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Article

Artificial Intelligence in Science Education: Ethical Challenges and a Conceptual Framework for Responsible Integration

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Abstract:

Artificial intelligence (AI) is increasingly shaping educational practices through technologies such as intelligent tutoring systems, automated assessment, and generative language models. In science education, these tools are often associated with personalized learning and support for inquiry-based instruction. However, their integration also raises important ethical concerns that remain underexplored within the disciplinary context of science education. This paper presents a theoretical analysis of the ethical challenges associated with the use of AI in science teaching and learning. Drawing on literature from AI ethics, educational technology, and science education, the study examines how AI-mediated learning environments interact with the core aims of science education, including inquiry, evidence-based reasoning, and conceptual understanding. The analysis identifies key ethical concerns such as the epistemic reliability of AI-generated scientific explanations, risks of student overdependence, challenges to academic integrity, and issues of fairness, transparency, and accountability. Based on this analysis, the paper proposes a conceptual framework for the responsible integration of AI in science education. The framework emphasizes epistemic responsibility, pedagogical mediation, learner autonomy, transparency, and equity as guiding principles. It highlights the need to maintain human judgment and promote critical engagement with AI tools to ensure that they support rather than replace scientific inquiry and reasoning. The study contributes to the emerging discourse on ethically grounded and human-centered uses of AI in education by sitting ethical concerns within the specific context of science education.

Keywords: AI in Education, Science Education, AI Ethics, Responsible AI

1. INTRODUCTION

Artificial intelligence (AI) has rapidly emerged as a transformative force in contemporary education, reshaping teaching, learning, and knowledge production across disciplines. Advances in machine learning, natural language processing, and data analytics have enabled the development of intelligent tutoring systems, automated assessment tools, adaptive learning environments, and generative language models capable of producing explanations, feedback, and instructional content. These technological developments have generated significant interest among educators and researchers who view AI as a means of enhancing personalized learning, improving access to educational resources, and supporting teachers in complex instructional environments (Holmes et al., 2019; Luckin et al., 2016; Zawacki-Richter et al., 2019). Consequently, AI has become a central area of inquiry within educational technology and digital learning innovation. Empirical studies have further examined teachers' awareness and perceptions of AI in science education, highlighting both the potential and the challenges of AI integration (Haque, 2024; Asagar, 2026a).

Research examining the applications of artificial intelligence in education suggests that AI systems can provide adaptive feedback, personalize learning pathways, and support data-informed instructional practices (Luckin et al., 2016; Holmes et al., 2019). A systematic review by Zawacki-Richter et al. (2019) indicates that AI technologies are widely used in intelligent tutoring systems, student performance prediction, and adaptive learning platforms. While these

developments highlight the potential of AI to enhance educational processes, scholars have also emphasized that the integration of AI into educational contexts raises complex ethical, pedagogical, and social questions (Selwyn, 2019; Williamson & Eynon, 2020). Concerns related to algorithmic bias, transparency, data privacy, and the possible displacement of human judgment in educational decision-making have become increasingly prominent in recent discussions (Floridi et al., 2018; UNESCO, 2021).

The emergence of generative AI has further intensified these concerns. Unlike earlier AI systems focused on data processing and adaptation, generative AI tools are capable of producing coherent responses, solving complex problems, and generating explanations in real time. While such capabilities expand the scope of AI in education, they also introduce new challenges related to the reliability and epistemic validity of AI-generated knowledge. Scholars have noted that generative AI systems may produce inaccurate or fabricated information, often described as "hallucinations," which can have significant implications for learning, particularly in disciplines requiring conceptual clarity and logical reasoning (Holmes et al., 2021; Selwyn, 2019). These developments raise critical questions about the role of AI in shaping how knowledge is accessed, interpreted, and validated in educational settings.

Within this broader context, science education provides a particularly important domain for examining the ethical implications of AI integration. The teaching and learning of science is grounded in inquiry, experimentation, and evidence-based reasoning, requiring learners to actively engage in processes such as questioning, investigation, and interpretation of data. From a constructivist perspective, scientific knowledge is constructed through interaction and critical engagement rather than passively received from authoritative sources (Driver et al., 1994). Research in science education consistently emphasizes the importance of inquiry-based learning environments that foster reasoning, conceptual understanding, and scientific literacy (National Research Council, 2000; Duschl et al., 2007). These characteristics distinguish science education from other domains and make it particularly sensitive to changes introduced by AI-mediated learning.

The integration of AI technologies into science education therefore raises important questions about how technological mediation may influence students' engagement with scientific knowledge and practices. While AI tools capable of generating explanations or solving problems may provide instructional support, they may also reduce opportunities for students to engage in essential cognitive processes such as hypothesis formation, experimentation, and evidence evaluation. Excessive reliance on AI-generated responses may shift learning from active inquiry to passive consumption, thereby challenging the epistemological foundations of science education. In this sense, ethical concerns about AI extend beyond issues of data privacy and bias to include deeper questions about the nature of knowledge construction and learning.

Another important concern relates to academic integrity and authentic learning. The increasing availability of generative AI systems capable of producing assignments, reports, and problem solutions has led to concerns that students may rely on these tools without engaging meaningfully with learning tasks. Such practices raise questions about the authenticity of student work and the development of independent reasoning and problem-solving skills. As Selwyn (2019) argues, the growing presence of automated systems in education has the potential to reshape relationships between learners, teachers, and knowledge, requiring a reconsideration of how learning and assessment are conceptualized in digital environments.

In addition to these concerns, AI integration in education raises broader ethical issues related to fairness, transparency, accountability, and equity. Ethical frameworks for artificial intelligence emphasize principles such as justice, transparency, accountability, and respect for human autonomy as central to responsible AI deployment (Floridi et al., 2018). These principles have been reflected in global policy discussions, including UNESCO's (2021) recommendations on the ethical use of AI. Within educational contexts, these considerations imply that AI technologies should support human-centered learning environments and should not undermine the agency of teachers and learners. At the same time, disparities in access to digital technologies and differences in institutional resources raise concerns about equity and inclusion in AI-supported learning environments.

Despite the growing body of research on artificial intelligence in education and the increasing attention to ethical issues, relatively limited work has examined these concerns specifically within the context of science education. Much of the existing literature focuses either on technological applications of AI or on general ethical principles, without adequately addressing how AI interacts with the pedagogical goals and epistemological foundations of specific disciplines. In the case of science education, where inquiry, reasoning, and evidence-based understanding are central, the ethical implications of AI integration may differ significantly from those in other subject areas. This gap highlights the need for theoretically grounded analyses that examine AI in relation to the distinctive nature of science learning.

In response to this need, the present study offers a theoretical examination of the ethical challenges associated with artificial intelligence in science education. Drawing on literature from AI ethics, educational technology, and science education research, the study seeks to analyze how AI-mediated learning environments intersect with the core aims of science teaching and learning. Specifically, it addresses the following questions: What ethical issues emerge in the integration of artificial intelligence within science education? How are these ethical concerns conceptualized in existing research? And what principles can guide the responsible integration of AI in science education? By addressing these questions, the paper aims to contribute to the development of a conceptual framework that supports ethically informed and pedagogically meaningful use of artificial intelligence in science education.

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2. RESEARCH OBJECTIVES

Based on the research questions, the study aims to achieve the following objectives:

1. To examine the existing literature on artificial intelligence in education and identify its relevance for science education.
2. To analyse the ethical concerns associated with the use of artificial intelligence in science teaching and learning.
3. To synthesize insights from AI ethics, educational technology, and science education research.
4. To propose a conceptual framework for the responsible and ethical integration of artificial intelligence in science education.

3. METHODOLOGY

This study adopts a theoretical and conceptual research design, focusing on the analysis of existing literature rather than the collection of empirical data. The aim is to critically examine current scholarship on artificial intelligence in education, synthesize perspectives from AI ethics and science education, and develop conceptual insights to guide responsible integration of AI in science learning contexts.

The study is based on a review of academic literature related to artificial intelligence in education, AI ethics, and science education. Sources include peer-reviewed journal articles, scholarly books, policy documents, and systematic reviews. Relevant literature was identified through databases such as Google Scholar, Scopus, ERIC, and Web of Science.

The selection of literature was guided by its relevance to three key areas: AI applications in education, ethical issues in AI and educational technology, and pedagogical principles of science education. Priority was given to peer-reviewed studies and influential academic works that examine the relationship between technology, learning processes, and ethical considerations.

The analysis followed a thematic and conceptual approach. First, key themes related to AI applications and ethical concerns were identified. Second, these themes were examined in relation to the core goals of science education, including inquiry, conceptual understanding, and scientific reasoning. Finally, insights from the literature were synthesized to develop a conceptual framework outlining ethical principles for the responsible use of AI in science education.

4. ETHICAL CHALLENGES OF ARTIFICIAL INTELLIGENCE IN SCIENCE EDUCATION

The integration of artificial intelligence (AI) into educational contexts has created new possibilities for enhancing teaching and learning processes, but it has also introduced a range of ethical challenges that demand critical examination. In science education, these concerns are particularly significant because learning is grounded in inquiry, reasoning, and evidence-based knowledge construction. Recent research indicates that while AI technologies can support personalized learning and instructional efficiency, they simultaneously raise complex ethical issues related to knowledge reliability, fairness, autonomy, and accountability (Zawacki-Richter et al., 2019; Holmes et al., 2021).

4.1. Epistemic Reliability of AI-Generated Knowledge

One of the central ethical concerns in AI-mediated science education is the reliability of AI-generated knowledge. Generative AI systems, including large language models, are capable of producing detailed scientific explanations; however, studies have shown that these systems may generate inaccurate or fabricated information (Gouvea, 2024; Holmes et al., 2021).

In science education, where conceptual understanding depends on accurate interpretation of evidence, such inaccuracies can lead to misconceptions and flawed reasoning. Research on AI in science education highlights that machine-generated explanations may not always align with scientific epistemology, thereby challenging the integrity of knowledge construction processes (Gouvea, 2024; Zhai et al., 2026).

Moreover, systematic reviews of AI in education emphasize that ensuring epistemic validity is one of the most critical challenges in integrating AI into teaching and learning (Garzón et al., 2025).

4.2. Academic Integrity and Authentic Learning

Another major ethical concern is the impact of AI on academic integrity. The widespread availability of generative AI tools enables students to produce assignments, reports, and solutions with minimal effort, raising concerns about plagiarism and authenticity. Research shows that AI tools blur the distinction between assistance and authorship, complicating traditional notions of academic honesty (Bittle, et al., 2025).

Recent studies further highlight that the use of generative AI may influence student behavior by encouraging shortcuts in learning, thereby reducing engagement with underlying concepts (Rizun, et al., 2026 ; Asagar, 2026a).

In science education, where learning involves experimentation, reasoning, and conceptual understanding, such practices can undermine the development of scientific thinking. Ethical concerns therefore extend beyond plagiarism to include the erosion of authentic learning processes.

4.3. Learner Autonomy and Overdependence

The issue of learner autonomy is closely linked to academic integrity. AI systems provide rapid responses and automated support, which may lead to overdependence among students. Studies on AI in education indicate that excessive reliance on AI tools can reduce students' critical thinking and problem-solving abilities (Garzón et al., 2025).

In science education, this is particularly problematic

because learning requires active engagement in inquiry processes such as hypothesis formulation, experimentation, and analysis. If AI tools replace these processes rather than support them, the fundamental goals of science education may be compromised.

Ethical frameworks for AI in education emphasize the importance of preserving learner agency and promoting active engagement in learning processes (Yan et al., 2025; An et al., 2024; Asagar, 2025b).

4.4. Transparency and Accountability

Transparency and accountability are widely recognized as essential principles in ethical AI deployment. Many AI systems operate through complex algorithms that are not easily interpretable, making it difficult for users to understand how outputs are generated.

Research highlights that lack of transparency in AI systems can lead to issues of trust, fairness, and accountability in educational decision-making (Floridi et al., 2018).

In science education, transparency is particularly important because scientific reasoning involves understanding the processes through which conclusions are derived. If AI systems provide answers without explanation, they may conflict with the epistemic principles of science learning.

Studies on AI governance in education further emphasize the need for explainability and human oversight to ensure responsible use of AI technologies (Alfiras, 2026; UNESCO, 2021).

4.5. Equity and Inclusion

Another critical ethical issue is equity and access. The availability of AI technologies is not evenly distributed across educational institutions, leading to disparities in access and opportunities. Research indicates that AI systems may reinforce existing inequalities due to differences in infrastructure, digital literacy, and resource availability.

Furthermore, algorithmic bias in AI systems can result in unequal treatment of different groups of learners, raising concerns about fairness and inclusivity in AI-supported education.

In science education, equitable access to technological tools is essential for ensuring that all students have opportunities to engage in scientific inquiry and develop relevant competencies.

4.6. Changing Role of Teachers

The integration of AI also raises questions about the evolving role of teachers. While AI can automate tasks such as grading and feedback, it cannot replace the interpretive, relational, and pedagogical functions of teachers.

Research suggests that AI should be viewed as a tool that supports teaching rather than replaces it, emphasizing the importance of maintaining human-centered educational practices (Akgun & Greenhow, 2022; Williamson & Eynon, 2020; Asagar, 2026b).

In science education, teachers play a crucial role in facilitating inquiry, guiding experimentation, and helping students interpret evidence. These functions require professional judgment and contextual understanding that AI systems cannot fully replicate.

5. CONCEPTUAL FRAMEWORK FOR RESPONSIBLE INTEGRATION OF ARTIFICIAL INTELLIGENCE IN SCIENCE EDUCATION

The increasing integration of artificial intelligence (AI) into educational environments has created a need for conceptual frameworks that guide the ethical and pedagogically meaningful use of these technologies. AI technologies have been widely applied in educational contexts to support adaptive learning systems, intelligent tutoring platforms, and automated assessment tools (Zawacki-Richter et al., 2019). Recent systematic reviews indicate that AI research in education has expanded rapidly since the emergence of generative AI technologies such as ChatGPT, highlighting the growing influence of AI in teaching and learning processes (Garzón et al., 2025).

At the same time, scholars emphasize that the integration of AI in education introduces complex ethical concerns that extend beyond technological functionality. These concerns include issues related to bias, privacy, accountability, transparency, and learner autonomy (Floridi et al., 2018; Holmes et al., 2021). Systematic reviews of AI ethics in education further demonstrate that ethical tensions emerge across multiple stakeholders—students, teachers, institutions, and policymakers highlighting the need for comprehensive frameworks that address these challenges (Yan et al., 2025).

Within science education, these ethical concerns become particularly important because scientific learning relies on inquiry, reasoning, and evidence-based knowledge construction. Emerging scholarship suggests that AI technologies can support scientific learning but may also reshape how students engage with knowledge, assessment, and inquiry practices (Zhai & Crippen, 2026).

Building on insights from research on AI ethics, educational technology, and science education, the present study proposes a conceptual framework for the responsible integration of artificial intelligence in science education. The framework consists of five interconnected principles: epistemic responsibility, pedagogical mediation, learner autonomy, transparency and accountability, and equity and inclusion.

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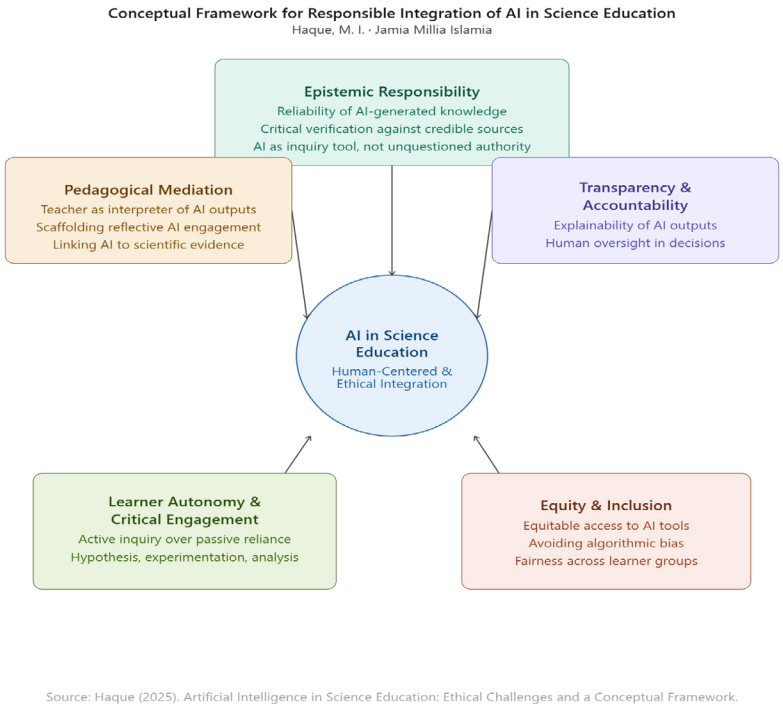

Fig 1: *Conceptual Framework for Responsible Integration of AI in Science Education*

Note. *The five principles are interconnected and mutually reinforcing. Arrows indicates the orientation of each principle toward the central goal of human-centered, ethical AI integration in science education*

5.1. Epistemic Responsibility

Epistemic responsibility refers to the obligation to ensure that knowledge generated or mediated by AI technologies is reliable and scientifically valid. Generative AI systems can produce explanations, summaries, and responses to complex questions; however, research has shown that these systems may occasionally generate inaccurate or fabricated information (Holmes et al., 2021). Such inaccuracies pose significant challenges for science education, where conceptual clarity and empirical accuracy are essential.

Recent studies examining ethical dilemmas in AI-supported science education highlight concerns regarding the reliability of machine-generated knowledge and the potential spread of misinformation in learning environments (Gouvea, 2024). Moreover, systematic reviews of AI in education emphasize that ensuring epistemic reliability is a central challenge when integrating AI into teaching and learning processes (Garzón et al., 2025).

Therefore, epistemic responsibility requires that AI-generated knowledge be critically evaluated and verified against credible scientific sources. Rather than serving as an unquestioned authority, AI should be used as a tool that encourages inquiry and critical thinking in science classrooms.

5.2. Pedagogical Mediation

The second principle of the framework emphasizes pedagogical mediation. While AI systems can automate tasks such as feedback generation and personalized learning recommendations, teachers remain central actors in interpreting and contextualizing AI outputs. Research examining AI integration in classrooms indicates that educators play a crucial role in guiding students' interactions with AI tools and helping them critically evaluate digital information (Akgun & Greenhow, 2021).

Pedagogical mediation involves teachers integrating AI technologies within inquiry-based learning environments that support conceptual understanding and scientific reasoning. Studies on AI-supported education emphasize that effective integration requires teachers to scaffold students' engagement with AI tools and encourage reflective use rather than passive reliance (Kim et al., 2023; Wiese, 2025; Asagar, 2025a). Furthermore, research on science teachers' digital readiness indicates that professional development is essential for enabling teachers to effectively integrate AI into their pedagogical practices (Haque & Haider, 2026; Haque & Haider, 2025).

In science education, such mediation is particularly important because teachers help students connect AI-generated information with experimental evidence, scientific reasoning, and disciplinary practices.

5.3. Learner Autonomy and Critical Engagement

Learner autonomy is another critical dimension of responsible AI integration. AI technologies can automate many learning processes, potentially reducing the need for students to engage deeply with complex concepts. Scholars have raised concerns that excessive reliance on AI tools may weaken students' critical thinking and problem-solving abilities if learners become passive consumers of automated responses (Yan et al., 2023).

Research on AI ethics in education highlights the importance of designing AI-supported learning environments that promote student agency and active engagement (An et al., 2024). In science education, maintaining learner autonomy means ensuring that AI technologies encourage exploration, experimentation, and hypothesis testing rather than simply providing ready-made answers.

For example, AI systems can support scientific inquiry by generating alternative hypotheses, simulating experiments, or providing feedback on experimental designs. When used appropriately, such tools can enhance rather than diminish students' engagement with scientific reasoning.

5.4. Transparency and Accountability

Transparency and accountability are widely recognized as essential principles in responsible AI development and governance. Many AI systems operate through complex algorithms that are not easily interpretable by users, creating challenges for understanding how outputs are generated. Ethical frameworks emphasize that transparency is necessary to ensure trust, accountability, and fairness in AI-supported decision-making (Floridi et al., 2018).

Recent research on responsible AI in education identifies transparency, explainability, and human oversight as key components of human-centered AI systems (Yan et al., 2025). Additionally, studies examining ethical challenges of generative AI in education highlight the need for regulatory frameworks and governance mechanisms to address issues of bias, privacy, and accountability.

In science education, transparency is particularly important because scientific reasoning involves understanding how conclusions are derived from evidence. AI tools used in educational contexts should therefore provide explanations or indications of how their outputs are generated so that students can critically evaluate them.

5.5. Equity and Inclusion

The final principle of the framework addresses issues of equity and inclusion in AI-mediated learning environments. Access to advanced technological tools varies across institutions and communities, potentially creating disparities in students' opportunities to benefit from AI-supported education.

Research on ethical AI highlights that algorithmic bias and unequal access to technological resources can reinforce existing social inequalities . Similarly, studies examining ethical challenges of AI integration emphasize that educational technologies must be designed and implemented in ways that promote fairness and inclusivity.

Ensuring equitable access to AI technologies is particularly important in science education, where engagement with technological tools influences students' participation in scientific and technological fields (Asagar, 2024; Asagar et al., 2025). Studies on science education in resource-constrained settings further highlight the challenges of equitable access to technology and professional development opportunities for teachers (Haque, 2024).

5.6. Integrating the Framework

Taken together, the five principles—epistemic responsibility, pedagogical mediation, learner autonomy, transparency and accountability, and equity and inclusion—provide a conceptual foundation for the responsible integration of artificial intelligence in science education. These principles align with emerging scholarship that emphasizes the importance of human-centered AI approaches in education, where technology supports rather than replaces human learning processes (Yan et al., 2025; Wiese, 2025).

The framework also highlights the need to balance technological innovation with ethical responsibility. By integrating insights from AI ethics, educational technology, and science education research, the framework contributes to ongoing discussions about how AI can be used to enhance learning while preserving the core values of scientific inquiry, critical reasoning, and equitable access to knowledge.

6. IMPLICATIONS OF THE STUDY

This study highlights that the integration of artificial intelligence in science education must be guided by both ethical and pedagogical considerations. It underscores the central role of teachers as mediators who can guide students in critically evaluating AI-generated information and using it to support inquiry rather than replace scientific reasoning. The findings suggest that AI tools should be integrated in ways that encourage questioning, investigation, and evidence-based thinking, while ensuring that students remain actively engaged in learning processes.

The study also points to the need for strengthening teacher education by incorporating AI literacy and ethical awareness, enabling teachers to understand the limitations, biases, and responsible use of AI technologies. At the same time, it identifies important directions for future research, particularly the need for empirical studies examining how AI influences inquiry-based learning, conceptual understanding, and classroom practices in science education.

From a policy perspective, the study emphasizes the importance of developing guidelines that ensure transparency, accountability, and equitable access to AI technologies, preventing the reinforcement of existing inequalities. It also highlights the responsibility of technology developers to design AI systems that align with educational values, support critical engagement, and promote meaningful learning rather than passive dependence.

The study suggests that responsible integration of AI in science education requires a human-centered approach that balances technological innovation with ethical responsibility and the core aims of scientific inquiry.

7. CONCLUSION

Artificial intelligence is increasingly transforming educational practices, offering new possibilities for personalized learning and instructional support in science

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education. However, its integration also raises critical ethical concerns related to the reliability of AI-generated knowledge, academic integrity, learner autonomy, transparency, and equity.

This paper examined these issues through a theoretical lens and highlighted that the use of AI in science education is not only a technological development but also a pedagogical and ethical concern. In response, it proposed a conceptual framework based on principles of epistemic responsibility, pedagogical mediation, learner autonomy, transparency, and equity to guide responsible AI integration.

The study emphasizes that AI should support, rather than replace, inquiry, reasoning, and human judgment in science learning. It also highlights the need for a human-centered approach involving teachers, researchers, and policymakers to ensure ethical and meaningful use of AI in education.

Overall, the responsible integration of AI in science education requires balancing technological innovation with ethical responsibility to preserve the core values of scientific inquiry and learning.

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Author(s) Contribution

All the Author(s) work equally to prepare the manuscript.

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