

A Systematic Review of AI-Enhanced Learning in Science Classrooms

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Abstract

Contemporary science learning increasingly involves artificial intelligence and its implications for the science classroom. This study utilizes the Education Resources Information Center (ERIC) database to explore AI-enhanced learning in science classrooms. The keyword “AI-enhanced learning science” was used for search along with the filters “artificial intelligence,” “technology uses in education,” and “science education” to screen relevant publications. A total of 23 articles were identified and screened. Eight articles were retained for critical review. The finding revealed that AI technology such as ChatGPT, AI chatbots, and AI robot image recognition are gaining significant attention in international research, particularly in promoting conceptual understanding and learner motivation. This review suggests that AI can be effectively integrated into science classrooms.

Keywords: Artificial Intelligence, Chatbot, Digital Technology, Science Education, Technology Education

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Introduction

Artificial intelligence (AI) has progressively influenced educational methodologies across various fields, particularly in science education. It has been employed to improve teaching techniques, facilitate inquiry processes, and customize learning experiences. In science classrooms, AI-enhanced tools such as intelligent tutoring systems, adaptive learning platforms, chatbots, and virtual laboratories, have been used to enhance learning efficiency and revolutionize students' cognitive processes, communication, and construction of scientific knowledge (Luckin, Holmes, Griffiths, & Forcier, 2016). Science education necessitates more than just information acquisition. It entails inquiry, observation, experimentation, and participation in rational discourse (Yip, 2004). AI technology can enhance these engagement methods by providing instant feedback, enabling simulations, monitoring, intricate learning processes and

assisting educators in creating demanding and developmentally suitable activities (Hooda, Rana, Dahiya, Rizwan, & Hossain, 2022). Despite the growing number of publications of educational research on AI in science education. Existing studies and systematic reviews and systematic reviews tend to address AI-enhanced learning from a broad or cross-disciplinary perspective. In addition, they often focus on technological innovation, system design, or general learning outcomes across multiple subject areas (Zawacki-Richter, Marín, Bond, & Gouverneur, 2019; Chiu, Xia, Zhou, Chai, & Cheng, 2023). As a result, science education is frequently treated as a secondary context rather than as a distinct domain with unique pedagogical goals, learning processes, and epistemic practices (Xu & Ouyang, 2022).

Moreover, prior reviews rarely provide an integrated synthesis that explicitly connects AI-enhanced learning with the development of teacher and student competencies in science classrooms. Although some studies discuss the role of AI in supporting such as instructional design, data-informed decision-making, and facilitation of inquiry-based learning (Xu & Ouyang, 2022). The lack of domain-specific and competency-oriented synthesis represents a significant gap in current literature. Furthermore, a systematic review can help educators understand educational technology. AI-enhanced learning is now promoted in different classrooms. A suitable classroom can employ AI and its applications for students.

Nonetheless, these advances also elicit apprehensions regarding equality, technical preparedness, algorithmic openness, and the ethical utilization of student data (Dimitriadou & Lanitis, 2023; Slade & Prinsloo, 2013; Gachago, Immenga, Cox, Mosienyane, & Govender, 2024). A thorough review is necessary to investigate the utilization of AI in science classrooms and to comprehend its effects on learners, educators, and educational systems. This paper seeks to consolidate existing research on AI-enhanced science education, providing a comprehensive examination of its benefits, drawbacks, and ramifications. The paper examines the various applications of AI, such as instructional support, assessment, and personalized learning, and analyzes its impact on students' learning behaviors, engagement, and the cultivation of scientific thinking skills. Furthermore, it analyzes the changing responsibilities of educators in the age of AI, including the creation of AI-enhanced learning experiences, the interpretation of AI-generated data, and the formulation of professional judgments based on pedagogical principles.

A comparable disparity exists for educators. Although AI is frequently presented as a mechanism for enhancing efficiency, limited research investigates the impact of AI on educators' capacities to facilitate inquiry, interpret multimodal learning data, or make ethical and pedagogical choices informed by AI-generated insights. This raises substantial unresolved questions about the competencies required by teachers to effectively manage AI-integrated science classes. This review transcends a mere descriptive presentation of previous studies and seeks to produce a structured synthesis of knowledge regarding AI-enhanced learning in science classrooms. The review aims to uncover consistent instructional methods, pedagogical

strategies, and competency-related trends that define both good and problematic use of AI in science education.

The study presents a conceptual framework that integrates evidence from learner, teacher, and system levels, elucidating the alignment of various AI applications with science learning objectives, student scientific reasoning abilities, and teacher professional capabilities. This approach aims to facilitate future research by identifying underexplored domains and methodological deficiencies, while also offering practical recommendations for curriculum building, instructional design, and teaching professional development in AI-enhanced science education contexts.

Objective

1. To study the use of artificial intelligence (AI) in science classrooms by analyzing recent studies drawn from the ERIC database.
2. To examine their effects on students' conceptual understanding, motivation, and learning behaviors.

Methodology

Research Design

This study employed a systematic literature review approach to critically examine the use of AI-enhanced learning in science classrooms. The review followed a structured and transparent process to identify, screen, and synthesize relevant empirical studies, ensuring methodological rigor and reproducibility. The review focused on peer-reviewed international research that examined AI applications in science education and reported evidence related to student learning, teacher roles, or instructional practices.

Data Source and Search Strategy

The Education Resources Information Center (ERIC) database was selected as the primary data source due to its comprehensive coverage of high-quality, peer-reviewed educational research and its use of a controlled thesaurus and subject descriptor system. This database supports precise retrieval of education-related studies. All articles were accessed freely through the ERIC platform.

ERIC provides comprehensive coverage of peer-reviewed educational research grounded in pedagogy, curriculum, learning theory, and classroom practice, which are central to the objectives of this review. Its controlled thesaurus and subject descriptor system also support precise retrieval of education-specific literature. While multidisciplinary databases such as Scopus and Web of Science offer broader international coverage, they include a substantial proportion of technically oriented AI studies beyond the pedagogical scope of this review. Nevertheless, limiting the search to a single database represents a methodological

constraint, and future studies may incorporate multiple databases to expand interdisciplinary coverage.

The literature search was conducted in September 2025. An initial exploratory search was performed using the keyword “AI science,” yielding 426 publications. This was followed by a refined search using “AI science learning,” which resulted in 296 publications. Finally, a targeted search using the keyword phrase “AI-enhanced learning science” was conducted. To further refine the results, ERIC filters related to *Artificial Intelligence*, *Technology Uses in Education*, and *Science Education* were applied.

Screening Procedure

A multi-stage screening procedure was applied to identify studies relevant to the objectives of this review. The screening process consisted of three sequential stages: title screening, abstract screening, and full-text review. At the title screening stage, publications were excluded if they were clearly unrelated to science education or did not involve AI-supported learning. During the abstract screening stage, studies were excluded if they focused solely on technical AI system development, did not report educational applications, or lacked relevance to classroom learning contexts. Full-text articles were then reviewed to ensure that they met all inclusion criteria and aligned with the focus on AI-enhanced learning in science classrooms.

Inclusion and Exclusion Criteria

To ensure consistency and transparency in study selection, explicit inclusion and exclusion criteria were applied, as summarized in Table 1.

Table 1 Inclusion and Exclusion Criteria for Study Selection

Criteria Category	Inclusion Criteria	Exclusion Criteria
Publication type	Peer-reviewed journal articles	Editorials, opinion pieces, book chapters, reports
Language	English	Non-English publications
Publication period	Published within the last 5 years (2021–2025)	Published before 2021
Research focus	AI applications in science learning contexts	AI studies unrelated to science education
Study design	Empirical studies (quantitative, qualitative, or mixed methods)	Conceptual papers without empirical data
Educational context	Classroom-based or formal learning settings	Purely technical or laboratory-based AI development
Outcomes reported	Student learning, teacher practices, or instructional design	No reported educational outcomes

A thorough literature study was performed to critically assess the incorporation of AI-enhanced learning in science courses. The Education Resources Information Center (ERIC) database was selected as the principal source for identifying relevant literature. ERIC is acknowledged as the most extensive and authoritative database in education, cataloging peer-reviewed international journals, research reports, conference proceedings, and dissertations. The structured metadata system, notably the implementation of controlled vocabulary, subject descriptors, and thesaurus terms, these features facilitate accurate and reproducible research on specialized subjects, including AI applications in science education. These attributes render ERIC particularly appropriate for systematic reviews that necessitate transparent filtering criteria and elevated search precision. Furthermore, ERIC offers complimentary public access, thereby facilitating accessibility for researchers and promoting intellectual transparency.

The search was carried out in September 2025. Three primary keywords were used: “AI science,” “AI science learning,” and “AI-enhanced learning science.” The initial search using *AI science* identified 426 publications. The second search using *AI science learning* returned 296 publications. Finally, the term *AI-enhanced learning science*, combined with ERIC subject descriptors such as *Artificial Intelligence*, *Technology Uses in Education*, and *Science Education*, yielded 23 publications. Inclusion criteria were applied to ensure the relevance and quality of the selected studies: (1) peer-reviewed research articles, (2) published within the last five years, and (3) focused on the use of AI to enhance science learning. After screening titles, abstracts, and full texts, 8 articles were retained for in-depth analysis. Figure 1 illustrates the search and article selection process.

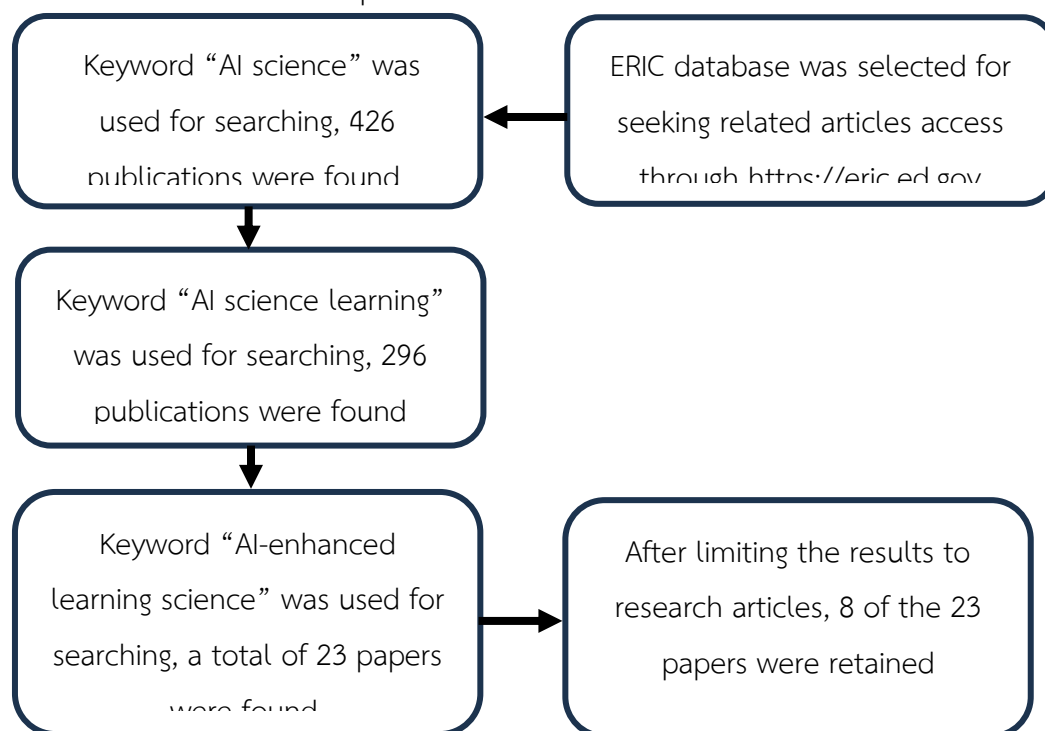


Figure 1. Search and article selection process for AI-enhanced learning in science classrooms

Conceptual Framework Guiding the Review

To provide analytical coherence and link the review to established scholarship, this study adopts a three-layer conceptual framework integrating perspectives from the learning sciences, AI pedagogy, and educational systems.

1. Learning science perspective (learner level) This perspective examines how AI supports students' cognitive and inquiry-based development in science. Central elements include conceptual change, questioning, model-based reasoning, experimentation, metacognitive regulation, and constructing explanations. AI tools, such as adaptive systems or virtual labs, are analyzed in terms of their alignment with established principles of effective science learning (National Research Council, 2012).

2. AI pedagogical integration perspective (teacher level) This component addresses how teachers design and implement AI-supported learning. It considers AI as a tutor (adaptive feedback), assistant (chatbots, automated scoring), cognitive partner (generative AI tools), or assessment instrument (multimodal learning analytics). It also examines emerging teacher competencies, including interpreting AI-generated data, integrating AI ethically, and making informed pedagogical decisions (Luckin, 2018; Holmes, 2020).

3. Systemic and ethical considerations perspective (system level) This perspective explores broader structural and ethical issues, such as equity in technological access, algorithmic transparency, data privacy, and infrastructural readiness. It also includes institutional and curricular considerations that influence how AI is adopted in science education (Slade & Prinsloo, 2013; Holmes et al., 2022).

Integrated Conceptual Model

The resulting three-layer conceptual model analyzes each selected study across three dimensions:

Learner level – How AI shapes students' scientific thinking, inquiry behaviors, engagement, and learning processes.

Teacher level – How teachers adopt, adapt, and make pedagogical decisions with AI tools.

System level – How ethical, infrastructural, and equity considerations mediate AI integration in science education.

This conceptual model provides a structured lens for synthesizing research findings across individual, instructional, and systemic dimensions. It ensures that the review moves beyond a tool-focused analysis and instead examines the implications of AI for deeper learning, teacher professionalism, and equitable educational environments.

Results

The growing integration of AI in science classrooms has increased attention to its pedagogical effectiveness. The following synthesis of 8 studies (2023-2025) highlights the scope

of AI's role in improving conceptual understanding, motivation, writing quality, and teacher preparedness in science education across different contexts and educational levels. AI-enhanced learning has a transformative impact on science education. From chatbots that guide inquiry to chatbots that support scientific writing, AI tools serve as effective partners in learning. These tools should be used critically and ethically for lesson and classroom activities (Table 2).

Table 2 Summary of Critically Reviewed Studies

List	Objective	Research method	Key results
(Ardyansyah, Yuwono, Rahayu, Alsulami, & Sulistina, 2024)	explore the perspectives of Indonesian university students on using GPT in chemistry	case study	Students view GPT as a useful tool that provides information quickly, systematically, and with quality. It can be used effectively as both a search tool and a research assistant. It is also easily accessible and adaptable to the user's context. Emotionally, students feel satisfied and comfortable receiving help. These factors are key motivators for students to choose GPT because it enhances productivity, simplifies complex topics, and provides concise and easy-to-understand explanations. However, students remain aware of limitations, such as potential inaccuracies, ethical issues, and limited ability to calculate certain formulas, so caution is needed when trusting its answers.
(Chen & Liu, 2024)	study the effects of learning using robotic AI image recognition technology	quasi-experiment study	Learning through AI robot image recognition technology is more effective than learning from textbooks, as it helps build conceptual understanding of cell division and stimulates motivation to learn.
(Williams, 2024)	study the performance of various AI types in writing biomedical science essays	the agreement among reviewers	A scored the highest at all levels (UG and PG). B is at a moderate level; the content is reasonably accurate but lacks depth and detail. C performed the worst, especially at the undergraduate level, with fabricated references.

(Anik, Kamal, Kabir, Uddin, & Moni, 2024)	study the experiences of students who use and non-use ChatGPT	qualitative research	Non-ChatGPT users encounter problems such as too broad research topics, writing that lacks continuity, difficulty in doing literature reviews, and trouble formulating research questions. Benefit from deeper analytical thinking and learning through seeking advice from instructors. ChatGPT users benefited from clearer writing, grammar correction, help in finding preliminary research, quickly setting objectives and tools, and writing structured reports.
(Ng, Wu, Leung, Chiu, & Chu, 2024)	compare the effectiveness of the creative AI chatbot (SRLbot) with the rule-based chatbot (Nemobot)	quasi-experiment	The group of students using SRLbot showed a significant improvement in their science knowledge and SRL behaviors. Interactions with SRLbot were positively associated with the development of learning skills. Students appreciated SRLbot's ability to provide adaptive guidance and reduce learning-related anxiety.
(Lee, An, Chu, Hong, & Martin, 2023)	study the use of a rule-based AI chatbot for teaching science	quasi-experiment	The use of AI Chatbots significantly improves achievement in understanding scientific concepts. Groups with low knowledge levels and female students show a significant increase in interest in science. Chatbots also help enhance the interest in scientific attitudes of the target student group.
(Sung et al., 2024)	study the effects of AI on student achievement	survey research	AI has a greater impact on learners with low achievement than on those with high achievement.
(Wusylko et al., 2025)	study the effects of curriculum development and teacher training that integrates AI into science teaching	research and development	Teachers have a better understanding of AI, and students have improved achievement and attitudes toward AI.

(Ardyansyah et al., 2024) examined Indonesian students' perspectives on using GPT for learning chemistry. The study employed 56 undergraduate and postgraduate students. Data were gathered through questionnaires, interviews, and GPT usage logs. The results revealed that students view GPT as a valuable and efficient tool for accessing quality information. However, participants noted limitations such as factual inaccuracies, ethical concerns, and computational constraints. Chatbot was seen as a supplementary learning aid when used critically and responsibly. (Chen & Liu, 2024) Pei-Yu Chen and Yuan-Chen Liu conducted a quasi-experimental study with 81 secondary students in rural Taiwan. The intervention involved students training AI robots to recognize cell division stages. AI's potential can promote interactive and constructivist science learning to students as well.

(Williams, 2024) Andrew Williams compared the essay-writing performance of 3 AI models across undergraduate and postgraduate biomedical science assessments. Four independent reviewers evaluated AI-generated essays; however the study did not compare AI output with actual student writing and only focused on long-form essays. Israq Ahmed Anik et al. (Anik et al., 2024). explored the experiences of 4 master's students among students who used and did not use ChatGPT/chatbots during science thesis writing. Chatbot users reported that it improved clarity, organization, and efficiency, as well as help with grammar, literature searches, and structuring research objectives. Conversely, non-users faced challenges with topic formulation and coherence but developed deeper analytical thinking through independent effort.

Davy Tsz Kit Ng et al. (Ng et al., 2024) conducted a quasi-experimental pilot study with 74 Hong Kong students to compare the effects of an AI-driven creative chatbot (SRLbot) and a rule-based chatbot (Nemobot) on science learning. Data from questionnaires and pre/post-tests showed that SRLbot users achieved higher knowledge gains and demonstrated improved self-regulated learning (SRL) behaviors. They also reported reduced anxiety and appreciated adaptive feedback. Juyeon Lee et al. (Lee et al., 2023) developed a rule-based chatbot to teach concepts of light and lenses to 192 sixth-grade students. The AI tools can promote inclusivity and engagement. Shannon Sung et al. (Sung et al., 2024) investigated students how AI influences learning achievement in geoscience. AI integration had a greater positive effect on low-achieving students, helping them close achievement gaps. The combination of quantitative and qualitative data enhanced the study's depth. (Wusylko et al., 2025) examined the impact of an AI-integrated curriculum involving 17 teachers and 326 students. Quantitative and qualitative data showed that teachers developed stronger understanding of AI concepts. while students improved in both science achievement and attitudes toward AI. The dual focus on teacher professional development and student outcomes is a key strength, providing a comprehensive view of AI's systemic impact.

Learning with artificial intelligence (AI) technology in science classrooms is gaining significant attention in international research, particularly in promoting conceptual

understanding and learner motivation. The eight research studies analyzed in this review reflect the use of AI tools, such as ChatGPT, AI chatbots, AI robot image recognition, and SRLbot, all of which play an important role in supporting science learning in more diverse formats. In this research, many studies show that AI can help students understand science concepts, especially in complex topics such as cell division, light and lenses, or thesis writing. Overall, students using AI exhibit increased satisfaction and motivation because AI can rapidly provide information clearly and tailored to the user's context (Nuangchalerm & Saregar, 2024). Furthermore, AI helps reduce learning anxiety and promotes self-regulated learning behaviors (Mnguni et al., 2024).

However, these studies still have conditions that should be considered, such as small sample sizes, implementation in specific contexts, such as rural schools, or the use of free versions of AI that may have inaccuracies in information and fabricated references. In addition, there are also ethical concerns about AI's capability for deep computation or analysis. In sum, The use of AI in science classrooms has high potential to enhance learning when activities are reasonably designed and the limitations of the tools are acknowledged. These studies therefore serve as an important evidence base for developing effective and equitable AI-based learning approaches in the future, for students, teachers, and science curriculum developers.

Thematic Synthesis of AI-Enhanced Learning in Science Classrooms

A thematic synthesis of the eight reviewed studies reveals both commonalities and variations in how artificial intelligence is applied in science education across contexts. Four overarching themes emerged from the analysis: (1) AI as cognitive support for conceptual understanding, (2) AI as a motivator and facilitator of self-regulated learning, (3) variability in AI tools and instructional designs, and (4) differential impacts across learner, teacher, and system levels.

Theme 1: AI as cognitive support for conceptual understanding. Across multiple studies, AI tools functioned as cognitive scaffolds that supported students' understanding of complex scientific concepts. ChatGPT and rule-based chatbots were commonly used to clarify abstract ideas, structure scientific writing, and assist with problem formulation, particularly in chemistry, optics, and biomedical sciences. Similarly, AI robot image recognition technology enabled students to visualize and comprehend processes such as cell division more effectively than traditional textbook-based instruction. These findings suggest that AI is most effective when it supports conceptual processing rather than merely delivering information.

Theme 2: AI as a motivator and facilitator of self-regulated learning. Several studies highlighted the motivational benefits of AI-enhanced learning. Students reported increased satisfaction, reduced learning anxiety, and greater engagement when interacting with adaptive AI systems, such as creative chatbots and self-regulated learning agents (e.g., SRLbot). AI tools also supported self-regulated learning behaviors by providing timely feedback, guiding goal setting, and enabling learners to manage their learning pace. However, some evidence

indicates that non-AI users may develop deeper analytical thinking through sustained instructor interaction, suggesting that AI's motivational benefits depend on balanced pedagogical integration.

Theme 3: Variability in AI tools and instructional designs. The reviewed studies differed substantially in the types of AI technologies employed and the instructional designs adopted. Tools ranged from generative AI chatbots and rule-based systems to robotic image recognition and AI-integrated curricula. Methodological approaches also varied, including case studies, quasi-experiments, qualitative research, surveys, and research-and-development designs. This variability highlights that AI effectiveness is context-dependent and influenced by how technologies are embedded within instructional activities rather than by the AI tools alone.

Theme 4: Differential impacts across learner, teacher, and system levels. While most studies focused on student outcomes such as achievement, motivation, and writing quality, fewer studies addressed teacher development and systemic change. Notably, AI-integrated curriculum and professional development initiatives contributed to teachers' improved understanding of AI and enhanced instructional practices. Additionally, AI demonstrated greater benefits for low-achieving learners, suggesting its potential to reduce achievement gaps. These findings indicate that the educational impact of AI extends beyond individual learners to include teacher competencies and curriculum design, underscoring the need for multi-level analysis in future research.

Discussion

Learning by using Artificial Intelligence (AI) technology in science classrooms is gaining significant attention in international research, particularly in promoting conceptual understanding and learner motivation. Eight research studies analyzed in this review reflect of using AI tools, such as ChatGPT, AI Chatbots and AI Robot Image Recognition. In this research, many studies show that AI can help students understand science study, especially in complex topics such as cell division, light and lenses, or thesis writing. Mostly, Students using AI exhibit increased satisfaction and motivation because AI can rapidly provide information clearly and tailored to the user's context (Nuangchalerm & Saregar, 2024). Furthermore, AI helps reduce learning anxiety and promotes self-regulated learning behaviors (Mnguni et al., 2024).

However, these studies still have conditions that should be considered, such as small groups of samples, implementation in specific contexts like rural schools, or the use of free versions of AI that may have inaccuracies in information and fabricated references. In addition, there are also ethical concerns about AI's capability for deep computation or analysis. In sum, AI used in science classrooms has high potential to enhance learning, if activities are reasonably designed and the limitations of the tools are acknowledged. These studies therefore serve as an important database for developing effective and equitable AI-based learning approaches in the future, for students, teachers, and science curriculum developers.

Conclusion

The use of AI in science education can enhance students' learning when students understand AI and use it responsibly. Students demonstrate improved understanding of scientific concepts, increased motivation to learn, and stronger self-directed learning skills. For example, AI chatbots can support students in clarifying complex topics such as cell division or chemical reactions by providing step-by-step explanations, while adaptive AI systems can offer personalized feedback that helps learners monitor their own progress. AI tools also help reduce learning anxiety and increase students' confidence by providing timely guidance and non-judgmental support during learning activities.

Nevertheless, there are still drawbacks of AI applications including concerns related to data integrity, privacy, and the accuracy of AI-generated information. For instance, reliance on generative AI tools may expose students to fabricated references or oversimplified explanations if critical evaluation skills are not emphasized. Therefore, the use of AI in science classrooms requires appropriate instructional design and careful supervision by teachers to ensure that AI functions as a supportive learning tool rather than a substitute for scientific reasoning. Such an approach is essential to maximize learning effectiveness while promoting ethical, responsible, and equitable use of AI in science education.

This review shows that AI enhances science learning most effectively when used as a pedagogical scaffold supporting inquiry, conceptual understanding, and self-regulated learning rather than as a stand-alone information source. The synthesis also identifies key benefits in student motivation and reduced learning anxiety, alongside critical challenges such as overreliance on AI, data integrity, and ethical concerns. The findings contribute theoretically by positioning AI as a cognitive support within constructivist and inquiry-based learning frameworks that require strong teacher mediation. Accordingly, future implementation should prioritize inquiry-oriented AI curriculum design, teacher training in AI-integrated pedagogical content knowledge, and clear ethical governance to ensure effective and equitable use of AI in science education.

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