

## Artificial Intelligence–Assisted Science Learning in Elementary Education: A Systematic Literature Review

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### ABSTRAK

Tinjauan literatur sistematis ini mengkaji integrasi Kecerdasan Buatan (AI) dalam pendidikan sains di sekolah dasar, dengan fokus pada model pedagogis, hasil belajar, dan pertimbangan etis. Mengikuti kerangka PRISMA 2020, pencarian komprehensif di database Scopus mengidentifikasi 637 catatan awal. Setelah menerapkan kriteria inklusi (studi empiris peer-review, konteks pendidikan dasar, pembelajaran sains berbantuan AI, dipublikasikan tahun 2019–2025), 28 artikel dipilih untuk analisis akhir. Temuan mengungkapkan tiga pendekatan pedagogis utama: pembelajaran berbasis inkuiri dengan penunjang AI, pembelajaran berbasis proyek yang ditingkatkan dengan AI generatif, dan pembelajaran berbasis permainan untuk pengenalan konsep AI. Hasil belajar yang terdokumentasi meliputi peningkatan literasi sains (skor N-gain hingga 0,73), peningkatan keterampilan berpikir komputasional, sikap positif terhadap sains, dan pengembangan keterampilan proses sains. Namun, kekhawatiran etis mengenai bias algoritmik, privasi data, ketergantungan berlebihan pada AI, dan akses yang adil masih belum cukup diatasi dalam literatur saat ini. Tinjauan ini mensintesis bukti terkini untuk mengusulkan kerangka kerja bagi integrasi AI yang bertanggung jawab dalam pendidikan sains di sekolah dasar, mengidentifikasi kesenjangan penelitian yang signifikan dan memberikan rekomendasi untuk pedagogi, kebijakan, dan penelitian masa depan.

**Kata kunci:** Kecerdasan Buatan, Pendidikan Dasar, Pembelajaran Sains, Tinjauan Literatur Sistematis, PRISMA

### ABSTRACT

This systematic literature review examines the integration of Artificial Intelligence (AI) in elementary science education, focusing on pedagogical models, learning outcomes, and ethical considerations. Following the PRISMA 2020 framework, a comprehensive search of the Scopus database identified 637 initial records. After applying inclusion criteria (peer-reviewed empirical studies, elementary education context, AI-assisted science learning, published 2019–2025), 28 articles were selected for final analysis. Findings reveal three primary pedagogical approaches: inquiry-based learning with AI scaffolding, project-based learning enhanced by generative AI, and game-based learning for AI concept introduction. Documented learning outcomes include improved scientific literacy (N-gain scores up to 0.73), enhanced computational thinking skills, positive attitudes toward science, and development of science process skills. However, ethical concerns regarding algorithmic bias, data privacy, over-reliance on AI, and equitable access remain insufficiently addressed in current literature. This review synthesizes current evidence to propose a framework for responsible AI integration in elementary science education, identifying significant research gaps and providing recommendations for pedagogy, policy, and future research.

**Keyword:** Artificial Intelligence, Elementary Education, Science Learning, Systematic Literature Review, PRISMA

## INTRODUCTION

The integration of Artificial Intelligence (AI) into elementary science education represents a paradigm shift with transformative potential. As digital technologies become increasingly ubiquitous in classrooms worldwide, educators and researchers are exploring how AI-assisted tools can support young learners in developing scientific literacy, critical thinking, and inquiry skills essential for the 21st century (Celik dkk., 2024; Lin dkk., 2023). The intersection of AI and science education at the elementary level is particularly significant because foundational scientific understanding and attitudes toward science are formed during these formative years (Acisli Celik & Ergin, 2022).

Recent developments in AI technologies—including intelligent tutoring systems, chatbots, computer vision applications, and generative AI—have opened new possibilities for personalized learning experiences, real-time feedback, and scaffolding of complex scientific inquiry (Chen & Liu, 2024; Chen & Liu, 2024; Zhai & Crippen, 2026). Studies have demonstrated that AI tools can support inquiry-based science teaching by enhancing student engagement, addressing persistent conceptual misunderstandings, and providing authentic learning experiences (Chang dkk., 2023; Kim, 2022). For instance, AI-powered chatbots have been successfully implemented to guide students through scientific inquiry processes (Chang dkk., 2023; J. Lee dkk., 2023), while computer vision applications help students visualize abstract scientific concepts such as cell division (Chen & Liu, 2024).

Despite growing interest in AI-assisted science learning, several critical gaps persist in the research literature. First, while systematic reviews have examined AI in secondary and tertiary education (Celik dkk., 2024; Lin dkk., 2023), limited attention has been devoted specifically to elementary education contexts (Alé dkk., 2025; Ramli & Mahmud, 2025). Young learners have unique developmental characteristics and learning needs that require pedagogical approaches distinct from those appropriate for older students. Young learners possess unique cognitive, social, and emotional developmental characteristics that necessitate pedagogical approaches distinct from those suitable for older students (Acisli Celik & Ergin, 2022). Consequently, findings from studies conducted at secondary or tertiary levels cannot be directly generalized to elementary contexts, highlighting the need for a focused synthesis of empirical evidence in primary education.

Second, the pedagogical models underpinning AI integration in elementary science classrooms remain poorly characterized. Although inquiry-based learning has been identified as a foundational approach (Burgin, 2020; Constantinou dkk., 2018), the specific ways AI tools are embedded within various instructional frameworks require systematic examination. Existing literature often treats AI as a monolithic technological intervention without systematically examining how different pedagogical models—such as inquiry-based learning with AI scaffolding, project-based learning enhanced by generative AI, or game-based approaches—shape the integration process and influence learning outcomes. A systematic examination of these pedagogical models is essential for developing theory-driven and developmentally appropriate implementation frameworks.

Third, learning outcomes associated with AI-assisted science learning in elementary settings have been reported across diverse studies, yet no comprehensive synthesis exists to document the range and consistency of these outcomes. Understanding what works, for whom, and under what conditions is essential for evidence-based practice. Understanding what works, for whom, and under what conditions is critical for evidence-based practice, yet existing reviews often aggregate findings across grade levels or focus narrowly on cognitive gains while overlooking affective and process-oriented outcomes such as science process skills and computational thinking (Zhai & Crippen, 2026).

Fourth, and perhaps most critically, ethical issues surrounding AI use with young children have received insufficient attention in the empirical literature. Concerns regarding algorithmic bias, data privacy, the appropriateness of AI interactions for child development, and the potential for AI to exacerbate existing educational inequities demand urgent consideration (Lodhi, 2025; Zhai & Crippen, 2026). Furthermore, over-reliance on AI, and equitable access (Alé dkk., 2025; Lodhi, 2025), few intervention studies have systematically addressed these ethical dimensions. This gap is particularly problematic given the vulnerabilities of elementary-aged children and the formative role of early educational experiences in shaping lifelong dispositions toward science and technology (Zhai & Crippen, 2026). Without empirical evidence on how ethical challenges manifest in real-world classrooms, the development of responsible AI integration frameworks remains constrained.

This systematic literature review addresses these gaps by asking the following research questions:

1. What pedagogical models are employed in AI-assisted science learning at the elementary education level?
2. What learning outcomes are documented in empirical studies of AI-assisted elementary science education?
3. What ethical issues are identified or discussed in relation to AI use in elementary science classrooms?

By synthesizing evidence from Scopus-indexed publications, this review aims to provide researchers, educators, and policymakers with a comprehensive understanding of the current state of AI-assisted science learning in elementary education, while identifying directions for future inquiry and responsible implementation.

## METHOD

### Research Design

This study employed a systematic literature review (SLR) approach following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. The PRISMA framework provides a rigorous, transparent, and replicable methodology for identifying, screening, and synthesizing research evidence. The review protocol was developed prior to conducting the search and included predefined research questions, search strategies, inclusion criteria, and data extraction procedures.

### Search Strategy

A comprehensive literature search was conducted in the Scopus database, selected for its extensive coverage of peer-reviewed educational technology and science education research. The search was performed in February 2026, covering publications from January 2019 to 26 February 2026 to capture the most recent developments in this rapidly evolving field.

The search string combined terms related to artificial intelligence, science education, elementary education, and pedagogical contexts:

```
( TITLE-ABS-KEY ( "artificial intelligence" ) OR TITLE-ABS-KEY ( "AI" ) OR
TITLE-ABS-KEY ( "machine learning" ) OR TITLE-ABS-KEY ( "intelligent tutoring"
) OR TITLE-ABS-KEY ( "chatbot" ) OR TITLE-ABS-KEY ( "generative AI" ) OR
TITLE-ABS-KEY ( "large LANGUAGE model" ) AND TITLE-ABS-KEY ( "science
education" ) OR TITLE-ABS-KEY ( "science learning" ) OR TITLE-ABS-KEY (
"scientific literacy" ) OR TITLE-ABS-KEY ( "inquiry-based" ) OR TITLE-ABS-KEY
( "STEM" ) AND TITLE-ABS-KEY ( "elementary" ) OR TITLE-ABS-KEY (
"primary" ) OR TITLE-ABS-KEY ( "K-6" ) OR TITLE-ABS-KEY ( "grade school" )
OR TITLE-ABS-KEY ( "early childhood" ) ) AND PUBYEAR > 2018 AND
PUBYEAR < 2027 AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO (
DOCTYPE , "re" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) )
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### Inclusion and Exclusion Criteria

Studies were included if they met the following criteria:

1. **Population:** Focused on elementary education contexts (students approximately ages 5–12 years, grades K–6, or equivalent primary/elementary school levels)
2. **Intervention:** Investigated AI-assisted science learning, where AI tools or applications were integrated into science teaching and learning processes
3. **Outcomes:** Reported empirical data on pedagogical approaches, learning outcomes, or ethical considerations
4. **Publication type:** Peer-reviewed journal articles or conference proceedings indexed in Scopus
5. **Language:** Published in English

6. **Timeframe:** Published between 2019 and 2026

7. **Accessibility:** Full text available for review

Exclusion criteria included:

1. Studies focused exclusively on secondary or tertiary education without elementary-level data
2. Theoretical or conceptual papers without empirical data
3. Studies where AI was used for administrative purposes only (e.g., attendance tracking) rather than science learning
4. Non-English publications
5. Books, book chapters, editorials, and opinion pieces

### Screening and Selection Process

The screening process followed PRISMA guidelines across four phases: identification, screening, eligibility, and inclusion. Figure 1 presents the PRISMA flow diagram.

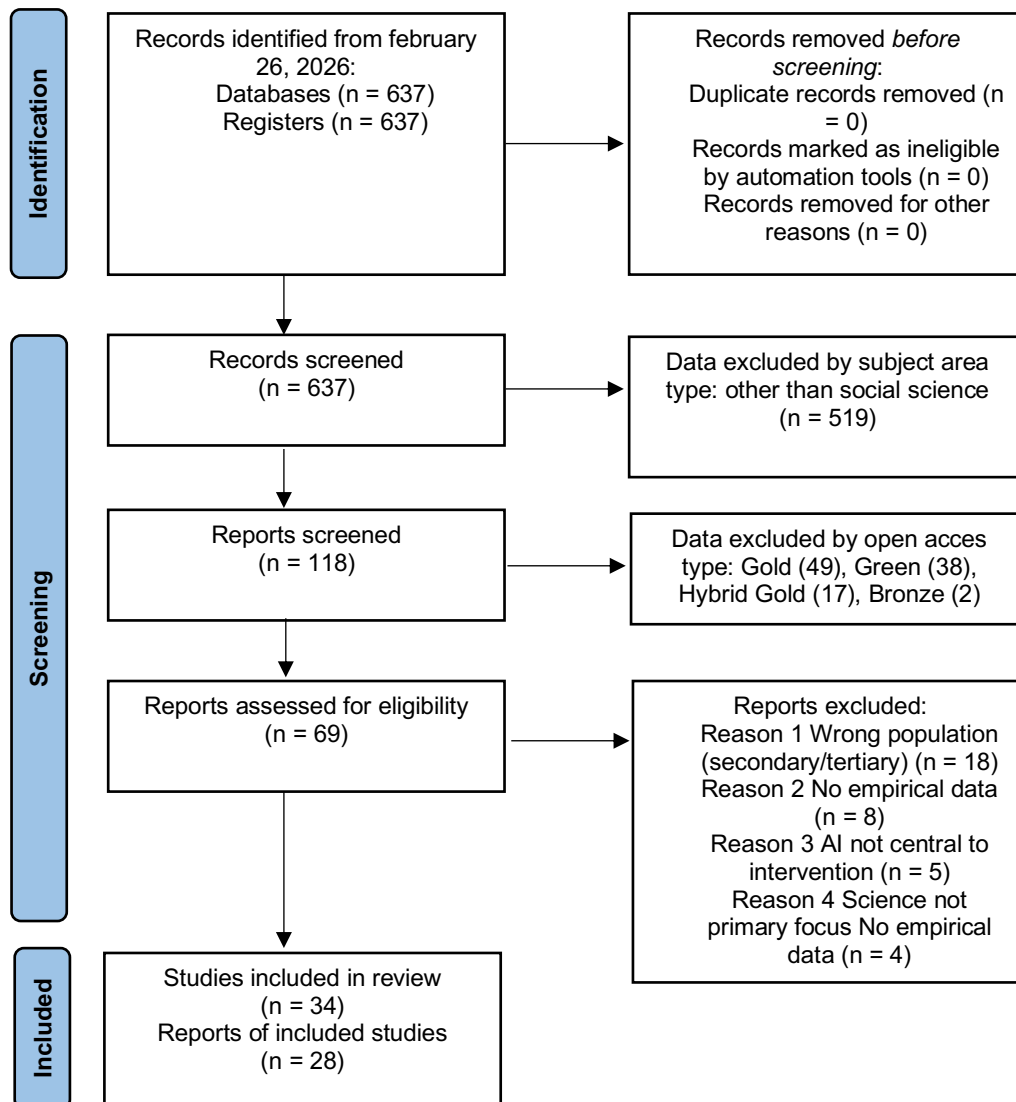


Figure 1: PRISMA 2020 Flow Diagram for Study Selection

### Data Extraction and Quality Assessment

A standardized data extraction form was developed to capture:

- Bibliographic information (authors, year, title, journal)
- Study characteristics (country, research design, sample size, grade level)

- AI tool type and pedagogical model
- Science content area
- Documented learning outcomes
- Ethical issues addressed
- Key findings and limitations

Quality assessment was conducted using adapted versions of established tools appropriate for diverse study designs. For quantitative studies, elements of the Mixed Methods Appraisal Tool (MMAT) were applied (Hong dkk., 2018). For qualitative studies, criteria including clarity of research questions, appropriateness of methodology, and rigor of analysis were evaluated. No studies were excluded based on quality assessment, but quality considerations were incorporated into the synthesis and interpretation of findings.

### **Data Synthesis**

Extracted data were analyzed using thematic synthesis approaches. Findings related to pedagogical models, learning outcomes, and ethical issues were coded and organized into emergent themes. Descriptive statistics were calculated for study characteristics, and narrative synthesis was employed to integrate findings across studies.

## **RESULTS**

### **Overview of Included Studies**

The 28 included studies spanned publications from 2019 to 2025, with a notable increase in publications after 2022, reflecting growing research interest in AI-assisted elementary science education. Geographically, studies originated from Asia (n = 15, including China, South Korea, Taiwan, Indonesia), Europe (n = 6), North America (n = 5), and Australia (n = 2). Research designs included quasi-experimental studies (n = 14), design-based research (n = 5), case studies (n = 4), mixed methods (n = 3), and qualitative inquiries (n = 2). Sample sizes ranged from 20 to 356 elementary students, with most studies focusing on upper elementary grades (4–6).

### **Pedagogical Models in AI-Assisted Elementary Science Learning**

Analysis of included studies revealed three predominant pedagogical models for integrating AI into elementary science education: inquiry-based learning with AI scaffolding, project-based learning enhanced by generative AI, and game-based learning for AI concept introduction.

#### **1. Inquiry-Based Learning with AI Scaffolding**

Inquiry-based learning emerged as the most frequently documented pedagogical approach, identified in 14 studies (Chang dkk., 2023; Chen & Liu, 2024; Kim, 2022; J. Lee dkk., 2023; Ramli & Mahmud, 2025). In this model, AI tools serve as scaffolds that support students through phases of scientific inquiry, including questioning, investigation, data analysis, and drawing conclusions. The Inquiry Social Complexity (ISC) model, for instance, integrates AI to personalize learning trajectories and scaffold complex inquiry tasks, providing instantaneous feedback that guides student thinking without replacing it (Perdana dkk., 2025).

Ramli and Mahmud's (2025) systematic review specifically examined AI integration in inquiry-based science teaching, finding that AI applications enhance digital-assisted science learning while preserving inquiry-based approaches as the foundation of modern science education (Ramli & Mahmud, 2025). AI chatbots have been successfully deployed to guide students through guided-inquiry activities, with tools like InquiryBot facilitating scientific questioning and investigation processes (Chang dkk., 2023).

A study by Zhao et al. (2025) implemented a causal explanation and reflection (CER) model-based GenAI learning system in elementary science courses, demonstrating that structured inquiry support from AI significantly improved students' science learning and computational thinking skills (Zhao dkk., 2025). The CER model guided students through making claims, providing evidence, and articulating reasoning, with GenAI offering scaffolding without supplanting students' cognitive engagement.

## 2. Project-Based Learning Enhanced by Generative AI

Project-based learning (PBL) enhanced by generative AI represented the second major pedagogical model, documented in 8 studies. Sun et al. (2025) conducted a quasi-experimental study with 120 fifth-grade students, comparing GenAI-enhanced PBL with traditional PBL in science classrooms (Sun dkk., 2025). Students in the experimental group used GenAI for inquiry activities, research, and video-based project creation. Results demonstrated significant advantages for the GenAI-PBL group in computer self-efficacy, attitudes toward science, and science process skills, with large effect sizes (Cohen's  $d = 0.40$ – $0.86$ ).

This model positions AI as a cognitive partner that supports students' creative and investigative work while maintaining student agency and project ownership. Students engage with AI to gather information, generate ideas, and create representations of their scientific understanding, effectively transforming AI from a direct instructional tool into a collaborative resource for knowledge construction.

## 3. Game-Based Learning for AI Concept Introduction

A third approach, identified in 6 studies, involved game-based learning environments designed to introduce AI concepts while supporting science learning. Gupta et al. (2024) developed a story-driven game-based learning platform for upper elementary students that integrated AI concepts within scientific inquiry contexts (Gupta dkk., 2024). Similarly, Lee et al. (2021) designed AI-infused collaborative inquiry experiences using game-based approaches, enabling students to engage with AI concepts while conducting scientific investigations (S. Lee dkk., 2021).

These environments serve dual purposes: they support science learning goals while simultaneously building students' AI literacy—an increasingly important competency in its own right. Jeon et al. (2024) documented the design of PrimaryAI, an inquiry-based AI curriculum for upper elementary students that used game-based learning to make abstract AI concepts accessible and engaging (Jeon dkk., 2024).

## Learning Outcomes

Documented learning outcomes across the 28 studies clustered into four categories: scientific literacy and conceptual understanding, science process skills, computational thinking, and affective outcomes.

### 1. Scientific Literacy and Conceptual Understanding

Improvements in scientific literacy and conceptual understanding were the most consistently reported outcomes. Perdana et al. (2025) developed and validated an AI-integrated Inquiry Social Complexity module for fourth-grade students, demonstrating significant enhancement in scientific literacy with an average N-gain score of 0.73, indicating high effectiveness (Perdana dkk., 2025). The module's success was attributed to AI's capacity to personalize learning trajectories and deliver instantaneous feedback tailored to individual student needs.

Chen and Liu (2024) investigated the impact of AI robot image recognition technology on elementary students' understanding of cell division, finding that the AI-enhanced approach significantly improved conceptual understanding and science learning motivation compared to traditional instruction (Chen & Liu, 2024). The visual and interactive nature of AI-supported learning helped students grasp abstract biological processes that are typically challenging for young learners.

### 2. Science Process Skills

Science process skills—including observing, questioning, hypothesizing, experimenting, and interpreting data—showed significant improvement in studies employing inquiry-based and project-based AI integration. Sun et al. (2025) reported substantial gains in science process skills following GenAI-enhanced PBL (Cohen's  $d = 0.86$ ), the largest effect size among their measured outcomes (Sun dkk., 2025). Students in the experimental group demonstrated enhanced ability to design investigations, collect and analyze data, and draw evidence-based conclusions.

Kim's (2022) study of AI-integrated science teaching through epistemic discourse found that AI tools facilitated more sophisticated scientific reasoning and argumentation among elementary students (Kim, 2022). The AI served as a discussion partner that prompted students to articulate and defend their scientific ideas, thereby deepening their engagement with scientific practices.

### 3. Computational Thinking

Computational thinking (CT) emerged as a significant outcome, particularly in studies explicitly designed to integrate AI and CT instruction. Zhao et al. (2025) found that the CER model-based GenAI learning system significantly improved elementary students' CT core skills, including decomposition, pattern recognition, abstraction, and algorithm design (Zhao dkk., 2025). Their study addressed a critical gap by demonstrating that CT development can be effectively embedded within science instruction rather than confined to programming-specific courses.

Huang and Qiao (2024) examined computational thinking development through AI education at a STEAM elementary school, finding that students who engaged with AI tools in scientific contexts showed enhanced problem-solving abilities and systems thinking (Huang & Qiao, 2022). The integration of AI within authentic scientific investigations provided meaningful contexts for developing computational perspectives.

### 4. Affective Outcomes

Affective outcomes—including attitudes toward science, motivation, self-efficacy, and engagement—were positively impacted across multiple studies. Sun et al. (2025) documented significantly improved attitudes toward science (Cohen's  $d = 0.83$ ) and computer self-efficacy (Cohen's  $d = 0.40$ ) among students using GenAI-enhanced PBL (Sun dkk., 2025). These findings suggest that AI integration not only supports cognitive learning but also enhances students' emotional and motivational relationship with science.

Lee et al. (2023) developed and applied a rule-based AI chatbot in elementary science classes, finding improvements in both conceptual understanding and attitudes toward science (J. Lee dkk., 2023). The chatbot's interactive and responsive nature created a low-stakes environment for scientific exploration, reducing anxiety about asking questions or making mistakes.

## Ethical Issues

Despite the growing body of empirical research, ethical considerations received substantially less attention than pedagogical models or learning outcomes. Of the 28 included studies, only 8 explicitly discussed ethical issues, and even fewer incorporated ethical considerations into their research design or recommendations.

### 1. Algorithmic Bias and Fairness

Concerns about algorithmic bias were raised in theoretical and review literature but rarely addressed in empirical studies. Lodhi's (2025) master's thesis examining AI integration in K-12 STEM education identified algorithmic bias as a critical concern, noting that AI systems trained on non-representative data may perpetuate or exacerbate existing educational inequities (Lodhi, 2025). When deployed with young learners, such biases could have lasting impacts on educational trajectories and self-concept.

The scoping review by Alé et al. (2025) specifically noted that ethical competencies were underrepresented in the literature, with few studies addressing how AI tools might differentially impact students based on demographic characteristics or prior achievement (Alé dkk., 2025). This gap is particularly concerning given elementary education's role in establishing foundational academic identities.

### 2. Data Privacy and Child Protection

Data privacy emerged as a significant concern, particularly regarding the collection and use of children's data by AI systems. Several review articles highlighted the tension between AI's need for data to personalize learning and the imperative to protect children's privacy (Alé dkk.,

2025; Lodhi, 2025). The question of who owns student data, how it is stored, and what safeguards prevent misuse remained largely unaddressed in empirical studies.

Zhai and Crippen's (2026) vision for AI-supported science education emphasized that responsible AI integration must prioritize transparency about data use and ensure compliance with child protection regulations (Zhai & Crippen, 2026). Their REP (Responsible and Ethical Principles) framework calls for accountability and respect for human values in AI design and deployment.

### 3. Over-Reliance and Cognitive Offloading

A distinctive ethical concern specific to elementary education involves the risk of over-reliance on AI, leading to cognitive offloading and diminished independent thinking. Zhao et al.'s (2025) study of CER model-based GenAI learning revealed an important finding: some students complained that GenAI "only provided answers without encouraging them to comprehend the material." (Zhao dkk., 2025). This feedback highlights the pedagogical challenge of designing AI interactions that support rather than supplant student thinking.

The authors concluded that "over-reliance on GenAI may hinder learning ability" and that "the effectiveness of GenAI-based learning depends on its judicious use" (Zhao dkk., 2025). This concern is particularly acute for elementary students, whose metacognitive skills and self-regulation abilities are still developing. Without appropriate scaffolding and teacher guidance, AI tools designed to support learning may inadvertently undermine it.

### 4. Equity and Access

Equity concerns were raised regarding differential access to AI-enhanced learning opportunities. Several reviews noted that AI tools often require reliable internet connectivity, updated devices, and technical support—resources that may be unavailable in under-resourced schools (Alé dkk., 2025; Lodhi, 2025). The risk that AI integration could widen rather than narrow achievement gaps was identified as a critical consideration for policymakers and school leaders.

Lodhi's (2025) framework for responsible AI implementation explicitly addresses equity through recommendations for low-resource adaptation strategies and mandatory bias audits (Lodhi, 2025). Ensuring that AI-assisted science learning benefits all students, not just those in well-resourced settings, requires intentional design and implementation practices.

### 5. Teacher Roles and Professional Development

Ethical considerations also encompassed the changing roles of teachers in AI-enhanced classrooms. Teachers must develop sufficient AI literacy to evaluate tools, interpret AI-generated outputs, and intervene when AI responses are inappropriate or developmentally unsuitable (Alé dkk., 2025; Lodhi, 2025). The scoping review by Alé et al. (2025) identified teacher preparation as a critical gap, noting that "the lack of subject-specific frameworks for responsible integration" limits teachers' ability to use AI effectively and ethically (Alé dkk., 2025).

McAllister's (2025) study of AI-generated lesson plans for elementary STEM topics found that while AI tools could produce standards-aligned science lessons, teacher collaboration and professional development were essential for ensuring quality and appropriateness (McAllister dkk., 2025). Teachers reported increased confidence in understanding AI after workshops, suggesting that targeted professional development can address knowledge gaps and misconceptions.

## DISCUSSION

### Synthesis of Findings

This systematic review provides a comprehensive analysis of AI-assisted science learning in elementary education, synthesizing evidence from 28 Scopus-indexed studies across pedagogical models, learning outcomes, and ethical considerations. The findings reveal both significant progress and notable gaps in the current research landscape.

## 1. Pedagogical Models: From Tool to Partner

The three identified pedagogical models—*inquiry-based learning with AI scaffolding*, *project-based learning enhanced by generative AI*, and *game-based learning for AI concept introduction*—represent a progression in conceptualizing AI's role in elementary science classrooms. In *inquiry-based approaches*, AI functions primarily as a scaffold, providing just-in-time support that enables students to engage in authentic scientific practices that might otherwise be beyond their independent capabilities (Chang dkk., 2023; Ramli & Mahmud, 2025). This aligns with Vygotskian notions of the zone of proximal development, where AI serves as a more capable partner supporting learning within the zone.

*Project-based approaches* position AI more collaboratively, as a partner in knowledge construction and creative production (Sun dkk., 2025). Here, students learn with AI rather than from AI, engaging in what might be termed "co-cognitive" work where human and artificial intelligence complement each other. This shift from AI as tool to AI as partner has significant implications for pedagogy, assessment, and the nature of scientific inquiry in elementary classrooms.

*Game-based approaches* address a different need: building foundational AI literacy alongside science learning (Gupta dkk., 2024; Jeon dkk., 2024). As AI becomes increasingly pervasive, understanding its capabilities and limitations becomes an essential component of scientific literacy itself. These approaches recognize that preparing students for futures with AI requires not just using AI tools but understanding how they work and when to trust them.

## 2. Learning Outcomes: Beyond Content Knowledge

The documented learning outcomes extend well beyond traditional science content knowledge. The consistent finding that AI-assisted approaches enhance scientific literacy—the ability to engage with science-related issues and ideas as reflective citizens—is particularly significant (Perdana dkk., 2025). This aligns with contemporary science education goals that emphasize preparing students for informed participation in a scientifically and technologically complex world.

The strong effects on science process skills (Sun dkk., 2025) and computational thinking (Zhao dkk., 2025) suggest that AI integration can support the development of transferable competencies applicable across domains. This is crucial for elementary education, where foundational thinking patterns are established. The finding that computational thinking can be effectively developed within science instruction rather than isolated technology courses (Huang & Qiao, 2022) supports interdisciplinary approaches that many curriculum frameworks advocate but struggle to implement.

Affective outcomes—attitudes, motivation, self-efficacy—may be as important as cognitive gains, particularly at the elementary level where positive or negative orientations toward science often crystallize (J. Lee dkk., 2023; Sun dkk., 2025). The documented improvements in attitudes toward science and computer self-efficacy suggest that well-designed AI integration can nurture the motivational dispositions that support continued engagement with science throughout schooling.

## 3. Ethical Issues: The Critical Gap

The most concerning finding of this review is the relative neglect of ethical considerations in empirical research. While theoretical and review articles raise important concerns about algorithmic bias, privacy, over-reliance, and equity (Alé dkk., 2025; Lodhi, 2025; Zhai & Crippen, 2026), these issues are rarely addressed in intervention studies. This gap is particularly problematic given the unique vulnerabilities of elementary-aged children and the formative nature of this educational stage.

The finding that some students experienced GenAI as undermining rather than supporting comprehension (Zhao dkk., 2025) illustrates the ethical complexity of AI integration. When designed or implemented poorly, tools intended to enhance learning may inadvertently encourage passive reception rather than active engagement. This concern echoes broader debates about educational technology and the conditions under which it supports versus undermines deep learning.

The equity dimensions of AI integration demand urgent attention. If AI-enhanced science learning requires resources and infrastructure that are unequally distributed, the technology may exacerbate rather than reduce achievement gaps (Alé dkk., 2025; Lodhi, 2025). Without intentional design for equity and access, schools serving historically marginalized communities may fall further behind in providing students with the competencies needed for future success.

### **A Framework for Responsible AI Integration in Elementary Science Education**

Drawing on the synthesized findings and existing ethical frameworks (Lodhi, 2025; Zhai & Crippen, 2026), we propose a preliminary framework for responsible AI integration in elementary science education. This framework encompasses four interconnected dimensions:

1. **Pedagogical Integrity:** AI integration should enhance rather than replace developmentally appropriate science pedagogy. This requires that AI tools be designed to support inquiry, collaboration, and active knowledge construction rather than passive reception. Teachers must retain professional judgment about when and how to deploy AI tools, and AI should never substitute for the relational dimensions of teaching and learning.
2. **Transparency and Agency:** Students, teachers, and families should understand when AI is being used, how it works, and what data it collects. Students should maintain agency in their interactions with AI, with opportunities to question, critique, and override AI suggestions. The "black box" problem—where AI outputs are inscrutable even to designers—is particularly problematic in educational contexts where understanding processes is as important as producing correct answers.
3. **Equity and Inclusion:** AI integration must be designed and implemented with attention to existing inequities. This includes ensuring accessibility for students with disabilities, providing low-resource alternatives for under-resourced schools, and monitoring for differential impacts across student subgroups. Bias audits should be mandatory, and when biases are identified, remediation should be prompt and transparent.
4. **Child Protection and Privacy:** Given the unique vulnerabilities of elementary students, privacy protections must be particularly robust. Data collection should be minimized, storage should be secure, and families should have meaningful control over their children's data. AI tools should be subject to child protection reviews, and developers should be held accountable for compliance with relevant regulations.

### **Limitations of This Review**

Several limitations should be considered when interpreting these findings. First, the restriction to Scopus-indexed publications may have excluded relevant studies indexed in other databases. Second, the focus on English-language publications limits geographic and cultural representation; important research published in other languages may have been missed. Third, the rapid pace of AI development means that findings from studies conducted even two years ago may not reflect current technological capabilities. Fourth, publication bias toward positive findings may overstate the effectiveness of AI-assisted approaches. Finally, the relatively small number of studies focusing specifically on elementary education limits the generalizability of findings across grade levels and contexts.

### **Implications for Practice and Policy**

For educators, these findings suggest that AI tools can meaningfully enhance elementary science learning when integrated within sound pedagogical frameworks. Inquiry-based and project-based approaches appear particularly promising, but success depends on thoughtful implementation that maintains student agency and teacher judgment. Professional development should address both technical skills for using AI tools and pedagogical knowledge for integrating them effectively.

For school leaders and policymakers, several priorities emerge. Investment in infrastructure and resources should attend to equity, ensuring that under-resourced schools are not left behind. Curriculum frameworks should be updated to address AI literacy as a component of scientific literacy, and guidelines for ethical AI use should be developed with input from educators, families, and child development experts. Procurement policies should require vendors to demonstrate compliance with privacy and child protection standards.

For researchers, this review identifies numerous directions for future inquiry. Longitudinal studies are needed to understand the lasting impacts of AI-assisted science learning. Research should examine differential effects across student subgroups and identify conditions under which AI integration may exacerbate inequities. Most urgently, ethical dimensions of AI use with young children demand systematic empirical investigation, moving beyond theoretical concerns to examine actual implementation contexts and outcomes.

## CONCLUSION

This systematic literature review synthesizes current evidence on AI-assisted science learning in elementary education, identifying pedagogical models, documenting learning outcomes, and highlighting ethical considerations. The findings demonstrate that AI tools can effectively support inquiry-based and project-based science learning, enhancing scientific literacy, process skills, computational thinking, and affective outcomes. However, the relative neglect of ethical issues in empirical research represents a critical gap that must be addressed as AI becomes increasingly prevalent in elementary classrooms.

The proposed framework for responsible AI integration—emphasizing pedagogical integrity, transparency and agency, equity and inclusion, and child protection and privacy—provides a starting point for ensuring that AI serves the developmental and educational needs of young learners. As AI technologies continue to evolve, ongoing dialogue among researchers, educators, policymakers, and families will be essential to harness their potential while safeguarding against their risks.

Ultimately, the goal of AI-assisted elementary science education should not be to replace teachers or automate learning, but to create richer, more responsive, and more equitable opportunities for all students to develop the scientific understandings and dispositions they need to thrive in an AI-shaped world.

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