and more accurate SLR writing: identification, screening, eligibility, and inclusion of articles. The SLR conducted includes search strategy, selection criteria, selection process, data collection, and data analysis ((Liberati et al., 2009).

Identification

According to Mohamed Shaffril et al. (2020), during the identification stage, it is recommended that keywords including synonyms, related terms, and keyword variations be carefully selected to ensure that the search results yield relevant studies. In this study, the keywords "artificial Intelligence" or "critical thinking" or "science education" were used to search for relevant articles through the databases Scopus, Web of Science, and Springer Link. These keywords were intended to retrieve articles related to the role of AI in developing students' critical thinking skills within the field of science.

Screening

The screening process is a procedure used to identify articles that meet the study criteria and are relevant to the systematic literature review (SLR) being conducted (Hayrol Azril, 2020). This screening stage aims to narrow down the number of articles and to select those that are suitable for the research topic by establishing several criteria, such as the year of publication, language, and type of reference material, as shown in Table 1, which outlines the inclusion and exclusion criteria for the articles. In this study, the publication year is limited to a five-year range, from 2020 to 2024, as this period represents a time frame during which the topic remains actively discussed and is still considered a current issue. In addition, all selected articles from the databases are in English only. Furthermore, only journal articles are selected in this study, as journal articles typically provide complete and detailed reporting, making them reliable reference materials.

Table 1
Article Selection Criteria

Criteria	Eligibility	Exclusion
Year published	2020 until 2024	2018 or earlier
Language	English	Articles in other than English language
Document Type	Article with empirical data	Book, book chapters, thesis, prosiding

Eligibility

The eligibility process involves manual selection by ensuring that articles meet the inclusion criteria and are suitable to be used in the current study to fulfill the research objectives. Figure 1 summarize the search and selection process following the PRISMA model. This screening is conducted by focusing on two key components, namely the tittle and abstract of the studies. Subsequently, articles that do not meet the criteria and theme are excluded. Therefore, after conducting several rounds of screening at this stages, 38 articles were found to not meet the study's criteria and only 18 articles fulfilled all the predetermined selection criteria and were included in the systematic literature review (SLR). The final screening resulted in 18 articles that met the criteria for addressing the research questions (Table 2).

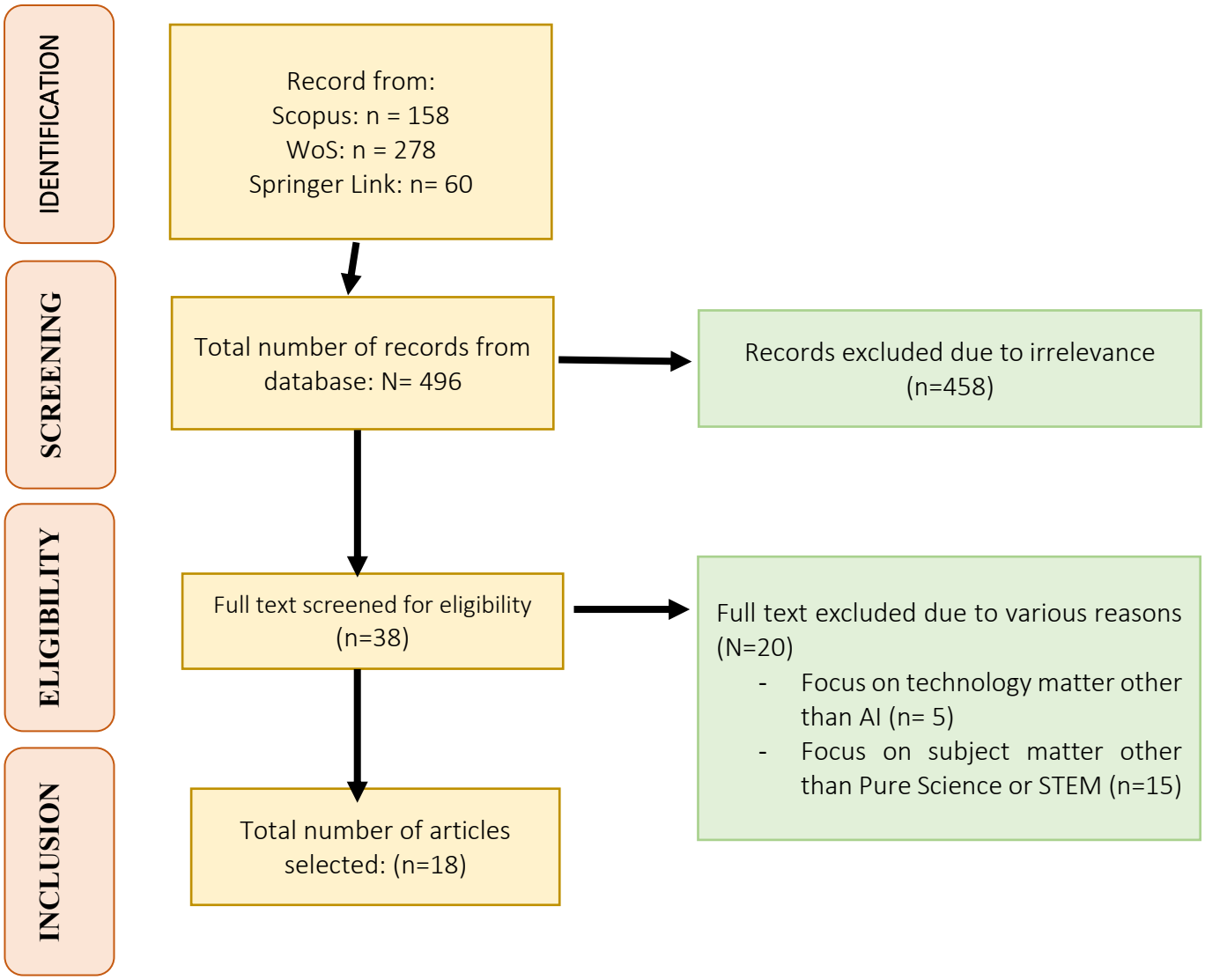

Figure 1: PRISMA Model Flow Chart
Source: Adapted from PRISMA Model by Page et al. (2021)

Table 2
List of Selected Articles

No	Author and year	Title of Article
1	Ganjoo et al., (2024)	*Beyond boundaries: exploring a generative artificial intelligence assignment in graduate, online science courses*
2	Almasri (2024)	*Exploring The Impact of Artificial Intelligence in Teaching and Learning of Science: A Systematic Review of Empirical Research*
3	Baker, Bowers & Ghassemi (2024); Ganjoo et al., (2024)	*Student perceptions of generative artificial intelligence in didactic patient presentations*
4	Tong et al., (2024)	*Reforming China's Secondary Vocational Medical Education: Adapting to the Challenges and Opportunities of the AI Era*
5	Blonder et al., (2024)	*Are They Ready to Teach? Generative AI as a Means to Uncover Pre-Service Science Teachers' PCK and Enhance Their Preparation Program*
6	Zhai, Nyaaba & Ma (2024)	*Can Generative AI and ChatGPT Outperform Humans on Cognitive- Demanding Problem-Solving Task in Science?*
7	Guerra (2024)	*The Contribution of Critical Thinking to STEM Discipline at The Time of Generative Intelligence*
8	Ramnarain et al., (2024)	*Pre-Service Science Teachers' Intention to use Generative Artificial Intelligence in Inquiry-Based Teaching*
9	Mnguni (2024)	*A Qualitative Analysis of South African Pre-service Life Sciences Teachers' Behavioral Intentions for Integrating AI in Teaching*
10	Feldman-Maggor et al., (2024)	*Perspectives of Generative AI in Chemistry Education Within the TPACK Framework*
11	Thompson & Fecher (2024)	*Using Adult Learning Theory to Guide Instruction in Training Physical Therapy Students on the Use of AI in Didactic Education*
12	Tang & Cooper (2024)	*The Role of Materiality in an Era of Generative Artificial Intelligence*
13	Cooper (2023)	*Examining Science Education in ChatGPT: An Exploratory Study of Generative Artificial Intelligence*
14	O'Connor (2023)	*Nursing education in the age of artificial intelligence powered Chatbots (AI-Chatbots): Are we ready yet?*
15	Park et al., (2023)	*Integrating Artificial Intelligence into Science Lesson: Teacher's Experience and Views*
16	Xia & Li (2022)	*Artificial Intelligence for Higher Education Development and Teaching Skills*
17	Xu & Ouyang, (2022)	*The application of AI technologies in STEM education: a systematic review from 2011 to 2021*
18	Gunawan et al., (2021)	*Implementation of Competency Enhancement Program for Science Teachers Assisted by Artificial Intelligence in Designing HOTS-based Integrated Science Learning*

Findings and Discussion

Background of studies

The number of articles published by year is as follows: one article in 2021, two articles in 2022, three articles in 2023 and 12 articles in 2024. The increasing number of articles published each year indicates a growing research interest among scholars in exploring the potential applications of artificial intelligence in science education. Figure 2 presents a bar graph illustrating the number of articles published over the past four years.

The analysis of the articles demonstrates that while AI offers considerable promise in promoting critical thinking, its implementation must be thoughtfully designed to avoid unintended drawbacks. This systematic review explores these dual impacts to help educators, policymakers, and stakeholders make informed decisions about integrating AI into science classrooms.

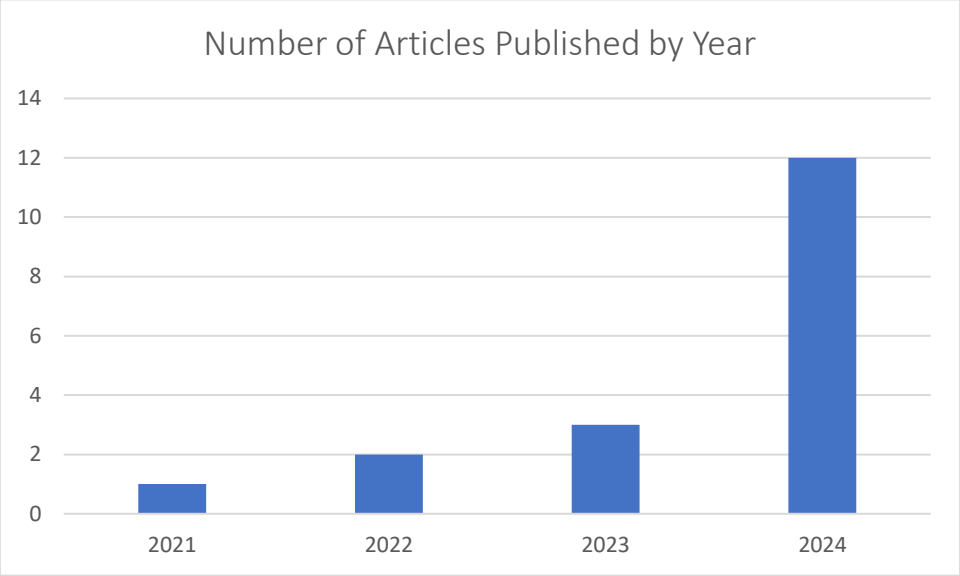

Figure 2: Bar chart of number of articles published between 2019 and 2024

How Artificial Intelligence (AI) support the development of critical thinking among science students?

AI as a Support Tool in Developing Critical Thinking

Table 3 summarize the reviewed literature consistently highlights that Artificial Intelligence (AI) holds significant potential in enhancing students' critical thinking skills, particularly in science education. All of the reviewed articles indicate that AI has great potential to support critical thinking among students. Critical thinking involves the evaluation of information and taking an analytical approach to the issues discussed. According to Dahliyah Abdul Jalil (2024), AI should only function as a supportive tool, not a replacement for human interaction, in order to ensure that students still receive sufficient social interaction throughout the learning process. Moreover, integrating AI into traditional learning approaches encourages a balance between theoretical ideas and practical applications.

Several articles state that the application of AI in traditional classroom contexts results in a more balanced learning ecology. In this model, students develop conceptual understanding through explicit teaching by teachers and then apply that conceptual understanding and do so using AI programs. AI programs can provide real-time modelling of real-world tasks, feedback specific to the student and exploration of what if scenarios (Almasri, 2024; Mnguni, 2024; Park et al., 2023; Xia & Li, 2022). The articles collectively identified the educator's role in establishing AI tools are used appropriately. Eight studies highlighted the importance of professional learning for teachers and supporting the deliberate integration of AI in the curriculum to ensure these tools can be used as scaffolding of thought, but not replace thought (Blonder, Feldman-Maggor & Rap, 2024; Ramnarain et al., 2024; Gunawan et al., 2021).

AI in Problem-Based Learning (PBL)

Problem-Based Learning (PBL) encourages students to interact with AI systems to solve complex and challenging problems. AI helps students analyse data, formulate problems, and find solutions — a process that encourages deep thinking, exploration of alternative solutions, and critical evaluation of decisions. Despite, PBL contexts prompt students to consider real scientific issues in the context of inquiry-based practices. AI serves the role of a powerful assistant by showing students how to interpret data, simulate a problem situation, and ultimately evaluate possible solution pathways (Ganjoo et al., 2024; Guerra, 2024; Xu & Ouyang, 2022).

There is evidence from ten studies that AI-enhanced tools promote higher-order thinking by further providing critical reflection, decision making, and evaluating (Baker, Bowers, & Ghassemi, 2024; Tong et al, 2024; Thompson & Fecher, 2024; Tang & Cooper, 2024; Cooper, 2023; O'Connor, 2023; Zhai, Nyaaba, & Ma, 2024). Together with AI, students engage with thinking about different perspectives and engage in thoughtful, deeper exploration of the problem space.

Table 3
Summary of Literature on the Role of AI in Developing Students' Critical Thinking

Theme	Author and Years	Key Finding
AI as a support tool	Almasri (2024); Blonder, Feldman-Maggor & Rap (2024); Ramnarain et al. (2024); Mnguni (2024); Feldman-Maggor, Blonder & Alexandron (2024); Park et al. (2023); Xia & Li (2022); Gunawan et al. (2021)	Effective AI use depends on educator training and thoughtful curriculum integration.
AI in Problem-Based Learning (PBL)	Ganjoo et al. (2024); Baker, Bowers & Ghassemi (2024); Tong et al. (2024); Zhai, Nyaaba & Ma (2024); Guerra (2024); Thompson & Fecher (2024); Tang & Cooper (2024); Cooper (2023); O'Connor (2023); Xu & Ouyang (2022)	AI enhances critical thinking through data analysis, problem formulation, and solution evaluation in PBL contexts.

What are the positive and negative impacts of AI use on the development of critical thinking among science students?

While AI holds significant potential for enhancing critical thinking in science education, the reviewed articles also discuss several key positive and negative impacts. Overall, the positive impact of broader access to diverse information stands out as the most significant contribution of AI to critical thinking while the most pressing negative impact is the overdependence on AI, which can undermine students' motivation and critical engagement with learning materials. Therefore, by considering these, both students and educators can better harness AI as a valuable tool for enriching learning and strengthening students' critical thinking skills. Table 4 and Table 5 summarize the reviewed literature on the positive and negative impact of AI on student's critical thinking.

Broader Access to Information

One of AI's major strengths is its ability to provide students with a wide range of information and perspectives that may not be easily accessible through traditional sources (Ganjoo et al. 2024; Tong et al. 2024; Mnguni 2024; Cooper 2023; Park et al. 2023). For instance, AI tools

like ChatGPT can process and deliver information from diverse domains. As a result, students can obtain answers from multiple perspectives including theoretical explanations, factual information, and real-world examples in science. With AI assistance, students can save time searching for information across different platforms and are encouraged to compare various viewpoints, expanding their understanding of a topic.

Increased Student Engagement and Motivation

AI can create more interactive and engaging learning experiences, such as educational simulations and AI-powered learning tools that allow students to explore scientific concepts in a hands-on manner (Baker, Bowers & Ghassemi, 2024; Mnguni, 2024; Feldman-Maggor, Blonder & Alexandron, 2024). When students perceive their learning as relevant and stimulating, they tend to develop greater interest in the subject. AI can make science learning more relatable by connecting scientific concepts to real-world applications, virtual experiments, and everyday life scenarios. This process encourages students to analyse information, make inferences, and formulate conclusions boosting both their understanding and critical thinking skills.

Enhanced Analytical Skills

The enhancement of analytical skills refers to students' ability to analyse, assess, and make decisions based on the information they receive especially when applied in problem- based learning (PBL) environments (Zhai, Nyaaba & Ma, 2024; Guerra, 2024; O'Connor, 2023; Xu & Ouyang, 2022). With AI providing access to vast and diverse data, students learn to process different types of content and arguments, sharpening their ability to evaluate the quality of information Regular interactions with AI also train students to question and critically assess content, encouraging active engagement rather than passive consumption of information.

Table 4
Summary of Reviewed Literature on the Positive Impacts of AI

Author and year	Positive impact of using AI		
	Broader Access to information	**Increased Engagement and Motivation**	**Enhanced Analytical Skills**
Ganjoo et al. (2024)	x		
Baker, Bowers & Ghassemi (2024); Ganjoo et al. (2024)		x	
Tong et al., (2024)	x		
Zhai, Nyaaba & Ma (2024)			x
Guerra (2024)			x
Ramnarain et al., (2024)		x	
Mnguni (2024)	x	x	
Feldman-Maggor et al. (2024)		x	
Cooper (2023)	x		
O'Connor (2023)	x	x	x

Park et al. (2023)	x		
Xia & Li (2022)	x		x
Xu & Ouyang (2022)	x		x
Gunawan et al., (2021)	x		

Overdependence on AI and Technology

Over time, students may become overly reliant on AI, leading to passivity in the learning process — simply waiting for AI-generated answers rather than actively seeking and processing knowledge. This dependence may also extend to writing, research, and task completion, ultimately impairing their ability to function effectively without technological assistance Ganjoo et al., 2024; Ramnarain et al., 2024; Tong et al., 2024). Furthermore, this reliance can hinder students' independent thinking abilities, as they may accept information at face value without evaluating its accuracy or relevance.

Ethical Challenges and Trust Issues

Ethical concerns and data privacy in the use of AI in education are serious matters, especially since many AI applications require the collection of student data for optimal performance. Such data may include personal information, academic records, and interactions with learning platforms (Almasri, 2024; Blonder, Feldman-Maggor & Rap, 2024; Cooper, 2023). If not securely stored, this data could fall into the wrong hands, leading to privacy breaches. There is also the issue of bias, if AI algorithms are trained on unbalanced data, they could produce skewed outcomes that disadvantage certain student groups based on their background or prior performance. These concerns could raise alarm among parents, which is why educational institutions must ensure ethical and responsible AI use and protect student data.

Inequality in Access to Technology

Another major challenge in using AI to foster critical thinking in science education is the inequality in access to advanced technology (Xia & Li, 2022; Gunawan et al., 2021; Feldman-Maggor, Blonder & Alexandron, 2024). Students in rural areas or schools with limited infrastructure such as weak internet access, insufficient digital devices, and a lack of trained teachers may not fully benefit from AI in their learning. Without access to such tools, these students are limited to traditional methods that may not sufficiently prepare them for modern-day challenges. To address this issue, steps such as expanding technological infrastructure to rural areas, subsidizing digital equipment, and offering AI training programs to teachers should be taken ensuring all students, regardless of background or location, can benefit from AI technology.

Table 5
Summary of Reviewed Literature on the Negative Impacts of AI

Author and year	Negative impact of using AI		
	Overdependence on AI	Ethical and Trust Issues	Inequality in Access
Ganjoo et al. (2024)	x	x	
Almasri (2024)		x	x
Tong et al., (2024)	x	x	
Blonder et al., (2024)		x	x
Zhai, Nyaaba & Ma (2024)	x		
Guerra (2024)	x		
Ramnarain et al., (2024)	x		
Feldman-Maggor et al., (2024)		x	x
Thompson & Fecher (2024)	X		x
Cooper (2023)	x	x	
O'Connor (2023)	x	x	
Xia & Li (2022)	x	x	x
Xu & Ouyang (2022)			
Gunawan et al. (2021)	x		x

Recommendation for Future Research

Future research is encouraged to explore more advanced applications of AI, including deep learning and emotional recognition, which could enhance interaction between AI systems and learners. Additionally, more studies are needed to determine the most effective ways to integrate AI with traditional teaching methods so that AI serves as a complement to, rather than a replacement for, teachers. With the right approach, AI has the potential to become a valuable tool in shaping the critical thinking skills of the younger generation, preparing them for a brighter and more complex future.

Conclusion

Overall, this Systematic Literature Review clearly demonstrates that AI plays a significant role in fostering critical thinking among students, particularly through adaptive and interactive approaches. However, to ensure that AI is truly effective in supporting the development of critical thinking, challenges such as algorithmic bias and the need for robust technological infrastructure must be addressed.

Also, this research contributes both theoretically and contextually to the growing discourse on the role of Artificial Intelligence (AI) in science education, particularly in developing students' critical thinking skills. Theoretically, this study enhances existing knowledge by synthesizing current empirical findings to present a nuanced understanding of

AI's dual impact both supportive and detrimental on critical thinking. It offers a framework for categorizing AI interventions based on their pedagogical purpose such as inquiry-based learning, problem-solving and content delivery thereby guiding future theoretical exploration on how technology mediates cognitive development.

Contextually, this study provides timely insight for educators, curriculum developers, and policymakers navigating the post-pandemic educational landscape, especially in contexts where AI integration is accelerating but remains uneven. By highlighting both the potential and the risks associated with AI in classroom settings, this study informs more flexible and reflective integration strategies in diverse educational environments. It is especially relevant in regions where digital inequality, teacher preparedness, and curriculum alignment with 21st-century skills remain key concerns. Thus, this research not only advances theoretical perspectives on AI in education but also plays a practical role in shaping future implementations and interventions.

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References

Almasri, F. (2024). Exploring the Impact of Artificial Intelligence in Teaching and Learning of Science: A Systematic Review of Empirical Research. *Research in Science Education*, *54*(5), 977–997. https://doi.org/10.1007/s11165-024-10176-3

Baker, C., Bowers, R., & Ghassemi, E. (2024). Student perceptions of generative artificial intelligence in didactic patient presentations. *Pharmacy Education*, *24*(1), 590–597. https://doi.org/10.46542/pe.2024.241.590597

Baker, T., & Smith, L. (2019). *Educ-AI-tion rebooted? Exploring the future of artificial intelligence in schools and colleges*. NESTA. https://www.nesta.org.uk/report/education-rebooted/

Blonder, R., Feldman-Maggor, Y., & Rap, S. (2024). Are They Ready to Teach? Generative AI as a Means to Uncover Pre-Service Science Teachers' PCK and Enhance Their Preparation Program. *Journal of Science Education and Technology*. https://doi.org/10.1007/s10956-024-10180-2

Cooper, G. (2023). Examining Science Education in ChatGPT: An Exploratory Study of Generative Artificial Intelligence. *Journal of Science Education and Technology*, *32*(3), 444–452. https://doi.org/10.1007/s10956-023-10039-y

Feldman-Maggor, Y., Blonder, R., & Alexandron, G. (2024). Perspectives of Generative AI in Chemistry Education Within the TPACK Framework. *Journal of Science Education and Technology*. https://doi.org/10.1007/s10956-024-10147-3

Ganjoo, R., Rankin, J., Lee, B., & Schwartz, L. (2024). Beyond boundaries: exploring a generative artificial intelligence assignment in graduate, online science courses. *Journal of Microbiology & Biology Education*, *25*(3). https://doi.org/10.1128/jmbe.00127-24

Guerra, E. (2024). The contribution of critical thinking to STEM disciplines at the time of generative intelligence. *STEM Education*, *4*(1), 71–81. https://doi.org/10.3934/steme.2024005

Gunawan, K. D. H., Liliasari, L., Kaniawati, I., & Setiawan, W. (2021). Implementation of Competency Enhancement Program for Science Teachers Assisted by Artificial

Intelligence in Designing HOTS-based Integrated Science Learning. *Jurnal Penelitian Dan Pembelajaran IPA*, *7*(1), 55. https://doi.org/10.30870/jppi.v7i1.8655

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., … Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. PLoS Medicine, 6(7). https://doi.org/10.1371/journal.pmed.1000100

Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). *Intelligence Unleashed: An Argument for AI in Education*. Pearson.

Mnguni, L. (2024). A Qualitative Analysis of South African Pre-service Life Sciences Teachers' Behavioral Intentions for Integrating AI in Teaching. *Journal for STEM Education Research*. https://doi.org/10.1007/s41979-024-00128-x

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. BMJ (Online), 339(7716), 332–336. https://doi.org/10.1136/bmj.b2535

O'Connor, S., & ChatGPT. (2023). Open artificial intelligence platforms in nursing education: Tools for academic progress or abuse? In *Nurse Education in Practice* (Vol. 66). Elsevier Ltd. https://doi.org/10.1016/j.nepr.2022.103537

Park, J., Teo, T. W., Teo, A., Chang, J., Huang, J. S., & Koo, S. (2023). Integrating artificial intelligence into science lessons: teachers' experiences and views. *International Journal of STEM Education*, *10*(1). https://doi.org/10.1186/s40594-023-00454-3

Ramnarain, U., Ogegbo, A. A., Penn, M., Ojetunde, S., & Mdlalose, N. (2024). Pre-Service Science Teachers' Intention to use Generative Artificial Intelligence in Inquiry-Based Teaching. *Journal of Science Education and Technology*. https://doi.org/10.1007/s10956-024-10159-z

Saavedra, A. R., & Opfer, V. D. (2012). Learning 21st-century skills requires 21st-century teaching. *Phi Delta Kappan*, 94(2), 8–13.

Tang, K. S., & Cooper, G. (2024). The Role of Materiality in an Era of Generative Artificial Intelligence. *Science and Education*. https://doi.org/10.1007/s11191-024-00508-0

Thompson, S. H., & Fecher, P. (2024). Using Adult Learning Theory to Guide Instruction in Training Physical Therapy Students on the Use of AI in Didactic Education. *Medical Science Educator*. https://doi.org/10.1007/s40670-024-02066-0

Tong, W., Zhang, X., Zeng, H., Pan, J., Gong, C., & Zhang, H. (2024). Reforming China's Secondary Vocational Medical Education: Adapting to the Challenges and Opportunities of the AI Era. In *JMIR Medical Education* (Vol. 10). JMIR Publications Inc. https://doi.org/10.2196/48594

Xia, X., & Li, X. (2022). Artificial Intelligence for Higher Education Development and Teaching Skills. *Wireless Communications and Mobile Computing*, *2022*. https://doi.org/10.1155/2022/7614337

Xu, W., & Ouyang, F. (2022). The application of AI technologies in STEM education: a systematic review from 2011 to 2021. In *International Journal of STEM Education* (Vol. 9, Issue 1). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1186/s40594-022-00377-5

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education – where are the educators? *International Journal of Educational Technology in Higher Education*, 16(1), 39.

Zhai, X., Nyaaba, M., & Ma, W. (2024). Can generative AI and ChatGPT outperform humans on cognitive-demanding problem-solving tasks in science? *Science & Education*. http://arxiv.org/abs/2401.15081