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The Impact of AI Tools on Critical Thinking in Science Education: A Systematic Review of Theoretical Advancements and Practical Outcomes

The current digital transformation of education is accompanied by the active integration of artificial intelligence (AI) tools into the educational process. In science education, this creates new questions and conditions for developing critical thinking in students and poses a challenge for researchers and practicing educators to analyze the effectiveness and risks of AI technologies. This paper presents a systematic literature review, conducted according to PRISMA standards, to analyze the impact of AI tools on the development of critical thinking in science education. The search was conducted in the Taylor & Francis, IEEE Xplore, Wiley Online Library, and Google Scholar databases for the period 2022–2025. Of the 546 identified publications, 12 studies were selected after applying the inclusion and exclusion criteria. The analysis revealed that the use of generative chatbots, machine learning, written work analytics, and AI-STEM projects in general contributes to the development of critical thinking, argumentation, reflection, and academic motivation. Risks identified include unreliable data, dependence on digital tools, decreased teacher creativity, and ethical and privacy issues. The review emphasizes the need for more rigorous research using standardized tools to assess critical thinking and expanding the scope of the study to include various disciplines within the natural sciences.

Keywords: critical thinking, science education, artificial intelligence, learning, systematic review, methods, cognitive skills, ChatGPT.

Introduction

The topic of developing critical thinking in the teaching system of natural sciences remains relevant to this day. According to Frima et al [1, 2], the dominant thinking skills that are needed in the 21st century are critical thinking skills. Defining critical thinking (CT) in a standardized manner remains a complex task, given its multifaceted nature as a psychological construct [3]. Diverse perspectives exist regarding its core attributes, and consequently, the conceptualization and definitions of CT have evolved over time. Diane F. Halpern and Dana S. Dunn [4] conceptualize critical thinking (CT) as the application of cognitive skills and strategies that enhance the likelihood of achieving favorable outcomes. It refers to deliberate, logical, and goal-oriented reasoning, typically engaged in tasks such as problem-solving, drawing inferences, estimating probabilities, and making decisions, where individuals employ context-appropriate and effective thinking strategies. Carlos Saiz and Silvia F. Rivas [5] describe the phenomenon of “Toulminian dominance” in critical thinking theory, whereby CT was primarily framed through the lens of argumentation and logic. In more recent scholarship, however, critical thinking has come to be understood not only in relation to argumentation (pre-decisional processes), but also as encompassing problem-solving and decision-making skills. However, it is generally accepted that, according to the classic work [6], the main components of this skill are: interpretation, analysis, evaluation, inference, explanation, and self-regulation. This expanded understanding of critical thinking reflects a shift from a narrowly logical approach to a more comprehensive, cognitive-metacognitive perspective. This highlights the need to develop pedagogical strategies that can not only develop individual analytical skills but also support the holistic development of critical thinking skills in the educational environment.

The development of students’ critical thinking is closely associated with enhanced socialization, greater levels of interaction, improved relationship building, and the advancement of communication skills [7]. Critical thinking (CT) has long been regarded as a highly desirable competency, not only within the field of edu-

cation but also across diverse sectors, including business, industry, and various professional organizations. Its value lies in fostering effective problem-solving, sound decision-making, and adaptability—skills that are increasingly essential in addressing the complex challenges of contemporary society. Consequently, CT is recognized as a key attribute for both academic development and professional success [4, 8]. Given the importance of critical thinking, many teachers and entire universities around the world are making it their mission to develop this skill in their students. Much research has been devoted to various pedagogical technologies, methods, techniques and forms of teaching that can contribute to the development of analytical skills and cognitive abilities of students both in secondary school and in higher education settings. So, according to two works [3, 9] (systematic and meta-analysis, respectively), one of the most successful forms of organizing the educational process for developing critical thinking is problem-based learning. Project-based learning fosters the development of students' critical thinking (CT) skills by emphasizing core concepts and principles, engaging learners in problem-solving and the completion of meaningful tasks, and encouraging independent knowledge construction through authentic experiences. Moreover, this approach enables students to produce realistic and valuable outcomes, thereby linking learning to practical application [10]. Other widely used methods include: cooperative learning [11], guided inquiry and predict-observe-explain (POE model) [12], a special teaching technique that uses socio-scientific issues and case studies [13]. Another set of strategies is aimed at developing metacognitive skills that are directly related to critical thinking and reflection [14]. In general, active learning methods and innovative technologies are preferable in the modern realities of natural science education for the development of 21st century skills.

The integration of artificial intelligence and its tools into science education is a new field of research that carries both potential opportunities and risks. Given the information generation capabilities of these systems, the need for critical thinking has increased for both teachers and students. The integration of artificial intelligence (AI) into education represents a substantial shift from traditional pedagogical approaches, enabling personalized learning and addressing diverse educational needs. At the same time, this transformation poses challenges, such as the necessity for extensive teacher training. According to Yoshija Walter [15], three skills are needed to successfully implement this technology in the classroom: AI literacy, prompt engineering, and critical thinking. These three skills are essential not only for harnessing the full potential of generative artificial intelligence but also for safeguarding users' cognitive and creative capacities. As highlighted in the systematic review by Chunpeng Zha and colleagues [16], excessive reliance on chatbots may undermine analytical thinking, problem-solving abilities, and decision-making strategies. This concern is supported by study [17], which analyzed the impact of AI tools on the development of critical thinking and problem-solving skills in students using an online survey. Although many students believed they already possessed developed critical thinking skills and that AI could enhance their independence, over 80 % feared it would undermine their autonomy in decision-making, and almost three-quarters cited the loss of responsibility and autonomy as the main risk. Despite concerns about AI, its role as an assistant to teachers and students should not be downplayed. For example, ChatGPT promoted successful lesson planning, openness, and improved teachers' critical approach to self-assessment [18]. Tools like ChatGPT can act as powerful tools—facilitating the preparation of educational materials, stimulating information analysis, and supporting individualized learning. However, without pedagogical support and targeted development of critical thinking skills, AI can contribute to a passive thinking style and a decrease in student independence.

Despite the growing body of research on artificial intelligence (AI) in education, the specific relationship between AI tools and the development of critical thinking in science education remains insufficiently explored. While individual studies have highlighted both the opportunities and challenges of integrating AI into learning environments, there is still a lack of a comprehensive synthesis that systematically evaluates these findings. This review seeks to address that gap by examining recent literature on the role of AI tools in fostering or constraining critical thinking within science education. The aim is to provide a structured overview of current evidence, clarify emerging trends, and identify challenges and opportunities for future research. Thus, this review emphasizes a focused, critical analysis of AI integration in the context of the rapid digital transformation of educational systems worldwide. This approach will help identify key trends, the most effective strategies for using AI tools, and the conditions under which their use fosters critical thinking. Furthermore, systematizing the data creates a foundation for new research and new ideas.

Methods and materials

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement guidelines [19]. The search was conducted in September 2025. The

protocol for the systematic literature review is presented in Table 1. The protocol includes the review objective, formulation of research questions, timeframe, list of databases, and search strategies. It also specifies the tools used for selecting and managing bibliographic data.

Table 1

Systematic literature review protocol

Description	Conditions/ Outcome
Objective	To conduct a systematic literature review about impact of AI on critical thinking in science education field.
Source of Data	Taylor and Francis, IEEE Xplore, Wiley online library, Additional literature sources were checked using Google Scholar.
Area of interest	Artificial intelligence in education, critical thinking, science education, teaching.
Covered period	2022 — 2025
Tools that were used to analyze the literature	Mendeley, Rayyan, Microsoft Excel.

The data were collected from scientific publication databases, including Taylor & Francis, IEEE Xplore, and Wiley Online Library. These sources are regarded as reliable and widely recognized within the international academic community. In addition, the mentioned platforms offer convenient tools for filtering literature and exporting bibliographic data in widely used formats, such as RIS and BibTeX. Inclusion and exclusion criteria are described in Table 2.

Table 2

Criteria for selecting literature

Inclusion criteria	Exclusion criteria
Time frame: studies published between 2022 and 2025 (considering the rapid growth of AI tools in education).	Studies before time frame.
Language: articles published in English.	Not in English language.
peer-reviewed.	Conference papers, book reviews, essays.
Articles that discuss: AI (in any form) and critical thinking in the context of science education.	Not in science education field, no direct impact of AI to critical thinking in context of science education, philosophy articles.

The following search terms were included and combined using the operators “AND”, “OR”, “NOT”: (“critical thinking” OR “cognitive skills” OR “reasoning” OR “analytical thinking”) AND (“science education” OR “STEM education” OR “chemistry education” OR “natural science”) AND (“artificial intelligence” OR “AI” OR “machine learning” OR “educational technology” OR “intelligent tutoring system” OR “chatbot” OR “ChatGPT” OR “generative AI”). Initially, a total of 546 articles were found (Fig. 1).

Forty articles were removed for various reasons (shown in Figure 1). The remaining 506 articles were screened by title, keywords, and abstract. This step typically removes the largest number of articles that does not meet the accepted criteria and the topic of the study.

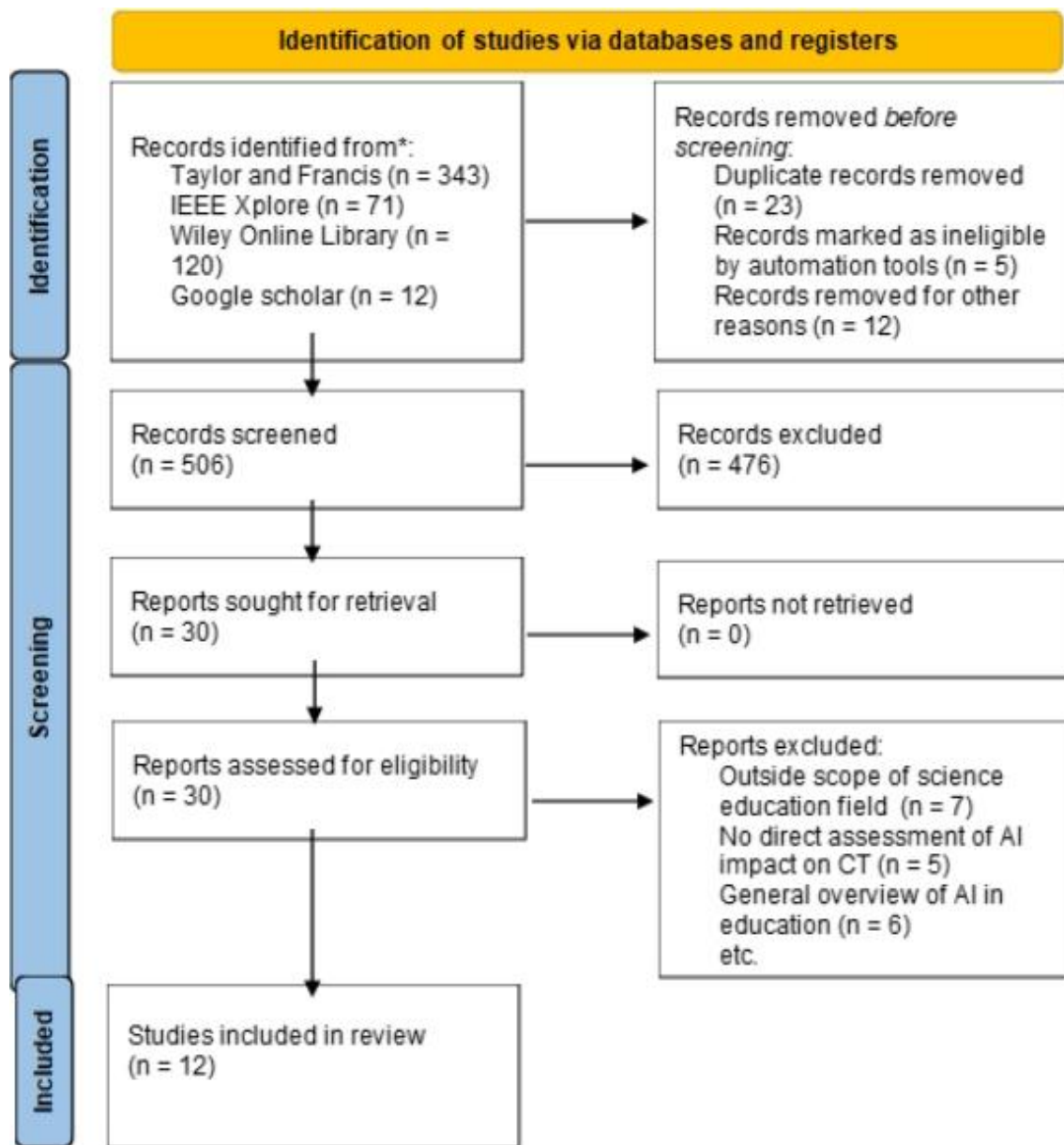


Figure 1. PRISMA flow chart of data extraction from the literature search

Using predefined inclusion and exclusion criteria, all records were screened, resulting in 476 publications being excluded at this stage as irrelevant. Full texts of the remaining 30 publications were successfully retrieved.

When evaluating the full-text versions, studies were excluded for several reasons. Seven publications were outside the field of science education and did not examine learning and teaching processes relevant to this work. Five publications did not provide a direct assessment of the impact of artificial intelligence tools on critical thinking, focusing instead on the general integration of technologies or other cognitive constructs. Six publications were general reviews or analytical articles about the role of AI in education, without empirical data or theoretical insights into the development of critical thinking. After applying all inclusion and exclusion criteria, 12 studies were included in the final analysis.

This systematic selection process demonstrates both the breadth and fragmentation of the current literature on artificial intelligence tools and critical thinking in science education. Although the initial search yielded over 500 potentially relevant publications, most were excluded at the title and abstract screening stage. The largest group of excluded papers were articles that, although they mentioned artificial intelligence, did not connect their research to science education or did not consider critical thinking as an outcome. Another significant subset of excluded papers included narrative reviews, philosophical perspectives, or theoret-

ical discussions (without any targeted practical theoretical developments or recommendations) of the role of AI, which, while useful for conceptual understanding, did not meet the selected criteria.

Results and Discussion

Twelve selected sources were analyzed and their main results are presented in Table 3. Each paper lists its authors, year and country of publication, research problem and objectives, sample size, research methods, and key findings. We believe this table format is optimal for reflecting the main ideas and trends in the field under study. This format is also convenient for readers, allowing them to easily familiarize themselves with the general content of each selected article.

Table 3

Results of the analysis of the selected 12 articles

Autors, year, country Ying Guo and Daniel Lee, 2023, USA [20]		
Problem and purpose of the study	Sample size	Methods or design of the study
To explore the use of ChatGPT for fostering critical thinking skills in higher education. The study specifically focuses on the use of ChatGPT in introductory chemistry courses [20].	N = 29 students were recruited from various sections of introductory chemistry courses	mixed-methods approach
<p>Key findings The ChatGPT-based activity resulted in statistically significant improvements in students' self-reported confidence regarding key critical thinking skills. This improvement was notable in their confidence to:</p> <ul style="list-style-type: none"> - ask insightful and probing questions (from 61 % to 89 %, $p = 0.03$) [21]; - analyze information and make logical conclusions (from 55 % to 84 %, $p = 0.003$) [21]; - understand complex concepts (from 64 % to 92 %, $p = 0.005$) [20]. <p>Positive perception of AI's challenging role: Students reported that ChatGPT was valuable because it provided diverse perspectives and challenged their current ways of thinking. Increased utilization for CT: following the activity, students showed an increased willingness to use ChatGPT to boost their self-efficacy in critical thinking [20]. Key limitations of ChatGPT: students identified concerns about the reliability and accuracy of information, including instances where ChatGPT provided nonexistent or unreliable sources [20].</p>		
Autors, year, country Grant Cooper, 2023, Australia [21]		
Problem and purpose of the study	Sample size	Methods or design of the study
A significant and relevant research gap examining ChatGPT-generated text in relation to science education topics or its potential application for creating learning resources [21].	Not applicable	Exploratory, self-study methodology
<p>Key findings The author came to several conclusions regarding the impact of ChatGPT on science education: Risk of Epistemic Authority: ChatGPT carries the risk of positioning itself as the "ultimate epistemic authority" whereby a "single truth" is assumed to exist. With the advent of generative AI, critical thinking is becoming more important than ever. It's the responsibility of educators to "prioritize critical thinking" and model responsible use of ChatGPT. Critical Evaluation of Resources: Educators should critically evaluate any AI-generated resources and adapt them to their specific teaching context. AI can be used to create rubrics, assessment criteria, and other learning materials [21].</p>		

Continuation of Table 3

Autors, year, country T.G. Olatunde-Aiyedun, 2024, Nigeria [22]		
Problem and purpose of the study	Sample size	Methods or design of the study
<p>The study is motivated by the need to prepare students for the changing demands of the digital age brought about by the rapid development of artificial intelligence technologies.</p> <p>Assess the impact of AI integration on student engagement.</p> <p>2. Assess changes in learning outcomes.</p> <p>3. Explore faculty and student perspectives on working with AI [22].</p>	N = 180 students	mixed-methods approach
<p>Key findings</p> <p>Key findings on research of three hypotheses:</p> <p>Student Engagement (H1): statistically significant correlation between AI integration and increased student engagement in science education [22];</p> <p>Learning Outcomes (H2): Performance indicators showed positive trends. The results suggest a statistically significant improvement in learning outcomes in AI-integrated courses compared to traditional courses [22];</p> <p>Perspectives on Use (H3): There was a statistically significant positive view among faculty and students regarding AI integration [22].</p> <p>Qualitative findings (faculty perspectives):</p> <p>1) Pedagogical approach: Faculty perceived AI as a pedagogical tool aimed at transforming classroom practice. AI enables the creation of a student-centered learning environment [22];</p> <p>2) Skill development (including critical thinking): The integration of ICT and AI is used to encourage student interaction, communication, innovation, and support creativity, critical thinking, and problem-solving as essential components of the curriculum [22].</p> <p>3) Advantages and disadvantages: Interactive AI tools linked to real-world applications are key factors in increasing engagement. However, faculty's low level of AI competencies and a lack of adequate materials and resources, such as computers, laptops, and Wi-Fi, are particularly noticeable in large class sizes [22].</p>		
Autors, year, country KokSingTang and Gde Buana Sandila Putra, 2025, Australia [23]		
Problem and purpose of the study	Sample size	Methods or design of the study
<p>Puposes:</p> <p>To explore the potential of customizable generative AI (GenAI) chatbots for developing dialogic learning and argumentation in science education.</p> <p>To fill the gap in empirical data on the mechanisms of dialogic interaction with chatbots in science education.</p> <p>To develop a chatbot that embodies the pedagogical principle of dialogic learning [23].</p>	N = 21 students aged 16–17 years old from two schools	instrumental case study methodology
<p>Key findings</p> <p>General conclusions and impact on critical thinking:</p> <p>The study confirms that embedding dialogic learning principles within the GenAI tool is crucial for developing critical thinking and argumentation skills.</p> <p>Through the DST principle, student-AI interactions shifted from passive information transfer to active dialogue. Students engaged in reflective thought processes that required considering alternative viewpoints, justifying their reasoning, and providing evidence.</p> <p>DST, designed based on Socratic dialogue, provides each student with an interlocutor who can scale dialogic pedagogy.</p> <p>The study emphasizes that GenAI should be designed and integrated to support the development of critical thinking and argumentation skills, particularly when working with social science problems [23].</p>		

Autors, year, country Yoshija Walter, 2024, Switzerland [15]		
Problem and purpose of the study	Sample size	Methods or design of the study
<p>The integration of artificial intelligence (AI) into education represents a transformative shift, but it comes with significant challenges: faculty workloads and skills shortages, and students' uncritical use of AI.</p> <p>Purpose: to explore the multifaceted role of AI in modern education, focusing on the importance of industrial engineering, AI literacy, and the development of critical thinking skills [15].</p>	Not applicable	a conceptual discussion based on a two-stage approach: a case study and a narrative literature review
<p>Key findings</p> <p>The authors note that in the era of AI there are three main skills:</p> <ol style="list-style-type: none"> 1) AI Literacy: Understanding that AI is a statistical model, not a truth generator. This includes recognizing its limitations, such as AI hallucinations (inventing false facts that sound authoritative), AI bias, and the AI lock-in problem (losing the full picture) [15]. 2) Prompt Engineering: Strategically formulating inputs to elicit desired answers. This is highlighted as a key skill for enhancing the learning experience and fostering critical thinking. Learning to effectively formulate prompts helps students recognize the limitations of AI, which in turn fosters their AI literacy [15]. 3) Critical Thinking: The ability to analyze information, evaluate different perspectives, and construct well-reasoned arguments in the context of AI [15]. <p>Autors also mentioned main problems of integrating AI to education field. They are: lack of training, rapid advancement of AI technologies and the difficulty of maintaining knowledge current, which are significant barriers [15].</p>		
Autors, year, country Xi-Hui Jia and Jui-Che Tu, 2024, Taiwan [24]		
Problem and purpose of the study	Sample size	Methods or design of the study
<p>The primary aim of the study is to investigate whether the presence of AI capabilities within a university environment can foster critical thinking awareness among students [24]</p>	N = 637 college students	quantitative study utilizing Structural Equation Modeling (SEM)
<p>Key findings</p> <p>AI capabilities were found to have an insignificant direct positive impact on students' critical thinking awareness. The authors suggest that although AI enhances efficiency, this gain does not automatically translate into improved in-depth analysis, logical reasoning, and independent thought required for critical thinking. AI capabilities indirectly enhance critical thinking awareness by first strengthening both general self-efficacy and learning motivation.</p> <p>The implementation of AI in universities significantly increases students' overall self-confidence (general self-efficacy).</p> <p>The widespread use of AI capabilities, particularly through real-time feedback and customized resources, has a noticeable positive impact on students' motivation to learn.</p> <p>Overall: the results suggest that AI capabilities are able to reshape the cognitive learning process [24].</p>		

Continuation of Table 3

Autors, year, country Peter W., Andrea W., Lukas M., Nowak A., and Borowski A., 2023, Germany [25]		
Problem and purpose of the study	Sample size	Methods or design of the study
Purpose: to explore the potential of Machine Learning (ML) combined with Natural Language Processing (NLP) to provide means for analytic, formative assessment of written reflections in science teacher education [25].	N = 149 preservice teachers	Machine Learning and Natural Language Processing, quantitative research approach focused on Writing Analytics
<p>Key findings</p> <p>The study demonstrated that Machine Learning (ML) and Natural Language Processing (NLP) tools can successfully enhance writing analytics in science education research, particularly for enabling analytic, formative assessment. An ML model (BERT), after being fine-tuned, was able to accurately and reliably filter specific sentences corresponding to higher-level reflective thought elements. This technology can facilitate the automation of essay evaluation and also become a tool for self-development of physics teachers in their professional activities [25].</p>		
Autors, year, country Lena Ivannova Ruiz-Rojas, Luis Salvador-Ullauri, and Patricia Acosta-Vargas, 2024, Ecuador [26]		
Problem and purpose of the study	Sample size	Methods or design of the study
To explore the impact of generative artificial intelligence tools on critical thinking and collaboration among university students [26].	N = 121 university students	mixed methods approach
<p>Key findings</p> <p>Positive Impact on Critical Thinking (Self-Reported): a substantial majority of students (64 %) reported that using generative AI tools significantly improved their ability to analyze and think critically. Specific GenAI tools, such as Chat PDF and YOU.COM, were identified as useful because they help students analyze, summarize, evaluate, and synthesize complex academic information.</p> <p>Despite the promising benefits, the research highlighted the importance of continuous training for both students and educators to ensure the effective and ethical use of GenAI and address concerns about fairness, algorithmic biases, and data privacy [26].</p>		
Autors, year, country Jeya Amantha Kumar, Min Zhuang, and Stephen Thomas, 2024, USA [27]		
Problem and purpose of the study	Sample size	Methods or design of the study
The study aimed to address this research gap by analyzing the initial perspectives of a small group of instructors concerning the strengths, weaknesses, opportunities, and threats (SWOT) associated with integrating ChatGPT 4.0 into their science course development [27].	5 participants were instructors teaching general education Natural Sciences courses	multimethod analysis approach, SWOT analysis framework
<p>Key findings</p> <p>The findings, summarized through the SWOT lens, highlight both benefits and significant risks associated with GAI integration. ChatGPT significantly enhances course design efficiency and reduces the time required for lesson planning, acting as a valuable tool for streamlining and customizing educational material. The tool effectively supports the alignment of course content with educational competencies and frameworks, such as UDL and Bloom's taxonomy. Autors also mentioned, there is a significant threat that heavy reliance on ChatGPT may hinder the cultivation of critical thinking abilities due to complacency and dependency, diminishing the instructor's personal engagement and creativity in the design process [27].</p>		

Autors, year, country Josef Šedlbauer, Jan Činčera, Martin Slavík, and Adéla Hartlová, 2024, Czech Republic [28]		
Problem and purpose of the study	Sample size	Methods or design of the study
The primary objective was to analyze the experience of undergraduate students' interaction with ChatGPT. The study aimed to contribute to identifying the problems arising from the widespread use of AI [28].	Junior university students (N = 25)	qualitative design focused on students' reflections
<p>Key findings</p> <p>The study found some evidence for enhancing critical thinking competence when using ChatGPT. This enhancement was primarily stimulated by the perceived imperfections in the AI's outputs, such as shallowness and limited reliability. Because students could not entirely rely on the AI, it made them feel compelled to think critically, seek other sources, and verify the outputs.</p> <p>Many students reflected that the AI showed them the topic (specifically environmental problems) from a different perspective, which helped them grasp the issue in higher complexity. AI also promoted their competence for sustainability by supporting the analysis of environmental and global problems [28].</p>		
Autors, year, country Paul P. Martin, David Kranz, Peter Wulff, and Nicole Graulich, 2023, Germany [29]		
Problem and purpose of the study	Sample size	Methods or design of the study
The study aimed to leverage deep learning following a methodological approach called computational grounded theory to extensively evaluate students' written arguments [29].	N = 64 students participated from an Organic Chemistry II course	Computational Grounded Theory (CGT), quantitative methods of data analysis
<p>Key findings</p> <p>Unsupervised machine learning (HDBSCAN) successfully identified 22 distinct, reproducible argumentation patterns across student responses, highlighting the degree of elaborateness, interconnectedness, and specificity of the chemical concepts applied.</p> <p>The multi-class deep learning model achieved almost perfect machine-human score agreement when automatically classifying the arguments according to the complex 20-category rubric [29].</p>		
Autors, year, country Hongwu Yang, Di Zhang, Weitong Guo, and Yanshan He, 2024, China [30]		
Problem and purpose of the study	Sample size	Methods or design of the study
To develop a systematic framework (AI-STEM PDF) for secondary school AI education to guide the design and implementation of AI courses. 2. To assess whether AI-STEM projects developed using this framework can significantly enhance students' AI literacy [30]	total of 64 middle school students	pre-post experimental design (a quasi-experimental design with a single group)
<p>Key findings</p> <p>The results demonstrated statistically significant improvements in students' overall AI literacy from the pre-test to the post-test;</p> <p>Significant positive differences were found across all three literacy dimensions (technical practices, interdisciplinary thinking, and ethical attitudes). More specifically, students exhibited notable advancements in higher-order cognitive abilities, including critical thinking, computational thinking, design thinking, innovation, and programming;</p> <p>Students reported that the project work, particularly the use of the project report book, was instrumental in enhancing their higher-order thinking. For instance, one student noted that the course taught them to integrate diverse perspectives and focus on understanding and simplifying problems rather than just applying formulas [30].</p>		

This systematic review summarizes the results of 12 studies published between 2023 and 2025, covering a wide geographic range: The United States, Australia, Nigeria, Taiwan, Switzerland, Germany, the Czech Republic, Ecuador, China, and elsewhere. Collectively, these studies analyze the impact of artificial intelligence (AI) tools — from generative chatbots (such as ChatGPT) to machine learning-based writing analytics and AI-STEM projects — on the development of critical thinking in students and teachers in the field of science education.

Geographical and methodological diversity. Most studies were conducted in high-income countries (e.g., the United States, Germany, Australia), but there is also representation from developing regions (Nigeria, Ecuador). Sample sizes ranged from small case studies with 5-25 participants to large survey studies with over 600 students. Mixed approaches predominated methodologically, often combining quantitative methods before and after experiments with qualitative interviews and reflections. Several studies employed advanced analytical methods, structured element modeling (SEM) [24], computational grounded theory [29], and deep learning [29] for text classification — reflecting a shift toward new approaches in pedagogical research.

Positive impact on critical thinking and related competencies. Overall, the integration of AI tools into science education demonstrated positive or some promising effects on the development of critical thinking. For example, AI activities increased students' confidence in asking questions, analyzing information, and understanding complex concepts [20]. Generative chatbots, built on the principles of dialogic learning, promoted the development of such important skills as: argumentation, reflection, and evidence-based reasoning [23]. Before/after studies within the AI-STEM framework demonstrated statistically significant increases not only in AI literacy but also in higher-order skills: critical and design thinking, interdisciplinary problem solving [30]. Large-scale quantitative analyses have shown that AI capabilities indirectly stimulate critical thinking by increasing students' learning motivation and self-efficacy, which in turn facilitates deeper cognitive engagement [24].

Conditions and mechanisms of impact on students. The review identifies several conditions under which AI facilitates the development of critical thinking. First, the implementation of dialogic or Socratic principles in AI shifts students from passive perception of information to active, evidence-based argumentation [23]. Second, AI's real-time feedback and adaptive capabilities create personalized support, encouraging students to reflect, test, and revise their own reasoning [21, 24]. Thirdly, automating some of the teacher's routine tasks frees up their time for more work with students [25]. These mechanisms are consistent with modern theories of self-regulated learning and socioconstructivist pedagogy.

Challenges and risks. Despite the obvious benefits, several studies warn of the dangers of overreliance on AI. The authors note that AI results can be superficial, biased, or inaccurate; factors that, paradoxically, stimulate critical thinking only when students are trained to question and verify information [15, 26, 27]. Faculty and students expressed concerns about algorithmic biases, data privacy, and the risk of teacher "professional degradation" [24]. One study emphasized that overreliance on ChatGPT in course design can undermine instructor creativity and reduce opportunities to model critical thinking for students [27]. These findings demonstrate that without a conscious pedagogical context, AI tools risk reinforcing passive consumption rather than critical engagement.

Theoretical and conceptual contributions. Beyond empirical data, the conceptual work presented in this review emphasizes the importance of artificial intelligence literacy and the development of specialized skills in this tool (e.g., prompt engineering) [15]. These new fundamental competencies are essential for the development of critical thinking. Understanding that AI is a probabilistic model, not as a truth generator, is key to developing epistemic awareness in students. This aligns with modern approaches in science education, where AI is viewed not as a tool for delivering academic content but as a catalyst for developing metacognitive skills and critical thinking dispositions [31, 32].

Despite the positive trends identified, the limited number of studies selected only 12 that met all criteria, which shows that the field is still in its infancy. Many available publications are general or theoretical in nature and do not contain rigorous experimental data and long-term pedagogical experiments. During the selection and screening process, we also noticed the fact that many studies on the integration of AI and its impact on critical thinking are being explored in the fields of programming education, humanities, and medical disciplines. Future work in this field should therefore prioritize (a) rigorous quasi-experimental or randomized designs, (b) standardized instruments for measuring critical thinking and evidence of the positive or

negative impact of AI on this thinking construct, and (c) include more research in the fields of teaching chemistry, physics, biology and geography.

Overall, the results of this systematic review demonstrate that artificial intelligence tools have significant, yet not yet standardized potential for enhancing critical thinking in science education. The combination of empirical and conceptual perspectives identified in this review lays the foundation for future research and innovation.

Conclusions

A systematic review found that integrating artificial intelligence tools into science education has significant potential for developing students' critical thinking. Generative chatbots, STEM-focused AI projects, writing analytics tools, and other technologies generally improve argumentation and reflection, reduce time spent on routine tasks, facilitate idea generation, and increase motivation for learning. Positive effects are most pronounced when AI is accompanied by pedagogically relevant integration and a dialogic or problem-based approach. However, some studies have identified risks: decreased teacher creativity due to excessive automation, increased reliance on digital tools, and ethical concerns. These factors require the development of strategies that leverage AI capabilities without compromising student autonomy and the professional role of teachers.

Based on the conducted work, we emphasize the need for more rigorous and long-term empirical research, the use of standardized instruments for assessing critical thinking, and the expansion of this research to various disciplines within the natural sciences. The resulting systematization of studies based on the selected criteria can serve as a basis for understanding new directions for educational strategies and developing innovative approaches to developing critical thinking skills in the context of the digital transformation of education influenced by AI.

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Жасанды интеллект құралдарының жаратылыстану біліміндегі сыни ойлауға әсері: әдебиеттерге жүйелі шолу

Білім берудің қазіргі цифрлық трансформациясы білім беру үдерісіне жасанды интеллект (ЖИ) құралдарын белсенді түрде енгізумен қатар жүреді. Ғылыми білім беруде бұл студенттердің сыни ойлауын дамыту және ілгерілету үшін жаңа жағдайлар жасайды және зерттеушілер мен педагогтарға осындай технологиялардың тиімділігі мен тәуекелдерін талдау міндетін ұсынады. Мақалада ЖИ құралдарының жаратылыстану біліміндегі сыни ойлауды дамытуға әсерін талдау үшін PRISMA стандарттарына сәйкес әдебиеттерге жүргізілген жүйелі шолуы ұсынылған. Іздеу *Taylor & Francis*, *IEEE Xplore*, *Wiley Online Library* және *Google Scholar* дерекқорларында 2022–2025 жылдар аралығында жүргізілді. Анықталған 546 жарияланымның ішінен қосу және алып тастау критерийлерін қолданғаннан кейін 12 зерттеу таңдалды. Талдау генеративті чат-боттарды, машиналық оқытуды, жазбаша жұмысты талдауды және жалпы ЖИ-STEM-жобаларын пайдалану сыни ойлауды, дәлелдеуді, рефлексияны және академиялық мотивацияны дамытуға ықпал ететінін көрсетті. Анықталған тәуекелдерге сенімсіз деректер, цифрлық құралдарға тәуелділік, оқытушы шығармашылығының төмендеуі, этикалық және құпиялылық мәселелері жатады. Шолу сыни ойлауды бағалау және жаратылыстану ғылымдары аясында әртүрлі пәндерді қамту үшін зерттеу ауқымын кеңейтуде стандартталған құралдарды пайдалана отырып, неғұрлым терең зерттеулер жүргізу қажеттілігіне баса назар аударады.

Кілт сөздер: сыни ойлау, ғылыми білім, жасанды интеллект, оқыту, жүйелі шолу, әдістер, когнитивтік дағдылар, ChatGPT.

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Влияние инструментов искусственного интеллекта на критическое мышление в естественнонаучном образовании: систематический обзор литературы

Современная цифровая трансформация образования сопровождается активной интеграцией инструментов искусственного интеллекта (ИИ) в образовательный процесс. В естественнонаучном образовании это создает новые условия для развития и стимулирования критического мышления учащихся и ставит перед исследователями и педагогами задачу анализа эффективности и рисков таких технологий. В данной работе представлен систематический обзор литературы, проведенный в соответствии со стандартами PRISMA, для анализа влияния инструментов ИИ на развитие критического мышления в естественнонаучном образовании. Поиск проводился в базах данных Taylor & Francis, IEEE Xplore, Wiley Online Library и Google Scholar за период 2022–2025 гг. Из 546 выявленных публикаций 12 исследований были отобраны после применения критериев отбора. Анализ показал, что использование генеративных чат-ботов, машинного обучения, аналитики письменных работ и проектов ИИ-STEM в целом способствует развитию критического мышления, аргументации, рефлексии и академической мотивации. Выявленные риски включают недостоверность данных, зависимость от цифровых инструментов, снижение креативности преподавателей, а также вопросы этики и конфиденциальности. В обзоре подчеркивается необходимость проведения более строгих исследований с использованием стандартизированных инструментов для оценки критического мышления и расширения сферы исследования за счет включения различных дисциплин в рамках естественных наук.

Ключевые слова: критическое мышление, научное образование, искусственный интеллект, обучение, систематический обзор, методы, когнитивные навыки, ChatGPT.

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