Artificial Intelligence in Integrated Science Education: Opportunities, Challenges, and Future Directions

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ABSTRACT

Artificial Intelligence (AI) is increasingly transforming education by enabling personalized learning, intelligent assessment, virtual experimentation, and data-informed instructional support. This paper examines the opportunities, challenges, and future directions of AI integration in Integrated Science education. A structured literature review approach was adopted, using scholarly literature published between 2020 and 2026 and identified primarily through the Education Resources Information Center (ERIC) and the Directory of Open Access Journals (DOAJ), with Google Scholar used as a supplementary source. Relevant literature was screened using predefined eligibility criteria and synthesized thematically. The review indicates that AI can support personalized and adaptive learning, virtual laboratories, scientific inquiry, immediate feedback, intelligent assessment, and teacher decision-making. However, effective integration is constrained by inadequate digital infrastructure, limited teacher preparedness and AI literacy, data privacy and ethical concerns, unreliable AI-generated content, academic integrity issues, and learner overdependence on automated systems. The review further identifies limited interdisciplinary evidence specifically addressing AI in Integrated Science, particularly in developing and resource-constrained contexts. Future research should therefore emphasize human-centred AI integration, teacher professional development, context-sensitive and inclusive research, longitudinal empirical studies, and responsible and explainable AI. Overall, AI offers significant potential for strengthening Integrated Science education when implemented responsibly, equitably, and in alignment with curriculum objectives and human pedagogical judgement.

Keywords: Artificial Intelligence; Integrated Science Education; Generative AI; Science Education; AI Literacy; Intelligent Learning; Responsible AI

INTRODUCTION

Artificial Intelligence (AI) has rapidly evolved into one of the most transformative technologies of the twenty-first century, influencing nearly every sector of human activity, including healthcare, agriculture, finance, manufacturing, transportation, and education. Advances in machine learning, natural language processing, computer vision, learning analytics, intelligent tutoring systems, and, more recently, and generative artificial intelligence have significantly expanded the capabilities of digital technologies to support teaching and learning. Within education, AI is increasingly viewed as an enabler of personalized instruction, adaptive assessment, automated feedback, curriculum innovation, and evidence-based educational decision-making (Yusuf et al., 2024; Almasri, 2024). Recent global developments have also accelerated interest in AI-enabled educational practices, prompting governments, educational institutions, and researchers to examine how AI can improve learning outcomes while ensuring ethical, equitable, and responsible implementation.

The growing integration of AI into education reflects the broader global movement toward digital transformation and the development of knowledge-based economies. Educational systems are increasingly

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expected to prepare learners with competencies such as critical thinking, creativity, collaboration, digital literacy, and problem-solving to meet the demands of rapidly changing technological environments. In response, AI technologies are being incorporated into various aspects of teaching and learning, including intelligent tutoring systems, automated grading, virtual laboratories, adaptive learning platforms, predictive analytics, and conversational agents. These technologies have demonstrated considerable potential for improving instructional efficiency, learner engagement, academic performance, and individualized learning experiences across different educational levels and disciplines (Almasri, 2024; Jia et al., 2024).

Recognizing the transformative potential of AI, the UNESCO has consistently emphasized that AI should be developed and deployed in ways that promote inclusive, equitable, and quality education while safeguarding fundamental human rights, privacy, transparency, and ethical values. UNESCO further argues that AI should complement rather than replace teachers, positioning educators at the center of educational innovation while using intelligent technologies to support teaching, learning, and educational administration. This human-centered approach underscores the importance of developing AI policies and practices that strengthen educational systems rather than creating new forms of inequality or exclusion.

Integrated Science education occupies a strategic position within contemporary school curricula because it combines knowledge from biology, chemistry, physics, environmental science, and earth science into a unified learning experience. Rather than teaching scientific disciplines in isolation, Integrated Science encourages learners to understand relationships among scientific concepts, develop inquiry skills, solve real-world problems, and appreciate the interconnected nature of scientific knowledge. The subject therefore plays a vital role in developing scientific literacy, innovation, and critical thinking, which are essential competencies for sustainable development and participation in modern society (Almasri, 2024).

Despite its educational significance, Integrated Science education continues to encounter numerous challenges that hinder effective teaching and learning. Many schools, particularly in developing countries, experience shortages of qualified science teachers, inadequate laboratory facilities, insufficient instructional materials, overcrowded classrooms, and limited access to modern educational technologies. Furthermore, many scientific concepts taught in Integrated Science are abstract and difficult for learners to visualize through conventional teaching approaches alone. These limitations often reduce students' engagement, weaken conceptual understanding, and restrict opportunities for inquiry-based and practical learning experiences. Consequently, educators continue to explore innovative instructional approaches capable of overcoming these barriers while improving students' academic achievement and scientific reasoning (Almasri, 2024).

Artificial Intelligence offers promising solutions to many of these long-standing educational challenges. AI-powered intelligent tutoring systems can provide personalized instruction based on individual learners' needs, adaptive learning platforms can recommend customized learning pathways, while predictive learning analytics can identify students at risk of poor academic performance and facilitate timely intervention. Similarly, AI-supported virtual laboratories and simulations enable students to conduct scientific investigations in environments where physical laboratory resources are limited or unavailable. Conversational AI systems and generative AI tools further support collaborative learning, scientific writing, lesson preparation, assessment development, and immediate feedback, thereby enhancing both teaching effectiveness and students' learning experiences (Yusuf et al., 2024; Cheung et al., 2025).

Recent studies indicate that AI applications in science education extend beyond instructional delivery to include automated assessment, intelligent feedback systems, scientific data visualization, personalized experimentation, curriculum support, and teacher professional development. A comprehensive systematic review conducted by Almasri (2024) revealed that AI technologies have been successfully applied across various domains of science education to improve students' learning outcomes, increase engagement, facilitate assessment, and enhance instructional effectiveness. Similarly, Jia et al. (2024) reported a substantial increase in research on AI in science education over the past decade, reflecting growing global interest in integrating intelligent technologies into science teaching and learning. These findings suggest that AI is increasingly becoming an integral component of science education research and practice.

Notwithstanding these opportunities, the adoption of AI in Integrated Science education also raises significant pedagogical, ethical, technological, and policy-related concerns. Researchers have identified issues relating to algorithmic bias, data privacy, cybersecurity, transparency, accountability, digital inequality, teacher preparedness, and excessive dependence on AI-generated content as important considerations for educational institutions. The emergence of generative AI has further intensified debates regarding academic integrity, originality, assessment validity, and the evolving role of teachers in AI-supported learning environments. These concerns highlight the need for responsible AI governance that balances technological innovation with educational quality, ethical principles, and human-centered pedagogy (Yusuf et al., 2024; Cheung et al., 2025).

Although the body of literature on Artificial Intelligence in education has expanded considerably, much of the existing research has focused on general educational applications or individual scientific disciplines rather than providing a comprehensive synthesis specifically addressing Integrated Science education. Furthermore, the rapid emergence of generative AI technologies after 2022 has substantially altered the educational landscape, creating new opportunities and challenges that are not fully reflected in earlier reviews. Consequently, there remains a need for an updated synthesis that consolidates current evidence, identifies prevailing research trends, examines implementation challenges, and outlines future research priorities for AI integration within Integrated Science education.

Accordingly, this paper presents a structured literature review of Artificial Intelligence in Integrated Science education. Specifically, the review synthesizes existing evidence on AI applications in Integrated Science teaching and learning, examines the opportunities and challenges associated with AI adoption, identifies current research gaps, and proposes future directions for research, policy, and classroom practice. By integrating findings from recent scholarly literature, this review aims to provide educators, researchers, curriculum developers, and policymakers with a comprehensive understanding of how AI can be responsibly and effectively leveraged to improve Integrated Science education in the digital age.

REVIEW METHODOLOGY

Accordingly, this paper presents a structured literature review of Artificial Intelligence in Integrated Science education. A structured review was considered appropriate because it provides a transparent, comprehensive, and reproducible method for summarizing research findings while minimizing selection bias. Unlike a traditional narrative review, a structured literature review uses predefined search and selection procedures to support transparent literature identification, screening, eligibility assessment, and thematic synthesis, thereby improving the consistency and credibility of the review process.

a. Search Strategy

A structured literature search was conducted to identify recent scholarly evidence on the application of artificial intelligence (AI) in Integrated Science and science education. The search focused on literature published between 2020 and 2026 and used the Education Resources Information Center (ERIC) and the Directory of Open Access Journals (DOAJ), with Google Scholar used as a supplementary source for identifying relevant publications and tracing additional scholarly evidence. Search terms combined keywords relating to artificial intelligence and science education, including "artificial intelligence," "generative AI," "ChatGPT," "machine learning," "Integrated Science," "science education," "science teaching," and "science learning." The search prioritized English-language, peer-reviewed publications addressing the application, opportunities, challenges, or future directions of AI in science education.

b. Search String:

("Artificial Intelligence" OR "AI" OR "Machine Learning" OR "Generative AI" OR "Intelligent Tutoring System") AND ("Integrated Science Education" OR "Science Education" OR "science teaching" OR "science learning") AND ("Teaching" OR "Learning" OR "Education")

The identified literature was screened according to predefined eligibility criteria. Relevant records were retained when they addressed AI applications or implications for science teaching and learning, while studies unrelated to educational contexts or without substantive relevance to science education were excluded.

Additional searches were performed using related keywords such as *adaptive learning*, *learning analytics*, *virtual laboratories*, *science instruction*, and *AI-assisted learning* to identify potentially relevant publications that may not have been captured by the primary search string

Table 1. Search Strategy and Keywords Used for the Literature Review

Search concept	**Keywords and Boolean combinations**
Artificial Intelligence	"artificial intelligence" OR AI OR "generative AI" OR ChatGPT OR "large language models" OR "machine learning"
Science Education	"Integrated Science" OR "science education" OR "science teaching" OR "science learning"
Application and educational context	education OR teaching OR learning OR classroom OR curriculum
Opportunities and challenges	opportunities OR benefits OR challenges OR barriers OR limitations OR "future directions"
Combined search	("artificial intelligence" OR AI OR "generative AI" OR ChatGPT OR "large language models" OR "machine learning") AND ("Integrated Science" OR "science education" OR "science teaching" OR "science learning") AND (education OR teaching OR learning OR classroom OR curriculum)

c. Eligibility Criteria

To ensure the quality and relevance of the review, explicit inclusion and exclusion criteria were established before the literature search. Only peer-reviewed journal articles published in English were included to ensure methodological quality and accessibility. Conference abstracts, editorials, opinion papers, dissertations, book reviews, duplicate publications, and studies unrelated to AI applications in science education were excluded. The review also excluded studies focusing exclusively on higher education administration, healthcare education, or non-educational AI applications.

Table 2. Inclusion and Exclusion Criteria

Criterion	**Inclusion Criteria**	**Exclusion Criteria**
Publication period	Studies published between 2020 and 2026	Studies published before 2020
Publication type	Peer-reviewed journal articles and relevant scholarly review studies	Non-scholarly materials, unpublished manuscripts, editorials, opinion pieces, and duplicate records
Language	Publications available in English	Publications in languages other than English
Subject focus	Studies addressing artificial intelligence, generative AI, machine learning, or related AI technologies in education or science education	Studies unrelated to education or science learning
Educational context	Studies addressing science education, Integrated Science, science teaching, science learning, or closely related educational contexts	Studies focused exclusively on non-educational applications of AI
Relevance	Studies examining AI applications, opportunities, challenges, impacts, or	Studies with no substantive connection to the review objectives

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	future directions relevant to science education	
Accessibility	Full-text publications accessible through the selected scholarly sources or available through open-access channels	Publications for which sufficient full text was unavailable for assessment

d. Study Selection Process

The identified publications were screened in stages to determine their relevance to the objectives of the review. From an initial identification of 345 records across ERIC, DOAJ, and Google Scholar, duplicate removal yielded 290 records. Following title and abstract screening, 225 records were excluded, leaving 65 full-text articles assessed for eligibility. Of these, 40 articles were excluded due to mismatch with inclusion criteria, resulting in a final inclusion of 25 studies for thematic synthesis. The potentially relevant publications were then assessed against the predefined inclusion and exclusion criteria, with particular attention to publication period, language, educational context, and relevance to AI applications, opportunities, challenges, and future directions in science education.

The final selection comprised studies that met the eligibility criteria and provided substantive evidence relevant to the review objectives. The literature selection process consisted of four sequential stages: identification, screening, eligibility assessment, and final inclusion, as illustrated in Figure 1.

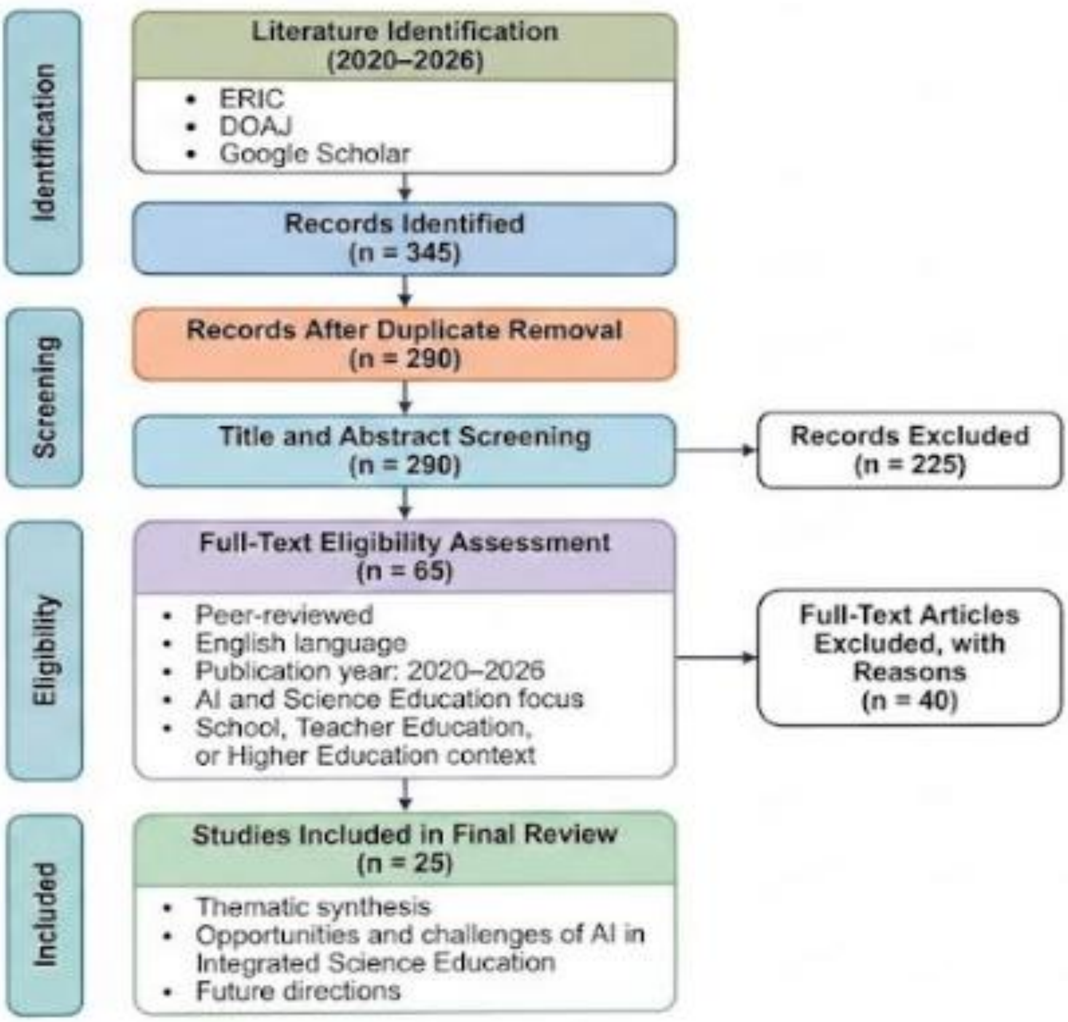

Figure 1. Literature Identification, Screening, Eligibility Assessment, and Selection Framework for the Structured Literature Review (2020–2026).

The systematic selection workflow—detailing the transition from initial database identification through duplicate removal, title/abstract screening, and full-text eligibility assessment down to the final included studies—is outlined in Figure 1.

e. Data Extraction and Synthesis

Relevant information was extracted from the selected publications using a structured approach. The extracted information included the author(s) and publication year, study context, educational level, type of AI technology examined, area of application, study type, and key findings relevant to Integrated Science and science education. These characteristics were organized to facilitate comparison across the selected literature and are summarized in Table 3.

The findings were synthesized thematically according to the major themes emerging from the reviewed literature, including the opportunities, applications, challenges, and future directions of AI in Integrated Science education. The synthesis focused on identifying common findings, areas of convergence and divergence, and gaps in the existing evidence. This approach provided the basis for the discussion of AI opportunities in Section 4, challenges in Section 5, and future directions in Section 6. The resulting evidence base provides the foundation for the literature review and subsequent thematic discussion of AI in Integrated Science education.

LITERATURE REVIEW

This section reviews recent literature on the application of artificial intelligence (AI) in education, science education, and Integrated Science. The review examines how AI is conceptualized and applied within science learning, synthesizes evidence from recent studies, and identifies gaps that justify further attention to the opportunities, challenges, and future directions of AI integration in Integrated Science education.

a. Artificial Intelligence in Education and Science Education

Artificial Intelligence (AI) has increasingly become an important component of educational innovation, with applications ranging from intelligent tutoring and adaptive learning to automated assessment, learning analytics, and generative AI. In education, AI systems can analyse learner interactions, generate instructional content, provide immediate feedback, and support teachers in planning and decision-making. These capabilities have increased interest in AI as a tool for improving the efficiency and responsiveness of teaching and learning, although its educational value depends on appropriate pedagogical integration and human oversight ((Fayzullina et al., 2025); Within science education, AI is particularly relevant because learning often involves complex concepts, inquiry, experimentation, problem-solving, and interpretation of scientific information. AI-supported tools can provide interactive learning environments in which students explore scientific concepts, receive feedback, and engage with simulated or digitally mediated learning activities. Recent research also indicates growing interest in generative AI and conversational systems for supporting science learning and inquiry, although concerns remain regarding the accuracy of AI-generated information, students' overdependence on automated responses, and the potential weakening of independent scientific reasoning (Cheung et al., 2025; Min et al., 2025).

The increasing use of AI therefore represents a shift from conventional technology-supported instruction toward more adaptive and interactive learning environments. However, the literature suggests that AI should be viewed as a support mechanism rather than a replacement for teachers or authentic scientific investigation. Its effective application requires alignment with curriculum objectives, teacher competence, learner needs, ethical principles, and the technological conditions of educational institutions. These considerations are particularly important in Integrated Science, where learning draws on concepts and practices from multiple scientific disciplines and requires students to connect knowledge across different areas of science. (Hwang et al., 2020).

b. Artificial Intelligence and Integrated Science Education

Integrated Science combines concepts and processes from disciplines such as biology, chemistry, physics, and environmental science to promote connected understanding of scientific phenomena. This interdisciplinary structure creates opportunities for AI-supported learning because AI tools can help learners access, organize, and relate scientific information across different domains. Rather than treating scientific concepts as isolated topics, AI-supported environments can facilitate connections between concepts and provide interactive support for exploring complex scientific problems (Almasri, 2024; Cheung et al., 2025).

The literature also suggests that generative AI and other intelligent technologies are increasingly relevant to science learning activities that require explanation, inquiry, problem-solving, and interpretation of scientific information. However, the value of these technologies depends on how well they are aligned with curriculum objectives and guided by teachers. In Integrated Science, therefore, AI should complement disciplinary knowledge and scientific reasoning rather than replace learners' active engagement in investigation and evidence-based thinking (Erümit & Özdemir Sarıalioğlu, 2025; Fayzullina et al., 2025)

c. Evidence from Recent Studies

The selected literature demonstrates a growing application of artificial intelligence across science education, with studies examining generative AI, intelligent tutoring, adaptive learning, learning analytics, and AI-supported inquiry. The evidence indicates that AI is increasingly being used to enhance learner engagement, provide personalized support, facilitate access to scientific information, and support teachers in instructional decision-making. However, the studies vary considerably in educational level, technological application, and research focus, indicating that the evidence base remains diverse rather than uniform (Fayzullina et al., 2025).

The characteristics and major contributions of the selected studies are presented in Table 3. The table provides a comparative overview of the evidence base and highlights the range of AI applications examined in science education between 2020 and 2026.

The evidence also shows that AI research in science education remains diverse and fragmented across educational levels, technologies, and scientific disciplines (Kesgin 2025). Recent research has examined AI-supported learning, generative AI, and AI-assisted scientific activities, but comparatively less attention has been given to how these technologies can be integrated across the interdisciplinary structure of Integrated Science (Erümit & Özdemir Sarıalioğlu, 2025; Fayzullina et al., 2025). This suggests the need for research that moves beyond examining individual AI tools and considers how AI can support connected learning across scientific domains while maintaining scientific reasoning, teacher guidance, and responsible use. The selected literature informing this review is summarized in Table 3.

Table 3. Characteristics and Major Contributions of Selected Studies on Artificial Intelligence in Science Education (2020–2026)

S/N	Authors/year	Context	AI Focus	Main Findings	Theme
1	Almasri (2024)	Science education	AI applications	Reviews empirical evidence on AI applications, benefits and challenges	General AI in science
2	Ng et al. (2024)	Secondary science	AI-supported learning	Examines AI-supported self-regulated learning among secondary students	Personalised learning
3	Zhai et al. (2024)	K–12 science	Generative AI	Examines GenAI performance on science-related tasks and implications for learning and assessment	Inquiry/ assessment
4	Eke Ogbu Eke	Nigeria	AI readiness in	Examines the role of AI in	Nigerian context

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	(2024)		Nigerian education	secondary science education	
5	Eke Ogbu Eke (2024)	Nigeria	AI in science teaching	Examines the role of AI in secondary science education	Nigerian context
6	Bali et al. (2024)	Nigeria	AI in education Examines AI integration into science education in Nigerian universities n	Highlights opportunities and infrastructure-related challenges of AI adoption	Implementation
7	Cheung et al. (2025)	K – 12 Science	GenAI	Synthesises empirical research on GenAI and science education	Opportunities/ Challenges
8	Min et al. (2025)	Secondary science	GenAI	Examines GenAI-supported scientific inquiry and experimental design	Scientific inquiry
9	de Putter-Smits et al. (2025)	Science teacher Education	GenAI	Examines opportunities and challenges for science teacher preparation	Teacher support
10	Doğru & Faulconer (2026)	Undergraduate	ChartGTP	Examines ChatGPT as a virtual laboratory teaching assistant	Practical learning
11	Min et al. (2025)	Biology	GenAI	Examines GenAI use in science lesson planning and teacher learning	Teacher support
12	Kim (2025/2026)	Secondary science	GenAI	Examines GenAI-supported science lesson design	Teacher support
13	Fayzullina et al. (2025)	Environmental science	GenAI	Examines relationships between GenAI, learning outcomes and metacognition	Learning outcomes
14	Bobson & Obafemi (2025)	Nigeria, Basic Science	AI assessment	Discusses AI opportunities and implementation challenges in assessment	Assessment
15	Bobson & Obafemi (2025)	Nigeria, Basic Science	Virtual laboratory	Provides evidence on digitally mediated practical science learning	Practical learning

Overall, the reviewed studies demonstrate that AI is being explored across multiple dimensions of science education, but the evidence remains uneven in scope and context. While several studies focus on specific AI technologies or individual science disciplines, fewer examine AI integration across the interconnected domains that characterise Integrated Science. This pattern supports the need for further attention to interdisciplinary applications of AI, teacher-mediated implementation, responsible use, and the contextual realities of educational systems with varying levels of technological capacity.

d. Synthesis of Evidence and Research Gap

The reviewed studies indicate that AI is developing from a supplementary digital resource into a broader component of science teaching and learning. However, the evidence remains uneven across educational levels, scientific disciplines, AI applications, and geographical settings. Much of the available research concentrates on specific technologies or individual science subjects, making it difficult to establish how AI can support the interdisciplinary knowledge integration that characterises Integrated Science (Oyeniyi and Awodun (2026)..

The evidence is also limited in developing educational contexts, where infrastructure, teacher preparedness, digital access, and institutional capacity may influence AI adoption. In addition, relatively few studies examine the long-term educational effects of AI integration or how teachers can balance AI-supported learning with students' independent reasoning and scientific inquiry (Fayzullina et al., 2025). The review explicitly examines AI applications across different scientific fields and educational settings and identifies varied applications and challenges.

These gaps indicate the need for a more context-sensitive understanding of AI integration in Integrated Science education. Accordingly, the present review synthesizes the opportunities, challenges, and future directions of AI integration, with particular attention to interdisciplinary learning, responsible use, teacher capacity, and the realities of resource-constrained educational environments.

It is important to note a methodological distinction within the current evidence base: while a significant portion of empirical research on AI in science education focuses on individual single-discipline contexts—such as undergraduate biology (e.g., Doğru & Faulconer, 2026) or specific environmental science settings (e.g., Fayzullina et al., 2025)—evidence specifically examining interdisciplinary or Integrated Science education remains comparatively scarce (Oyeniyi & Awodun, 2026). Consequently, several insights regarding virtual laboratories, automated feedback, and inquiry support are synthesized across broader science contexts and applied here to the interdisciplinary structure of Integrated Science.

OPPORTUNITIES OF ARTIFICIAL INTELLIGENCE IN INTEGRATED SCIENCE EDUCATION

The reviewed evidence indicates that artificial intelligence (AI) has the potential to enhance Integrated Science education by extending the capacity of teachers and learners to access, explore, analyse, and apply scientific knowledge. Its value is particularly evident in areas such as personalised learning, virtual experimentation, scientific inquiry, intelligent assessment, and data-informed instructional support. However, these opportunities are most effective when AI is integrated with established pedagogical practices and aligned with curriculum objectives, teacher expertise, and learners' needs. (Chen et al., 2020; Almasri, 2024).

a. Personalized and Adaptive Learning

AI can analyse students' learning behaviours and performance to support the provision of individualized instructional content, activities, and feedback. Adaptive learning systems can adjust learning pathways according to learners' needs, potentially supporting students who progress at different rates or experience difficulties with particular scientific concepts. In Integrated Science, this capability can support differentiated learning across interconnected areas such as biology, chemistry, physics, and environmental science (Fayzullina et al., 2025; Almasri, 2024).

AI-supported personalisation may also help teachers identify patterns in learner performance and provide targeted support where misconceptions or learning difficulties emerge. However, adaptive systems should complement teacher judgement rather than replace it, particularly when addressing complex scientific reasoning and interdisciplinary learning.

b. Virtual Laboratories and Scientific Simulation

AI-supported simulations and virtual laboratories can provide learners with opportunities to explore scientific phenomena and conduct experiments in digital environments. These tools are particularly valuable where schools have limited laboratory facilities, equipment, or materials. Virtual environments allow learners to manipulate variables, observe outcomes, repeat experiments, and explore scientific relationships in ways that may be difficult to achieve in conventional classrooms (Fayzullina et al., 2025; Erümit & Özdemir Sarıalioğlu, 2025).

For Integrated Science education, such environments can support the investigation of problems that cut across disciplinary boundaries, enabling learners to connect concepts from biology, chemistry, physics, and environmental science. AI-supported simulations can therefore complement practical laboratory experiences by providing additional opportunities for experimentation, visualisation, and inquiry, particularly in resource-constrained educational settings.

c. Enhanced Scientific Inquiry and Problem-Solving

AI can facilitate inquiry-based learning by helping learners formulate questions, explore possible explanations, analyse information, generate hypotheses, and receive interactive guidance during scientific investigations. Generative AI and conversational systems can provide explanations, alternative perspectives, and prompts that encourage learners to examine scientific problems from different viewpoints. These capabilities may be particularly valuable in Integrated Science, where learners are expected to connect concepts across disciplines and apply scientific knowledge to complex real-world problems (Cheung et al., 2025; Fayzullina et al., 2025).

However, AI-supported inquiry should complement rather than replace students' own reasoning, experimentation, and critical evaluation. Teachers therefore remain essential in guiding learners to verify AI-generated information, evaluate evidence, recognise inaccuracies, and develop independent scientific reasoning. Used appropriately, AI can function as an interactive support mechanism that extends opportunities for inquiry and problem-solving without displacing the cognitive processes central to science learning (Gunsaldi et al. (2025).

d. Intelligent Assessment and Immediate Feedback

AI can support formative assessment by analyzing learner responses and providing rapid feedback. Automated systems may assist teachers in identifying misconceptions and areas of difficulty, enabling timely instructional intervention (Latif and Zhai, 2024). Generative AI can also assist in developing questions and learning activities, although teacher verification remains necessary to ensure scientific accuracy and assessment quality (Hwang et al., 2020; Yusuf et al., 2024).

e. Teacher Support and Data-Informed Instruction

AI-powered learning analytics can provide teachers with information about learner engagement, progress, and performance. Such information can support evidence-based instructional decisions and help teachers identify learners who may require additional assistance. AI can therefore function as a decision-support tool that enhances teacher capacity rather than replacing professional judgment (Hwang et al., 2020).

Table 4. Opportunities and Potential Educational Benefits of AI in Integrated Science Education

Opportunity	AI Application	Potential Educational Benefit
Personalized learning	Adaptive learning systems	Individualized instruction
Virtual experimentation	AI simulations and virtual laboratories	Improved conceptual understanding
Scientific inquiry	Interactive AI systems	Enhanced inquiry and problem-solving
Intelligent assessment	Automated assessment and feedback	Timely identification of learning difficulties
Teacher support	Learning analytics	Data-informed instructional decisions

Overall, AI offers substantial opportunities to make Integrated Science education more personalized, interactive, inquiry-oriented, and responsive. However, these opportunities can only be realized when AI is appropriately aligned with curriculum objectives, teacher expertise, available infrastructure, and responsible educational practice.

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CHALLENGES OF ARTIFICIAL INTELLIGENCE IN INTEGRATED SCIENCE EDUCATION

Despite the opportunities presented by Artificial Intelligence (AI), its integration into Integrated Science education is accompanied by several challenges. These challenges are not solely technological; they also involve pedagogical, ethical, infrastructural, and human factors. Addressing them is essential for ensuring that AI contributes meaningfully to science education rather than creating new forms of inequality or educational dependency.

a. Inadequate Digital Infrastructure

Effective AI integration requires reliable electricity, internet connectivity, computing devices, and appropriate digital platforms. Schools with limited technological infrastructure may be unable to implement AI-supported learning effectively. This challenge is particularly relevant in resource-constrained educational contexts, where unequal access to digital technologies may widen existing educational disparities (Hwang et al., 2020; UNESCO, 2023).

b. Teacher Preparedness and AI Literacy

Teachers require sufficient technological and pedagogical knowledge to select, evaluate, and effectively integrate AI tools into science instruction. Limited AI literacy may result in inappropriate use of AI or excessive dependence on automated systems. Professional development is therefore necessary to enable teachers to understand both the capabilities and limitations of AI while maintaining their role as instructional decision-makers (Hwang et al., 2020; UNESCO, 2023; Eke Ogbu Eke, 2024).

c. Data Privacy and Ethical Concerns

AI systems often depend on the collection and analysis of learner data. This raises concerns about privacy, data security, informed consent, and the responsible management of personal information. In addition, algorithmic bias may produce unfair or inaccurate outcomes if AI systems are trained on incomplete or unrepresentative data. Responsible implementation therefore requires clear ethical standards, transparency, and appropriate data governance (UNESCO, 2021; UNESCO, 2023).

d. Accuracy, Bias, and Reliability of AI-Generated Content

Generative AI systems can produce inaccurate information, misleading explanations, or fabricated references. This is particularly problematic in science education, where inaccurate information may lead to misconceptions. Students and teachers therefore need the ability to critically evaluate AI-generated content rather than accepting it without verification (Yusuf et al., 2024).

e. Academic Integrity and Overdependence on AI

The increasing use of generative AI creates concerns about plagiarism, unauthorized assistance, reduced originality, and students' overreliance on automated systems . Excessive dependence on AI may weaken independent reasoning and problem-solving if learners use AI to obtain answers without engaging with the underlying scientific concepts. Consequently, AI integration should emphasize critical thinking and inquiry rather than simply automating the learning process (Yusuf et al., 2024).

Overall, the challenges associated with AI demonstrate that technological adoption alone cannot guarantee improved Integrated Science education. Successful implementation requires adequate infrastructure, teacher preparation, ethical safeguards, reliable AI systems, and pedagogical strategies that preserve students' active intellectual engagement.

FUTURE DIRECTIONS

The future integration of Artificial Intelligence (AI) into Integrated Science education will depend on moving beyond technology adoption toward responsible, evidence-based, and pedagogically meaningful implementation. The literature indicates that future research should examine not only what AI can do, but also how it can be integrated effectively, ethically, and equitably within different educational contexts (Hwang et al., 2020; UNESCO, 2023).

a. Human-Centred AI Integration

Future AI applications should complement teachers rather than replace them. Research should therefore investigate human–AI collaboration models in which AI provides analytical and instructional support while teachers retain responsibility for pedagogical decisions, classroom interaction, and student development. Such an approach can preserve the human and social dimensions of science education.

b. Teacher Professional Development

Future research should place greater emphasis on AI literacy and professional development for science teachers. Teachers need practical knowledge of AI tools, their limitations, ethical implications, and appropriate classroom applications. Professional development should therefore combine technical competence with pedagogical knowledge and critical evaluation skills.

c. Context-Specific and Inclusive AI Research

More research is needed across diverse educational settings, particularly in developing and resource-constrained contexts. AI solutions designed for technologically advanced education systems may not be directly transferable to schools with limited connectivity, electricity, devices, or financial resources. Future studies should therefore examine context-specific AI models that promote accessibility and reduce rather than reinforce educational inequalities (UNESCO, 2023).

d. Longitudinal and Empirical Research

Much of the emerging literature focuses on potential benefits and short-term applications. Future research should employ longitudinal and comparative designs to determine whether AI produces sustained improvements in students' scientific knowledge, inquiry skills, critical thinking, and problem-solving abilities. Research should also compare AI-supported learning with conventional instructional approaches across different Integrated Science contexts.

e. Responsible and Explainable AI

Future AI systems should prioritize transparency, fairness, privacy, and explainability. Teachers and learners should be able to understand, at an appropriate level, how AI-supported recommendations or assessments are generated. Stronger governance frameworks are also needed to address data protection, algorithmic bias, academic integrity, and the reliability of AI-generated content (UNESCO, 2021; UNESCO, 2023).

The future of AI in Integrated Science education therefore lies not simply in increasing the use of AI tools but in developing **responsible, inclusive, teacher-supported, and evidence-based approaches** that strengthen scientific learning. The major research gaps and corresponding future directions identified from the literature are summarized below.

Table 5. Research Gaps and Future Research Agenda

Research Gap	Implication	Future Research Direction
Limited long-term empirical evidence	Sustained learning effects remain uncertain	Conduct longitudinal studies
Limited research in developing contexts	Contextual applicability is unclear	Conduct context-specific and cross-country research
Inadequate teacher AI	Effective classroom integration may	Develop AI-focused teacher

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preparedness	be limited	professional development
Ethical and privacy concerns	Learner data may be exposed to risks	Develop responsible AI governance frameworks
Reliability of AI-generated content	Students may encounter inaccurate information	Develop verification and explainability mechanisms
Risk of student overdependence	Independent thinking may be weakened	Investigate human-centred AI pedagogies
Limited interdisciplinary evidence on AI in Integrated Science	Evidence from individual science disciplines may not fully explain AI's potential in interdisciplinary Integrated Science learning	Conduct interdisciplinary research on AI applications in Integrated Science

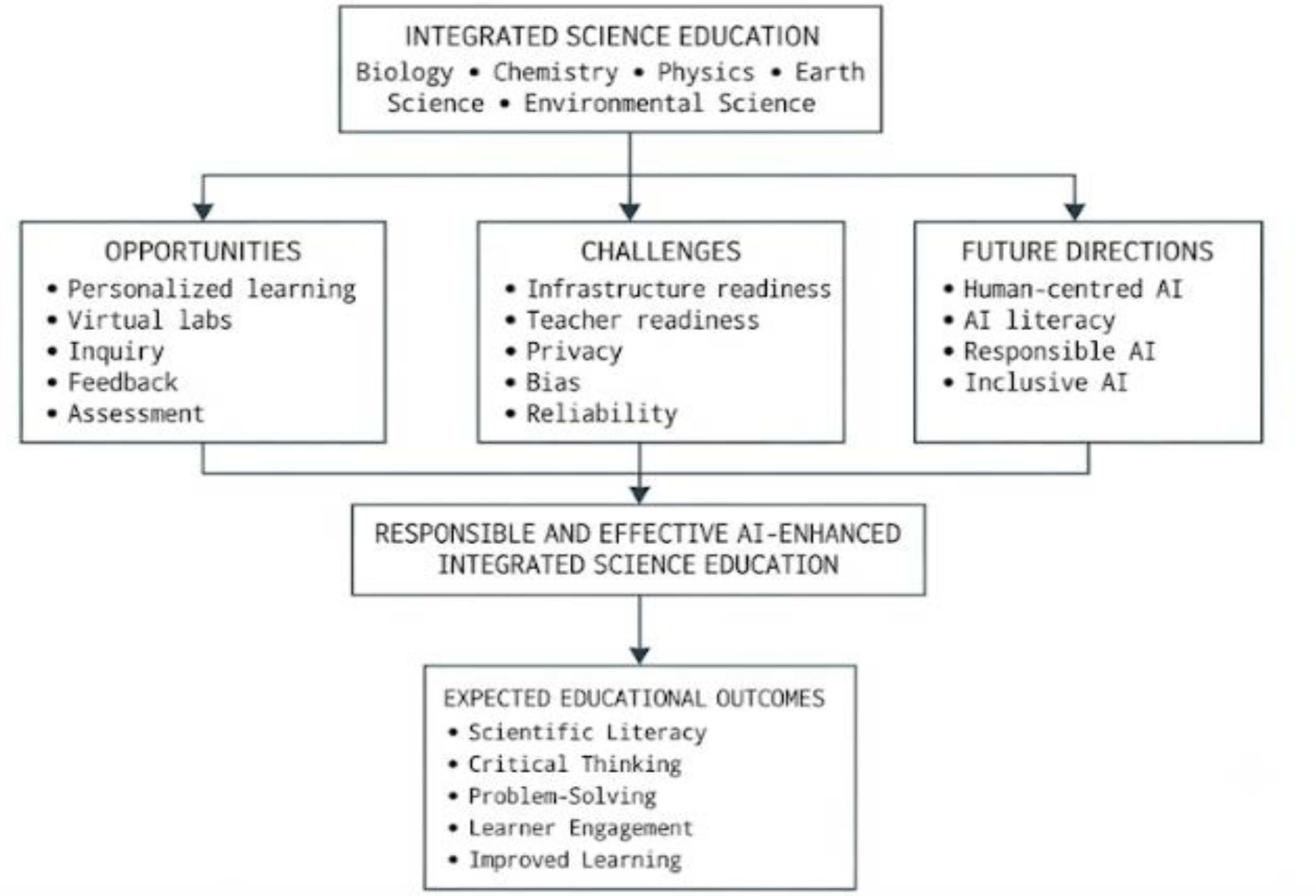

Figure 2: AI in Integrated Science Education: Opportunities, Challenges, and Future Directions

CONCLUSION

Artificial Intelligence is increasingly influencing educational practice and offers important possibilities for strengthening Integrated Science education. The literature reviewed in this study indicates that AI can support personalized learning, adaptive instruction, virtual experimentation, scientific inquiry, automated assessment, immediate feedback, and data-informed teaching. These applications have the potential to make science learning more interactive, flexible, and responsive to individual learner needs.

However, the integration of AI also presents significant challenges. Inadequate digital infrastructure, limited teacher preparedness, data privacy concerns, algorithmic bias, unreliable AI-generated information, and risks to academic integrity may constrain effective implementation. These challenges demonstrate that AI should not be viewed as a substitute for teachers or established pedagogical practices. Rather, it should be integrated as a supportive technology within a human-centred educational framework.

The review further highlights important directions for future research. Greater attention is needed to long-term empirical evidence, teacher professional development, responsible and explainable AI, equitable access, and research in developing and resource-constrained educational contexts. In particular, more research should directly investigate AI applications in Integrated Science rather than assuming that findings from general education or single-discipline science contexts can automatically be transferred to Integrated Science.

Ultimately, the educational value of AI will depend less on the sophistication of the technology than on how effectively it is aligned with curriculum objectives, teacher expertise, learner needs, ethical principles, and local educational realities. A responsible approach that combines AI capabilities with human judgement, scientific inquiry, and active learner engagement can contribute to a more inclusive and effective Integrated Science education system. Future efforts should therefore focus on developing evidence-based and context-sensitive models for AI integration that enhance, rather than diminish, the Central role of teachers and learners in the educational process.

REFERENCES

1. Almasri, F. (2024). *Exploring the impact of artificial intelligence in teaching and learning of science: A systematic review of empirical research*. *Research in Science Education, 54*, 977–997. https://doi.org/10.1007/s11165-024-10176-3
2. Bobson, E. F., & Obafemi, D. T. A. (2025). Effect of virtual laboratory-based instruction and field trip method on students' performance and retention in Basic Science in Bonny Local Government Area, Rivers State, Nigeria. *International Journal of Research and Innovation in Applied Science*. https://doi.org/10.51584/IJRIAS.2025.10030032
3. Cheung, K. C. C., Zerouali, A., Koenen, J., & Erduran, S. (2025). *Do generative artificial intelligence (GenAI) and science education mix? A systematic review of the literature*. *Studies in Science Education*. https://doi.org/10.1080/03057267.2025.2578091
4. Cheung, K. K. C., Long, Y., Liu, Q., & Chan, H.-Y. (2025). Unpacking epistemic insights of artificial intelligence (AI) in science education: A systematic review. *Science & Education, 34*, 747–777. https://doi.org/10.1007/s11191-024-00511-5
5. Chen, L., Chen, P., & Lin, Z. (2020). Artificial intelligence in education: A review. *IEEE Access, 8*, 75264–75278. https://doi.org/10.1109/ACCESS.2020.2988510
6. Danjuma, S. G. (2025). Artificial intelligence in Basic Science education: A Nigerian perspective on enhancing assessment. *BW Academic Journal, 2*.
7. de Putter-Smits, L. G. A., Pols, C. F. J., Dekkers, P. J. J. M., Runhaar, P. R., Timmer, M., & Van der Veen, J. T. (2025). Exploring the role of generative AI in science teacher education programs: A qualitative study. *International Journal of Educational Research Open, 9*, Article 100492. https://doi.org/10.1016/j.ijedro.2025.100492
8. Doğru, M. S., & Faulconer, E. K. (2026). ChatGPT as a virtual laboratory teaching assistant in undergraduate biology. *Research in Science Education, 56*, 379–399. https://doi.org/10.1007/s11165-025-10271-z
9. Eke Ogbu Eke, E. (2024). Assessing the readiness and attitudes of Nigerian teacher educators towards adoption of artificial intelligence in educational settings. *Journal of Educational Technology and Online Learning, 7*(4), 473–487. https://doi.org/10.31681/jetol.1503305
10. Fayzullina, A. R., Filippova, A. A., Garnova, N. Y., Astakhov, D. V., Kalmazova, N., & Zaripova, Z. F. (2025). Artificial intelligence in science education: A systematic review of applications, impacts, and challenges. *Contemporary Educational Technology, 17*(4), Article ep613.
11. Gunsaldi, M. S., Guner, E. G., Uckan, M., & Bati, K. (2025). The impact of generative AI applications on student learning outcomes in science education: A systematic review. *Journal of Education in Science, Environment and Health, 11*(3), 196–208.
12. Hwang, G.-J., Xie, H., Wah, B. W., & Gašević, D. (2020). Vision, challenges, roles and research issues of artificial intelligence in education. *Computers and Education: Artificial Intelligence, 1*, 100001.
13. Kesgin, K. (2025). Bibliometric analysis and predictive modeling map the role of artificial intelligence in science education from research trends to classroom integration. *Discover Education, 4*, Article 464.
14. Kim, W. J. (2026). Teachers' use of generative artificial intelligence for designing science lessons in

support of environmental science agency. *Research in Science Education, 56*, 203–222. https://doi.org/10.1007/s11165-025-10262-0

15. Latif, E., & Zhai, X. (2024). Fine-tuning ChatGPT for automatic scoring. *Computers and Education: Artificial Intelligence, 6*, Article 100210. https://doi.org/10.1016/j.caeai.2024.100210
16. Ng, D. T. K., Tan, C. W., & Leung, J. K. L. (2024). Empowering student self-regulated learning and science education through ChatGPT: A pioneering pilot study. *British Journal of Educational Technology, 55*(4), 1328–1353. https://doi.org/10.1111/bjet.13454
17. Oyeniyi, M. O., & Awodun, A. O. (2026). *Harnessing artificial intelligence to transform STEM and Integrated Science education for sustainable development in Nigerian secondary schools*. International Journal of Science and Research Archive, *19*(1). https://doi.org/10.30574/ijsra.2026.19.1.0756
18. UNESCO. (2023). *Guidance for generative AI in education and research*. UNESCO.
19. UNESCO. (2021). *Recommendation on the ethics of artificial intelligence*. UNESCO.
20. Yusuf, A., Pervin, N., Román-González, M., & Noor, N. M. (2024). Generative AI in education and research: A systematic mapping review. *Review of Education, 12*, e3489. https://doi.org/10.1002/rev3.3489
21. Yan, L., Greiff, S., & others. (2024). Practical and ethical challenges of large language models in education: A systematic scoping review. *British Journal of Educational Technology, 55*(1), 90–112. https://doi.org/10.1111/bjet.13370