

## **Between Promise and Practice: A Critical Review of AI Implementation in Primary Education and Literacy Development**

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### **ABSTRACT**

The rapid integration of artificial intelligence (AI) in primary education has transformed how young learners engage with knowledge and develop foundational literacy skills. This article critically examines AI implementation in primary education, focusing on AI literacy development, pedagogical applications, teacher preparedness, and ethical considerations across diverse contexts. A systematic critical synthesis of 40 scholarly sources published between 2023 and 2025 was conducted using thematic coding and comparative analysis. The findings reveal a clear gap between AI's promised benefits and classroom realities. Although AI tools demonstrate potential to enhance learning engagement and literacy outcomes, their effectiveness is strongly shaped by teacher readiness, contextual factors, and unresolved ethical issues. Moreover, existing AI literacy frameworks remain fragmented and inconsistently applied across education systems. The study concludes that AI integration in primary education requires a context-sensitive approach that balances technological innovation with pedagogical quality and ethical responsibility, supported by comprehensive teacher training and inclusive literacy frameworks.

**Keywords:** Artificial Intelligence in Education, Primary Education, Literacy Development, AI Literacy, Teacher Preparedness

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## **INTRODUCTION**

The global educational landscape is undergoing a profound transformation as artificial intelligence (AI) technologies are increasingly integrated into primary education. This shift presents both unprecedented opportunities and substantial challenges for educators, policymakers, and researchers. As AI applications move from experimental innovations to routine instructional tools, understanding how they are implemented across diverse educational contexts becomes essential to ensure that technological advancement supports, rather than disrupts, fundamental educational goals.

Current scholarly discourse on AI in primary education spans several interconnected dimensions, including subject-specific instructional applications, the development of AI

literacy among young learners, teacher preparedness for AI-supported pedagogy, and ethical concerns related to data privacy and algorithmic bias. While recent studies suggest that AI technologies can enhance personalized learning, student engagement, and instructional efficiency, their implementation remains uneven and highly context dependent (Chiu, 2024; Zhou, 2025). These inconsistencies highlight the need for critical examination beyond technological potential alone.

The literature on AI in primary education has evolved noticeably in recent years. Early studies tended to emphasize innovation and technological possibility, often adopting an optimistic stance toward AI-driven transformation in schools (Mannila, 2024). More recent research, however, reflects a growing critical orientation, focusing on implementation challenges, ethical implications, and the complex relationship between technological innovation and pedagogical effectiveness (Wieczorek et al., 2025). This shift signals a maturation of the field from technology-centered enthusiasm toward evidence-based and context-aware analysis.

One prominent strand of research addresses AI literacy development in primary education. Studies have shown that children enter classrooms with pre-existing and sometimes anthropomorphic conceptions of AI, which significantly influence how they interpret and engage with AI-related learning experiences (Mertala et al., 2022). Pedagogical approaches such as digital storytelling have been found effective in supporting AI literacy by integrating technical understanding with critical reflection on AI's societal roles and limitations (Ng et al., 2022). Collectively, these findings suggest that AI literacy extends beyond technical competence to include ethical awareness and critical thinking.

Another substantial body of research examines subject-specific applications of AI in primary education. Empirical studies report positive outcomes in mathematics learning (Alvarez et al., 2024; Li & Manzari, 2025), English language acquisition (Kim, 2024), and science education (Zhu & Zhang, 2025). However, these studies also emphasize that learning gains are mediated by factors such as instructional design, teacher facilitation, student engagement, and curriculum alignment. AI effectiveness, therefore, cannot be assumed to be universal or automatic.

Teacher perspectives and professional development constitute a third critical theme in the literature. Research consistently identifies teachers as central agents in determining the success of AI integration. Bas and Kiraz (2025) highlight substantial professional development needs among primary school teachers in AI-supported STEM education, while Kuzu et al. (2025) demonstrate that AI tools such as ChatGPT can enhance teachers' capacity to design complex and multilingual learning tasks. These findings underscore the importance of teacher agency, pedagogical judgment, and experiential learning in AI adoption.

Despite the growing volume of research, several gaps remain. First, existing studies often address technological, pedagogical, or ethical dimensions of AI in isolation, with limited integrative frameworks that capture their interdependence. Second, much of the literature focuses on specific tools or localized contexts, leaving broader cross-contextual patterns underexplored. Third, the perspectives of key stakeholders—particularly students and parents—remain relatively underrepresented.

In response to these gaps, this article presents a critical synthesis of recent scholarship on AI implementation in primary education. Specifically, it examines: (1) approaches to AI literacy development; (2) subject-specific pedagogical applications; (3) teacher preparedness and professional development; (4) ethical considerations and responsible implementation; and (5) regional and equity-related variations. By synthesizing evidence across these domains, the

study aims to provide a more comprehensive understanding of the current state of AI integration in primary education and to identify directions for future research and practice.

## METHODS

This study employs a systematic critical synthesis methodology to examine the current state of AI implementation in primary education. This approach is particularly suited to integrating diverse forms of evidence, identifying cross-study patterns, and generating analytical insights through critical interpretation rather than descriptive summarization.

The analytical corpus comprises 40 scholarly sources published between 2022 and 2025, including empirical studies, theoretical frameworks, conference proceedings, and regional reports. All sources were drawn from the provided reference list and reflect research on AI implementation in primary education across diverse geographical contexts, with particular emphasis on literacy development, curriculum integration, and pedagogical practices.

Reference selection was guided by four criteria: (a) direct relevance to AI implementation in primary education; (b) methodological rigor; (c) contribution to theoretical or practical understanding; and (d) representation of diverse cultural and educational contexts. While peer-reviewed journal articles constitute the majority of sources, selected book chapters and conference proceedings were included to capture emerging trends and innovative practices.

The analytical framework is informed by ecological systems theory (Bronfenbrenner, 1979), adapted to the context of educational technology implementation. This framework enables analysis across multiple levels of influence: the microsystem (classroom interactions among teachers, students, and AI tools), mesosystem (connections across classroom contexts), exosystem (institutional policies and resources), and macrosystem (broader cultural, economic, and policy environments). Such a multi-level perspective supports a comprehensive understanding of the factors shaping AI implementation in primary education.

Data analysis proceeded through several stages. First, all sources were subjected to close reading to identify key themes, methodologies, findings, and limitations. Second, thematic coding was applied based on primary focus (e.g., AI literacy, subject-specific applications, teacher perspectives, ethical considerations), methodological approach, and geographical context. Third, comparative analysis within each thematic category was conducted to identify patterns, tensions, and gaps. Finally, cross-theme analysis explored interconnections among different dimensions of AI implementation.

Analytical validity was strengthened through multiple strategies, including source triangulation to confirm patterns and identify outliers, reflexive analysis to address potential interpretive bias, and attention to methodological diversity across studies. The analysis also explicitly acknowledges limitations and alternative interpretations of the evidence.

Unlike traditional literature reviews, this systematic critical synthesis prioritizes analytical integration over descriptive aggregation. Rather than cataloging individual findings, the approach interrogates underlying assumptions, synthesizes divergent perspectives, and generates higher-order insights. This methodology is particularly appropriate for emerging fields such as AI in education, where technological advancement often outpaces theoretical consolidation and comprehensive analytical frameworks remain under development.

## RESULT AND DISCUSSION

The synthesis of the literature reveals a complex and often contradictory landscape of artificial intelligence (AI) implementation in primary education, characterized by a persistent gap between technological promise and pedagogical reality. This section integrates results and discussion by presenting key thematic findings while simultaneously interpreting their

significance, moving beyond description to examine what these patterns imply for the future of primary education.

### **The Tension Between Technical and Critical AI Literacy**

A central tension emerges in the conceptualization and implementation of AI literacy for young learners. On one hand, several studies advocate technically oriented approaches that emphasize foundational knowledge of algorithms, data, and machine learning processes. For example, Terrón and Román-González (2025) demonstrate the potential of platforms such as LearningML to engage primary students in hands-on creation of machine learning models. On the other hand, a contrasting perspective promotes an intelligence-based framework that prioritizes understanding AI's limitations, decision-making logic, and societal impact over technical implementation skills (Yim, 2024). This tension is not merely theoretical; it reflects divergent views on the fundamental aims of primary education in the AI era.

The significance of this debate lies in its implications for citizenship education. As cautioned by Fang and Du (2025), an overemphasis on technical competencies risks cultivating passive users of AI rather than critically informed individuals capable of questioning, interpreting, and shaping AI-driven systems. Moreover, AI literacy development extends beyond formal instruction. Research indicates that children often enter classrooms with pre-existing, frequently anthropomorphic conceptions of AI that can hinder accurate understanding if left unaddressed (Mertala et al., 2022). Extending this socio-ecological perspective, parental studies reveal that parents' AI literacy significantly influences their self-efficacy in supporting children's learning (Guo et al., 2025). Collectively, these findings reframe AI literacy as a shared responsibility among schools, families, and communities, underscoring the need for multi-stakeholder approaches that move beyond a school-centric model.

### **The Contingent Efficacy of AI in Pedagogy**

The literature documents numerous subject-specific applications of AI with positive learning outcomes. Empirical studies report improvements in mathematics achievement and engagement through AI-supported applications (Alvarez et al., 2024; Li & Manzari, 2025), personalized support for English language learners (Kim, 2024), and the introduction of complex scientific concepts via digital game-based learning (Dorouka & Kalogiannakis, 2023). However, a critical synthesis reveals that such benefits are highly contingent rather than inherent to the technology itself.

The effectiveness of AI-mediated pedagogy is shaped by a constellation of contextual variables, including curriculum alignment, instructional design, and teacher implementation strategies. Zha et al. (2025) identify a “paradox of AI empowerment” in primary physical education, where AI tools may disrupt interaction and reduce instructional efficiency when poorly aligned with pedagogical objectives. Similarly, studies from less developed regions highlight how infrastructural limitations and resource scarcity constrain the feasibility of AI adoption (Lv et al., 2023). These findings constitute a strong rebuttal to techno-solutionist narratives, demonstrating that AI is not a pedagogical panacea. Instead, meaningful integration depends on pedagogical judgment and contextual sensitivity, shifting the focus from technological acquisition to instructional capacity-building.

### **The Central Role of Teacher Agency and Preparedness**

Across the literature, teachers consistently emerge as the most influential mediators of AI implementation in primary education. While studies confirm substantial professional development needs related to AI-supported instruction (Bas & Kiraz, 2025), they also highlight teacher agency as a decisive factor in successful integration. Kuzu et al. (2025) demonstrate that teachers who actively experimented with generative AI tools such as ChatGPT developed more nuanced and pedagogically grounded applications than those who received passive, tool-oriented training. This finding supports professional development models grounded in

exploration, reflection, and co-design rather than top-down technical instruction (Mannila, 2024).

At the same time, AI integration introduces new challenges to teacher autonomy. Using an Actor-Network Theory lens, Sperling et al. (2022) reveal how the opacity of AI systems can obscure decision-making processes, generating tension between algorithmic outputs and teachers' professional judgment. Teachers are thus positioned as ethical gatekeepers responsible for selecting age-appropriate and pedagogically sound technologies (Beach, 2025). Far from reducing teachers' roles, AI integration intensifies professional demands, requiring educators to act simultaneously as pedagogues, critical technologists, and ethical decision-makers. These findings underscore that teacher empowerment, rather than automation, must form the foundation of AI-related educational policy and investment.

### **Ethical Imperatives and the Equity Challenge**

Ethical and equity-related concerns represent the most pressing challenges identified in the literature. A systematic review by Wiczorek et al. (2025) identifies critical issues including data privacy, algorithmic bias, surveillance, and the potential amplification of existing educational inequalities. Importantly, these concerns are not speculative; they are already shaping classroom realities. Despite growing recognition of their importance, AI ethics education at the primary level remains underdeveloped and frequently subordinated to technical instruction (Ma et al., 2025).

Equity concerns are further illuminated through regional and national analyses. The implementation of AI within well-resourced systems such as Finland (Kujala & Hakala, 2020) contrasts sharply with contexts marked by economic and infrastructural constraints, such as Afghanistan (Baiza, 2020) and the Philippines (Bustos-Orosa, 2020). These disparities highlight the risk of a new digital divide, wherein AI-enhanced learning disproportionately benefits students in affluent settings while marginalizing those in under-resourced regions (Lv et al., 2023). Studies from Bhutan emphasize that culturally grounded and holistic educational values must guide technological integration to ensure equity and sustainability (Choden, 2025; Tshering, 2025). Collectively, these findings call for AI frameworks that are not only ethically robust but also culturally responsive and explicitly equity-oriented.

### **Synthesis**

In sum, the literature indicates that AI in primary education has entered a phase of critical pragmatism, moving beyond early technological optimism. The successful and responsible integration of AI depends less on technological sophistication than on the development of balanced AI literacy, context-sensitive pedagogy, empowered teachers, and ethical frameworks that prioritize inclusion and equity. These findings position AI not as a transformative force in isolation, but as a sociotechnical tool whose educational value is ultimately shaped by human judgment, cultural context, and pedagogical intent.

### **CONCLUSION**

This article has provided a critical synthesis of recent research on the implementation of artificial intelligence (AI) in primary education, addressing key gaps identified in the literature. Specifically, it responds to the limited availability of integrative frameworks by examining AI implementation through interconnected technological, pedagogical, and ethical dimensions rather than isolated applications. The findings reveal a persistent gap between the anticipated benefits of AI and its classroom-level realization, underscoring the importance of context-sensitive and pedagogically grounded approaches.

In relation to the identified research gaps, the synthesis offers several contributions. First, it moves beyond application-focused studies by highlighting broader patterns of AI use across subject areas and educational contexts. Second, it clarifies conceptual ambiguities

surrounding AI literacy by demonstrating the need for balanced approaches that integrate technical understanding with critical and ethical reflection. Third, it addresses the underexplored role of teachers by emphasizing teacher agency and professional competence as central mediators of effective AI integration. Fourth, it foregrounds ethical and equity-related concerns—particularly data privacy, algorithmic bias, and access disparities—that remain insufficiently addressed in much of the existing research.

These findings have implications for theory, practice, and policy. Theoretically, they support ecological perspectives on educational technology integration that account for multiple, interacting influences. Practically, they point to the need for sustained teacher professional development and curriculum frameworks that embed AI literacy within broader educational goals. From a policy perspective, the results highlight the necessity of clear ethical guidelines to support responsible and equitable AI adoption in primary education.

Overall, this review demonstrates that effective AI implementation in primary education cannot be achieved through technological innovation alone. Addressing the identified research gaps requires integrated, ethically informed, and contextually responsive approaches that align AI use with fundamental educational values and the developmental needs of young learners.

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