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Article

ARTIFICIAL INTELLIGENCE METHODOLOGIES IN DIGITAL EDUCATION

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Abstract: The integration of artificial intelligence into digital education has rapidly accelerated, yet the field lacks a cohesive understanding of the methodologies, theoretical frameworks, and empirical evidence guiding this transformation. This systematic review examines artificial intelligence methodologies in digital education through an IMRAD (Introduction, Methods, Results, and Discussion) structure. The study analyzes recent peer-reviewed literature, frameworks, and empirical studies published between 2023 and 2025. The results identify three primary categories of AI methodologies: theoretical pedagogical frameworks for AI integration (including i-TPACK, SAMR, and 3wAI), technical implementation architectures (such as bidirectional personalization systems and GNN-RL hybrid models), and AI literacy development approaches. Meta-analytic evidence demonstrates a significant positive effect of AI technologies on learning outcomes (Hedges' g = 0.86), with generative AI and chatbots showing the strongest effects (g = 1.02). However, significant heterogeneity across studies indicates that contextual factors and implementation strategies critically moderate efficacy. The discussion synthesizes these findings into a integrated model of AI educational methodologies and identifies implications for researchers, educators, and policymakers. This review concludes that effective AI integration requires the deliberate alignment of pedagogical frameworks, technical architectures, and literacy development within specific educational contexts.

Keywords: artificial intelligence, digital education, generative AI, pedagogical frameworks, intelligent-TPACK, adaptive learning, AI literacy

1. Introduction

It The integration of artificial intelligence into digital education represents one of the most significant pedagogical transformations of the twenty-first century. Recent surveys indicate that 92% of undergraduates have incorporated AI-generated content tools into their daily learning activities, utilizing these technologies for concept explanation, article summarization, and research ideation (Higher Education Policy Institute, 2025, as cited in). Concurrently, educators face mounting pressures, with 72% of teachers reporting administrative task overload and 61% of students underserved by standardized curricula.

Despite widespread adoption and significant EdTech investment—only 18% of schools have systematically implemented AI solutions—a critical fragmentation characterizes the current landscape. Existing systems address isolated needs: student-facing tutoring platforms lack integration with teacher workflows, while instructor-focused assessment tools offer no adaptive learning features. This fragmentation reflects a deeper theoretical fragmentation. The field lacks coherent methodological frameworks

that simultaneously address pedagogical theory, technical implementation, and human competency development.

Previous reviews have examined either AI literacy frameworks, technical architectures, or empirical efficacy in isolation. No current synthesis integrates these dimensions into a unified understanding of AI methodologies in digital education. This gap impedes both researchers seeking theoretical coherence and practitioners navigating implementation decisions.

This review addresses three research questions:

1. What theoretical and pedagogical frameworks currently guide AI integration in digital education?
2. What technical methodologies and implementation architectures characterize contemporary AI educational systems?
3. What is the empirical evidence regarding the efficacy of these methodologies, and what moderating factors influence their effectiveness?

By systematically examining these interrelated dimensions, this review aims to provide a comprehensive map of the methodological landscape and identify pathways toward more coherent, evidence-informed practice.

2. Materials and Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure methodological rigor and transparency.

2.1 Search Strategy

A comprehensive literature search was conducted across multiple electronic databases: IEEE Xplore, ScienceDirect, ERIC, HAL Open Science, and the Association for the Advancement of Computing in Education (AACE) digital library. The search period encompassed publications from January 2023 through December 2025, capturing the most recent developments following the widespread availability of generative AI technologies.

The search strategy employed Boolean combinations of keywords organized into three conceptual categories: (1) AI technologies ("artificial intelligence," "generative AI," "large language models," "machine learning," "intelligent tutoring systems"); (2) educational contexts ("digital education," "online learning," "higher education," "K-12," "teacher education"); and (3) methodological approaches ("framework," "model," "methodology," "pedagogy," "implementation," "architecture"). Reference lists of included studies were manually searched to identify additional relevant publications.

2.2 Inclusion and Exclusion Criteria

Studies were included if they: (a) addressed artificial intelligence applications in digital education contexts; (b) proposed, tested, or evaluated specific methodologies, frameworks, or technical architectures; (c) were published in peer-reviewed journals or conference proceedings; (d) were written in English; and (e) were published between 2023 and 2025 to ensure contemporary relevance.

Studies were excluded if they: (a) addressed AI in education only tangentially; (b) focused exclusively on AI for administrative purposes without pedagogical application; (c) were opinion pieces, editorials, or non-empirical essays without methodological contribution; or (d) duplicated content already represented in more comprehensive sources.

2.3 Data Extraction and Synthesis

A standardized data extraction form captured: publication characteristics (authors, year, source), educational context (level, subject, setting), AI methodology category (theoretical, technical, literacy), specific framework or architecture, implementation approach, outcome

measures, and reported efficacy. Given the heterogeneity of study designs and outcome measures, a narrative synthesis approach was employed, supplemented by meta-analytic findings from included systematic reviews. The synthesis was organized thematically according to the three research questions.

2.4 Quality Assessment

The quality of included empirical studies was assessed using appropriate instruments: the Mixed Methods Appraisal Tool (MMAT) for primary studies and the AMSTAR-2 checklist for systematic reviews. Studies were not excluded based on quality ratings, but methodological limitations were considered in the synthesis and interpretation of findings.

3. Results

3.1 Theoretical and Pedagogical Frameworks for AI Integration

The analysis identified a proliferation of theoretical frameworks developed specifically to address the unique challenges of AI integration in education. These frameworks cluster into three distinct categories: comprehensive literacy frameworks, teacher knowledge frameworks, and technology integration frameworks.

3.1.1 Comprehensive AI Literacy Frameworks

Multiple organizations and research groups have proposed frameworks defining what learners and educators should know about AI. The 3wAI framework, introduced by Bozkurt (2024), conceptualizes generative AI as a "dragon" requiring ethical harnessing by informed "riders" across three dimensions: Know What (theoretical understanding of AI technologies, limitations, and synthetic content generation), Know How (practical competencies including prompt engineering, output evaluation, and tool adaptation), and Know Why (ethical, critical, and philosophical aspects including data privacy, transparency, social justice, and sustainability) .

The ED-AI Lit framework (Allen & Kendeou, 2024) integrates learning sciences and cognitive psychology to organize AI literacy into six interconnected components: Knowledge (foundational concepts), Evaluation (critical interpretation of outputs), Collaboration (productive interaction with AI systems), Contextualization (real-world application and knowledge transfer), Autonomy (self-directed informed engagement), and Ethics (fairness, accountability, bias mitigation).

UNESCO's AI Competency Framework for Students (2024) provides a globally adaptable model organizing twelve competency blocks across four aspects—human-centered mindset, ethics of AI, AI techniques and applications, and AI system design—structured across three progressive mastery levels: Understand, Apply, and Create . Similarly, the OECD AI Literacy Framework (2025) defines four interrelated domains—Engaging with AI, Creating with AI, Managing AI, and Designing AI—integrating knowledge, skills, and attitudes while weaving ethical principles throughout rather than isolating them.

A significant conceptual contribution distinguishes AI literacy from AI competency. Chiu and colleagues (2024) define AI literacy as the ability to explain how AI works, understand societal implications, use it ethically, and communicate with AI systems, whereas AI competency encompasses the confidence and proficiency to apply these abilities in practice . Their co-designed framework, developed with 30 experienced AI teachers, comprises five interrelated components—Technology, Impact, Ethics, Collaboration, and Self-Reflection—operationalized through five essential learning experiences: community engagement, case studies, hands-on activities, exhibitions, and culturally responsive learning.

3.1.2 Teacher Knowledge Frameworks: From TPACK to Intelligent-TPACK

The Technological Pedagogical Content Knowledge (TPACK) framework has been substantially extended to address AI's unique characteristics. Mishra, Warr, and Islam (2023) examined how generative AI disrupts assumptions across all TPACK domains, arguing that Technological Knowledge must now encompass understanding of AI's unpredictability and propensity to hallucinate, while pedagogical practices must shift toward critical engagement and reflective assessment.

The most systematic extension emerges in Intelligent-TPACK (i-TPACK). Celik's (2023) original model added Ethics as a co-equal domain alongside i-TK (AI tools knowledge), i-TPK (orchestrating AI in teaching), and i-TCK (AI representation of disciplinary ideas). Recent work has significantly extended this model. Messina and Panciroli (2025) examined the TPAIK model (Technological, Pedagogical, Artificial Intelligence Knowledge), which similarly recognizes AI's distinct epistemological status.

The most comprehensive development comes from the integrated i-TPACK approach. This extension adds two previously underspecified domains: i-CK (AI-as-content, or teaching about AI across subject areas) and i-PD (AI-for-professional development, or teachers' sustained learning with AI). Critically, this framework threads a five-stage AI-literacy progression—Know → Use → Evaluate → Ethics → Create—within each knowledge domain, treating ethics as distributed and iterative rather than appended. Implementation of this framework in a three-week teacher preparation module demonstrated statistically significant gains across all six i-TPACK domains, with medium-to-large effect sizes. Qualitative analysis documented instances of layered ethical decision-making addressing privacy, bias, transparency, provenance, and accountability.

Additional frameworks include the S.P.Ai.C.E. model (Synergy between People and Artificial Intelligence for Collaborative Education), designed to guide educators in selecting and validating AI tools in contexts of rapid technological obsolescence.

3.1.3 Technology Integration Frameworks: SAMR and Three-Level Integration

Two frameworks specifically address how AI tools should be progressively integrated into instructional practice. The SAMR model (Substitution, Augmentation, Modification, Redefinition) has been operationalized for AI-generated content integration. Wu and colleagues (2025) developed an active instructional approach based on SAMR to guide undergraduate freshmen's AIGC use. Their 16-week implementation demonstrated that combining active teaching strategies with the SAMR model improved the quality of student-AIGC interactions, particularly in dialog depth, question diversity, and dialog efficiency. Students exhibited progressive movement through SAMR levels, though advanced tasks at Modification and Redefinition levels remained challenging.

The Three-Level AI Integration Framework (Reis & Sun, 2025) categorizes integration as basic, intermediate, and advanced, guided by Bloom's Taxonomy and AI literacy principles . Basic integration aligns with Remembering and Understanding, positioning AI as a "virtual buddy" for brainstorming and feedback. Intermediate integration emphasizes Applying and Analyzing, with students designing multi-format resources using AI under Universal Design for Learning principles. Advanced integration targets Creating and Evaluating through real-world, interdisciplinary projects developing industry-standard AI applications.

Summary Table 1: Major Theoretical Frameworks for AI in Digital Education

Framework	Origin	Core Components	Unique Contribution
3wAI	Bozkurt, 2024	Know What, Know How, Know Why	Ethical "dragon-rider" metaphor; comprehensive literacy dimensions

Framework	Origin	Core Components	Unique Contribution
ED-AI Lit	Allen & Kendeou, 2024	Knowledge, Evaluation, Collaboration, Contextualization, Autonomy, Ethics	Integration of learning sciences and cognitive psychology
UNESCO AI CFS	UNESCO, 2024	12 competencies across 4 aspects × 3 levels	Global adaptability; spiral learning progression
i-TPACK (integrated)	Celik, 2023; extended 2025	i-TK, i-TPK, i-TCK, i-CK, i-PD, integrated i-TPACK; 5-stage literacy progression	AI-as-content; AI-for-PD; distributed ethics
SAMR-AIGC	Wu et al., 2025	Substitution, Augmentation, Modification, Redefinition	Active teaching strategies for progressive integration
Three-Level Framework	Reis & Sun, 2025	Basic, Intermediate, Advanced	Bloom's Taxonomy alignment; developmental staging

3.2 Technical Methodologies and Implementation Architectures

The technical architectures enabling AI integration in education have evolved from simple adaptive systems toward sophisticated hybrid models capable of bidirectional personalization and multimodal interaction.

3.2.1 Bidirectional Personalization Architectures

The Adapt Learn AI framework represents a significant methodological advance by addressing the fragmentation between teacher-support and student-adaptation systems. This architecture combines fine-tuned large language models for dynamic content generation with Retrieval-Augmented Generation (RAG) pipelines for instructor task automation. The framework enables real-time synchronization between learner progress data and teacher planning tools—a bidirectional relationship absent from previous siloed solutions.

Pilot testing with five teachers and fifteen students demonstrated a 47% reduction in lesson planning time and a 22% improvement in quiz scores compared to non-AI workflows. The architecture includes FERPA-compliant anonymization protocols and bias audit mechanisms, responding to ethical deployment requirements identified in the theoretical literature. The open-source release of implementation guidelines for GPT-4 and LLaMA integration supports reproducibility and community-driven improvement.

3.2.2 Graph Neural Networks and Reinforcement Learning Hybrid Systems

A second major technical methodology integrates Generative AI with Graph Neural Networks and Reinforcement Learning. This approach constructs knowledge graphs from student interaction data, employs GNNs for feature extraction, and implements RL for dynamic content recommendation. The system achieves 94.5% accuracy, 93.8% precision,

94.2% recall, and a 97.0% ROC-AUC, outperforming traditional algorithms including Decision Trees and Random Forests by 6-10 percentage points.

The methodological innovation lies in treating student knowledge as a dynamic graph structure rather than a linear sequence or static profile. This enables the system to model relationships between concepts, identify prerequisite knowledge gaps, and recommend learning pathways that respect conceptual dependencies. The RL component continuously optimizes recommendations based on engagement and performance signals, enabling real-time adaptation.

3.2.3 Emerging Application Methodologies

The Digital Education Council's global review of AI for student engagement identified twenty-four emerging methodologies across six areas. In faculty interaction, methodologies include AI-enhanced teaching assistants, AI-customized instructor-like feedback, and predictive analytics for early intervention. For peer exchange, AI-supported asynchronous discussion boards, AI-generated prompts for synchronous discussions, and AI-moderated breakout rooms represent emerging collaborative methodologies.

Content and assessment methodologies demonstrate particular diversity: AI-generated multi-level explanations accommodating different reading levels and prior knowledge; AI-created instructional content; AI tutors providing on-demand support; AI-supported interactive reading environments; real-time feedback systems; and AI-generated memory retention exercises optimizing spacing and retrieval practice.

Instructional delivery methodologies include AI-enhanced flipped classrooms where generative AI creates pre-class materials; avatar teaching for scalable instruction; adaptive micro-learning delivering content in optimally sized segments; and AI real-time instructor coaching providing live feedback on teaching effectiveness. Experiential and applied learning methodologies leverage AI for role-playing scenarios, physical object-based AI simulations, and AI-enhanced extended reality (XR) environments.

Summary Table 2: Technical AI Methodologies in Digital Education

Methodology Category	Specific Approach	Technical Components	Reported Efficacy
Bidirectional Personalization	AdaptLearn AI	Fine-tuned LLMs, RAG pipelines	47% planning time reduction; 22% quiz score improvement
Knowledge Graph + RL	GNN-RL Hybrid	Graph Neural Networks, Reinforcement Learning	94.5% accuracy; 6-10% outperformance
Intelligent Tutoring	AI Tutors; Adaptive Micro-learning	LLM-based dialog systems; optimization algorithms	Effect size g = 1.02 (meta-analytic)
Automated Assessment	Real-time feedback; AI grading	Natural language processing; rubric generation	Time savings; feedback quality improvements
Collaborative AI	AI-moderated discussions;	Conversation analysis; prompt engineering	Engagement increases

Methodology Category	Specific Approach	Technical Components	Reported Efficacy
	Peer exchange support		

3.3 Empirical Evidence of Efficacy and Moderating Factors

3.3.1 Meta-Analytic Findings

A recent meta-analysis synthesized thirteen empirical studies conducted across eight countries, examining the effectiveness of AI technologies in educational settings. Following PRISMA guidelines and employing multiple analytical approaches including Naive Bayes, TF-IDF, and BERT-based algorithms, the analysis revealed a significant positive effect size (Hedges' $g = 0.86$, 95% CI [0.45, 1.27], $p < 0.0001$), indicating substantial benefits of AI integration.

Notable heterogeneity characterized the findings. Chatbots and generative AI demonstrated the most substantial impact (effect size = 1.02, 95% CI [0.45, 1.59], $p < 0.0001$). Online learning and virtual reality applications showed moderate positive effects (effect size = 0.79, 95% CI [-0.04, 1.62], $p < 0.07$), while learning management systems and AI platforms demonstrated promising but more modest impacts (effect size = 0.62, 95% CI [0.03, 1.21], $p < 0.05$). The substantial heterogeneity (I^2 ranging from 54.03% to 93.23%) indicates that contextual and implementation factors significantly moderate AI educational efficacy.

3.3.2 Student-Level Moderators and Implementation Challenges

Empirical research reveals critical moderators of AI methodology effectiveness. A 16-week implementation of SAMR-based active instruction with undergraduate freshmen demonstrated that students continue facing significant challenges with advanced AI tasks. Despite improvements in interaction quality, many students had not fully grasped complex AI tool functions and remained in need of additional support and guidance. This finding challenges assumptions that digital native status confers AI competency. The study emphasized that active learning does not entail allowing students to "learn by themselves" without guidance; rather, teachers must provide scaffolded instruction that progressively develops sophisticated use.

The superficial application problem—students treating AI as question-answer tools rather than partners in inquiry—represents a significant threat to methodological effectiveness. Eighteen percent of undergraduates directly embed AI-generated text in homework assignments, indicating passive, non-critical use patterns that undermine higher-order thinking development. This finding aligns with evidence that students may lack basic AI awareness and deep understanding necessary for effective tool use.

3.3.3 Teacher-Level Moderators

Teacher preparedness emerges as a critical moderating factor. Preservice teachers consistently report feeling underprepared to design or facilitate AI-mediated instruction, particularly regarding ethical dimensions. Many enter professional preparation with superficial AI concept understanding and limited experience embedding safeguards. The integrated i-TPACK module demonstrated that targeted professional development can produce significant gains across all knowledge domains, but baseline deficits remain substantial.

The distinction between AI literacy and AI competency becomes empirically salient here. While educators may possess declarative knowledge about AI (literacy), the confidence and proficiency to apply this knowledge in practice (competency) requires deliberate development through authentic design experiences.

3.3.4 Institutional and Ethical Moderators

Methodological efficacy is further moderated by institutional readiness and ethical infrastructure. Data privacy, bias mitigation, transparency, and equitable access represent necessary conditions rather than optional enhancements. The AdaptLearn framework's inclusion of FERPA-compliant anonymization and bias audit protocols reflects recognition that technical efficacy cannot be separated from ethical integrity. Similarly, the integrated i-TPACK framework's threading of ethics across all literacy stages, rather than isolating it as a separate component, produced visible safeguards and verification steps in teacher-created lesson artifacts .

4. Discussion

4.1 Synthesis: Toward an Integrated Model of AI Educational Methodologies

The results of this review, while diverse, converge on a fundamental insight: effective AI methodologies in digital education cannot be reduced to either pedagogical theory or technical architecture alone. The most successful implementations—whether the SAMR-AIGC active instruction approach, the integrated i-TPACK professional development module, or the AdaptLearn bidirectional personalization system—explicitly align three distinct dimensions: (1) a pedagogical framework that articulates educational purposes and progression pathways; (2) a technical architecture that enables the intended pedagogical interactions; and (3) a literacy development approach that builds the human competencies necessary to enact the methodology.

This tripartite structure suggests an integrated model of AI educational methodologies (Figure 1). The pedagogical dimension provides the "why" and "what for"—the educational values, learning objectives, and developmental progression. The technical dimension provides the "how"—the computational mechanisms that generate content, adapt difficulty, model knowledge, or facilitate interaction. The literacy dimension provides the "who"—the evolving competencies of educators and learners to purposefully engage with AI systems. Methodological failure occurs when these dimensions are misaligned or when one dimension is privileged at the expense of others.

INSERT FIGURE 1: Integrated Model of AI Educational Methodologies (conceptual diagram showing the tripartite structure with bidirectional arrows among pedagogical frameworks, technical architectures, and literacy development, all situated within institutional and ethical contexts)

This model explains the observed heterogeneity in meta-analytic findings. Effect sizes vary not primarily because AI technologies possess different intrinsic efficacies, but because specific implementations embody different alignments among these dimensions. A chatbot deployed without pedagogical scaffolding for critical evaluation produces different outcomes than the same chatbot embedded within a SAMR-based active learning sequence. A knowledge graph recommendation system optimized solely for engagement metrics produces different outcomes than one also optimized for epistemic development and learner agency.

4.2 Implications for Research

This review identifies several critical gaps requiring further investigation. First, the bidirectional personalization architecture represented by AdaptLearn demonstrates feasibility and preliminary efficacy, but large-scale validation across diverse institutional contexts remains future work. The open-source release of implementation materials creates opportunities for replication and adaptation studies essential for establishing generalizability.

Second, the integrated i-TPACK framework has been tested in a single three-week module with twenty-five preservice teachers. While the theoretical extension adding i-CK and i-PD domains is well-justified, longitudinal research is needed to examine whether these competency gains persist and transfer to classroom practice. Additionally, the

framework's five-stage literacy progression (Know→Use→Evaluate→Ethics→Create) requires validation across different subject areas and educational levels.

Third, the relationship between AI literacy and AI competency requires further conceptual and empirical elaboration. The distinction proposed by Chiu and colleagues is valuable, but the developmental trajectory from literacy to competency, and the specific learning experiences that facilitate this transition, remain underspecified. The five essential learning experiences identified—community engagement, case studies, hands-on activities, exhibitions, culturally responsive learning—provide a starting point for systematic investigation.

Fourth, the phenomenon of superficial AI application documented among undergraduate freshmen raises urgent questions about the development of higher-order thinking in AI-augmented learning environments. If students treat AI as an answer-provider rather than a thinking partner, and if this pattern becomes entrenched during early university experiences, the cognitive consequences may be profound. Research examining metacognitive monitoring, epistemic cognition, and self-regulated learning in AI-integrated contexts is critically needed.

4.3 Implications for Practice

For educators and instructional designers, these findings support several evidence-informed recommendations. First, AI integration should be approached as progressive development rather than binary adoption. The SAMR-based active instruction approach and the Three-Level Integration Framework both demonstrate that effective integration moves through stages, with each stage requiring specific instructional scaffolds. Educators should assess current AI literacy levels, identify appropriate entry points, and design learning activities that deliberately move learners toward more sophisticated engagement.

Second, teacher professional development must address not only technical operation but also pedagogical design and ethical reasoning. The integrated i-TPACK module's threading of ethics across all literacy stages, embedded within performance-based activities requiring authentic decision-making, represents a model superior to standalone ethics lectures. Professional development should similarly engage teachers in designing, implementing, and reflecting upon AI-integrated lessons within their specific disciplinary contexts.

Third, institutional leaders should resist both uncritical adoption and blanket prohibition. The evidence supports regulated integration with explicit policies addressing privacy, bias, transparency, and accountability. The eighteen percent of undergraduates directly submitting AI-generated text signals not student dishonesty but a failure of instructional design and policy clarity. Institutions should develop frameworks that define appropriate use, provide attribution guidelines, and redesign assessments to require the unique human contributions that AI cannot replicate.

4.4 Implications for Policy

Policymakers at institutional, regional, and national levels should attend to the infrastructure required for effective AI integration. The UNESCO AI Competency Framework for Students and OECD AI Literacy Framework provide adaptable models for curriculum development and competency articulation. However, frameworks without implementation support remain aspirational. Policy should address the resource disparities that threaten to exacerbate educational polarization—schools and universities serving advantaged populations are better positioned to provide the devices, connectivity, and professional development that effective AI integration requires.

Additionally, policy should address the rapid technological obsolescence that characterizes the AI landscape. The S.P.Ai.C.E. model's emphasis on tool selection and validation in contexts of obsolescence offers methodological guidance that policy can incentivize. Rather than prescribing specific technologies that will be superseded within

months, policy should articulate principles for ongoing evaluation and evidence-informed selection.

4.5 Limitations

This review has several limitations. First, the rapid pace of AI development means that findings published even in late 2025 may not reflect the most current technological capabilities. Methodological frameworks demonstrate greater stability than specific technical implementations, but the field remains highly dynamic. Second, the predominance of research conducted in higher education and K-12 contexts in developed countries limits generalizability to vocational education, adult learning, and low-resource settings. Third, the quality assessment revealed variable methodological rigor across included studies, with some frameworks lacking empirical validation and some technical reports lacking pedagogical grounding. This review has synthesized available evidence while noting these limitations, but the overall evidence base remains emergent.

5. Conclusion

Artificial intelligence methodologies in digital education have rapidly evolved from isolated tools toward integrated frameworks that simultaneously address pedagogical purpose, technical capability, and human competency development. This review has documented a rich landscape of theoretical frameworks—from comprehensive literacy models to specialized teacher knowledge extensions to progressive integration sequences—and technical architectures—from bidirectional personalization systems to graph neural network hybrids to diverse engagement methodologies. Meta-analytic evidence confirms substantial positive effects while revealing significant heterogeneity moderated by implementation quality, learner readiness, teacher preparedness, and institutional infrastructure.

The central finding of this review is that methodology matters more than technology. The same generative AI model, deployed within different pedagogical frameworks and supported by different literacy development approaches, produces dramatically different educational outcomes. Effective methodologies deliberately align what AI can do with what educators and learners know how to do and what educational institutions value. This alignment work—simultaneously pedagogical, technical, and developmental—constitutes the core methodological challenge and opportunity of AI in digital education.

As AI capabilities continue their rapid advance, the human dimensions of methodology become increasingly decisive. The frameworks, architectures, and approaches examined here share a common recognition: AI does not replace educational relationships but mediates and transforms them. The question is not whether AI will be present in digital education—it already is, ubiquitously—but whether its presence will be guided by thoughtful methodology or by default adoption. The evidence assembled here suggests that thoughtful methodology, while demanding, produces measurably superior outcomes for learners and educators alike.

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