

Trends in 21st-Century Learning Technology Research: Digital Transformation, AI, and Adaptive Learning

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Abstract

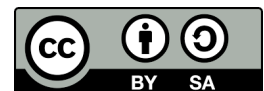
The rapid evolution of digital technologies, artificial intelligence (AI), and adaptive learning is reshaping 21st-century education, yet their interrelationships and research trajectories remain fragmented. This study systematically reviews research published from 2020 to 2026 to examine the evolution, dominant and emerging themes, and conceptual relationships across digital transformation, AI, and adaptive learning. Using a systematic literature review with thematic synthesis, relevant studies were analyzed temporally and thematically to identify shifts in research orientation and emerging directions. The findings reveal a progressive transition from technology integration and digital learning environments toward intelligent tutoring, personalization, adaptive learning, and, more recently, generative AI and human–AI collaboration. Conceptually, digital transformation functions as the enabling ecosystem, AI as an intelligent capability, and adaptive learning as a learner-responsive application. Importantly, AI-enabled personalization does not necessarily constitute adaptive learning; meaningful adaptation requires continuous responsiveness to learner performance, needs, feedback, and learning trajectories. The synthesis further indicates that technological advancement alone is insufficient, highlighting teacher agency, learner autonomy, organizational readiness, data governance, and ethical accountability. The study proposes a human-centered and responsible orientation in which AI augments pedagogical judgment rather than displacing it.

Keywords: Digital Transformation; Artificial Intelligence; Adaptive Learning; Generative AI; Human-Centered AI

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INTRODUCTION

The transformation of learning technology in the 21st century has moved beyond the digitization of instructional resources toward increasingly connected, intelligent, personalized, and data-driven learning environments. Digital technologies have reshaped how educational content is accessed, learning activities are organized, and interactions among learners, teachers, and institutions are conducted (Timotheou et al., 2023). Within this transformation, artificial intelligence (AI) has emerged as a major technological driver, enabling systems to analyze learner data, support instructional decision-making, and automate or augment aspects of teaching and learning (Chen et al., 2020). Adaptive learning represents a further development of this trajectory by using learner information to dynamically adjust content, feedback, and learning pathways according to individual needs (Gligorea et al., 2023). These developments indicate that contemporary learning technology

research is increasingly concerned not simply with technology adoption, but with how digital systems can become responsive components of learning processes.

The research landscape has evolved accordingly. Historical evidence shows that AI and education have developed through successive phases of technological and pedagogical innovation, with research priorities shifting as new computational capabilities and educational applications have emerged (Doroudi, 2023). A twenty-year analysis of AI research in education further demonstrates increasing scholarly attention and diversification of research topics over time (Guan et al., 2020). More recent reviews identify AI applications across intelligent tutoring, assessment, personalization, prediction, and learning support, indicating a transition from general technology adoption toward intelligent educational functions (Bozkurt et al., 2021; Zhang & Aslan, 2021). In parallel, adaptive learning has become an increasingly visible research area because of its potential to operationalize personalization through data-informed instructional adaptation (Maghsudi et al., 2021). The emergence of generative AI has subsequently expanded the research agenda beyond conventional predictive and adaptive systems toward interactive and content-generating forms of AI in education (Giannakos et al., 2025).

This evolution is shaped by both technological opportunities and implementation conditions. The effectiveness of digital transformation depends on institutional capacity, technological infrastructure, organizational readiness, and the ability of educational stakeholders to integrate technology into meaningful pedagogical practices (Timotheou et al., 2023). For adaptive learning, organizational readiness and stakeholder acceptance can determine whether technological capabilities are translated into sustainable educational implementation (Mirata & Bergamin, 2023). At the instructional level, AI integration requires learning designs that clarify how teachers and students collaborate with AI rather than simply introducing AI tools into existing practices (Kim et al., 2022). Ethical considerations further complicate this development, particularly regarding data privacy, transparency, accountability, bias, and the appropriate boundaries of AI-supported educational decision-making (Abulibdeh et al., 2024; Sharples, 2023). Consequently, technological advancement does not automatically produce pedagogical transformation.

Despite the rapid expansion of this literature, the current evidence base remains fragmented across technological and educational domains. Existing reviews have examined AI in education broadly (Chen et al., 2020), AI-supported STEM education (Xu & Ouyang, 2022), intelligent tutoring systems (Lin et al., 2023), adaptive learning (Gligorea et al., 2023), and generative AI in higher education (Chiu, 2024). These contributions provide important knowledge about individual technologies or applications, but they offer less integrated evidence concerning how digital transformation, AI, and adaptive learning have developed as interconnected research domains. In particular, it remains insufficiently clear how research priorities have shifted over time, which themes have become dominant or emerging, and how the increasing prominence of AI and adaptive learning relates to the broader transformation of digital learning research. This fragmentation limits a comprehensive understanding of the intellectual development and future direction of 21st-century learning technology research.

Addressing this gap is increasingly important because the research landscape is changing faster as new AI capabilities introduce questions that extend beyond earlier digital learning paradigms. Generative AI, for example, has created new pedagogical possibilities while simultaneously raising questions about human agency, instructional design, assessment, and educational ethics (Chiu, 2024; Hall, 2024). At the same time, adaptive and personalized learning continue to provide an important pathway for translating intelligent technologies into learner-responsive environments (Bhutoria, 2022). An integrated examination of these developments is therefore needed to distinguish established research trajectories from emerging themes and unresolved areas.

This study examines the evolving research landscape of 21st-century learning technology through the interconnected domains of digital transformation, artificial intelligence (AI), and adaptive learning. The study focuses on how these domains have been conceptualized and investigated in the existing literature, which themes have become dominant or are emerging, and how the three domains intersect in shaping technology-enabled learning. Specifically, the study addresses three research questions:

RQ1 : How has research on 21st-century learning technology evolved across the domains of digital transformation, artificial intelligence, and adaptive learning?

RQ2 : What dominant and emerging themes characterize the existing research landscape?

RQ3 : What conceptual interconnections, research gaps, and future research directions emerge from the synthesis of these interconnected domains?

By integrating evidence across these research domains, this study seeks to move beyond fragmented examinations of individual technologies and develop a coherent understanding of the field's evolution, current research priorities, and emerging directions. The study thereby provides an integrated perspective on how digital transformation, AI, and adaptive learning have collectively shaped the development of 21st-century learning technology research.

METHOD

This study employed a Systematic Literature Review (SLR) with thematic analysis to examine the global development of 21st-century learning technology research across the interconnected domains of digital transformation, artificial intelligence (AI), and adaptive learning. The review focused on research development, dominant and emerging themes, conceptual interconnections, research gaps, and future directions. The review followed systematic review procedures described by Snyder (2019) and was reported in accordance with the PRISMA 2020 guideline (Page et al., 2021).

A systematic literature search was conducted using Scopus and ERIC, supplemented by Google Scholar to identify additional relevant studies. The search combined terms such as “*learning technology*,” “*digital transformation*,” “*artificial intelligence*,” “*AI in education*,” “*adaptive learning*,” and “*personalized learning*,” together with relevant synonyms and Boolean combinations. The search covered publications from 2000 to 2026. Studies were included if they addressed educational or learning contexts and provided empirical, conceptual, or theoretical contributions related to at least one of the three focal domains. Only peer-reviewed journal articles published in

English were included. Duplicate records, non-educational studies, irrelevant publications, and non-scholarly documents were excluded.

Study selection followed four stages: identification, screening, eligibility assessment, and final inclusion. Titles, abstracts, and keywords were screened for relevance, followed by full-text assessment against the predefined eligibility criteria. The number of records identified, screened, excluded, and included was documented in accordance with PRISMA 2020 to ensure transparency and reproducibility (Page et al., 2021). Data were extracted systematically, including publication year, research context, technological domain, thematic focus, research approach, and key findings.

The extracted data were analyzed thematically by coding recurring concepts, grouping related codes, and identifying broader dominant and emerging themes. Temporal comparison was conducted to examine shifts in research emphasis from 2020 to 2026, while cross-study analysis identified conceptual interconnections, research gaps, and emerging research directions across the three domains. For analytical consistency, digital transformation was treated as the broader transformation of learning environments and practices through digital technologies; AI as intelligent and data-driven technologies applied to learning; and adaptive learning as technology-supported approaches that dynamically adjust content, feedback, or learning pathways to learner needs. The three domains were analyzed as interconnected but conceptually distinct, enabling an integrated account of the evolution and thematic structure of 21st-century learning technology research.

RESULTS AND DISCUSSION

1. Research Evolution Across Digital Transformation, AI, and Adaptive Learning

RQ1: How has research on 21st-century learning technology evolved across the domains of digital transformation, artificial intelligence, and adaptive learning?

The temporal distribution of the 35 studies published between 2020 and 2026 indicates a dynamic rather than linear development of research on 21st-century learning technologies. Research initially emphasized digital learning environments and technology integration, followed by increasing attention to artificial intelligence, intelligent tutoring, personalization, and adaptive learning. From 2023 onward, generative AI and human–AI collaboration emerged more prominently, signaling a shift toward intelligent, interactive, and learner-responsive applications. Overall, the trajectory reflects an expanding research agenda from technological integration toward personalized and human-centered learning ecosystems.

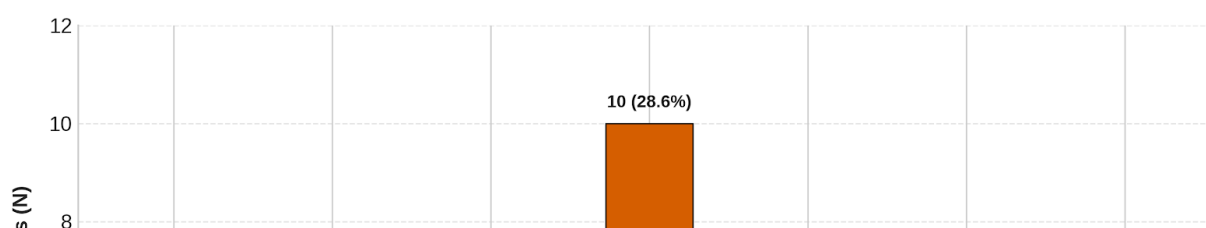


Figure 1. Temporal Distribution of Publications (2020–2026, N = 35)

Figure 1, research output increased from 3 studies (8.6%) in 2020 to 5 (14.3%) in 2021 and 7 (20.0%) in 2022, reaching a peak of 10 (28.6%) in 2023, followed by a temporary decline to 3 (8.6%) in 2024 and a resurgence to 6 (17.1%) in 2025; the 2026 count of one study (2.9%) reflects partial-year coverage. This non-linear trajectory indicates a substantive shift in research attention from the adoption and integration of digital learning technologies toward AI-enabled personalization and adaptive learning, with increasing convergence among the three domains. Rather than reflecting publication growth alone, the pattern suggests that digital transformation increasingly functions as the enabling context, while AI becomes a central capability for delivering more personalized and adaptive learning experiences.

Table 1. Research Phases and Emerging Orientations

Period	Publications	Dominant Research Orientation	Main Domain	Characteristic of Research Evolution
2020–2021	8	Digital transformation and foundational AI	Digital learning and AI	Research emphasized educational digitalization, digital learning environments, the potential of AI, and the historical and conceptual development of AI in education.
2022–2023	17	AI-enabled, personalized, and adaptive learning	AI and adaptive learning	Research expanded toward personalized education, adaptive systems, intelligent tutoring, affective feedback, AI-supported STEM learning, and the implementation of AI in educational settings.

2024–2026	10	Generative AI, human–AI collaboration, and intelligent learning ecosystems	AI, generative AI, and adaptive learning	Research generative transformation, collaboration, readiness, ethics, and integrated learning environments.	broadened AI, pedagogical human–AI organizational acceptance, and integrated intelligent	toward
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Note. The classification represents a thematic synthesis of the reviewed studies rather than mutually exclusive categories. Individual studies may address more than one domain. The 2026 count represents partial-year coverage.

Table 1 indicates a non-linear but increasingly application-oriented research trajectory across 2020–2026. The 2020–2021 period (8 studies; 22.9%) represents an initial phase centered on educational digitalization, digital learning environments, and the emerging role of AI. Research activity intensified substantially in 2022–2023, which accounted for 17 studies (48.6%) and marked the strongest concentration of publications, accompanied by a shift from general digitalization toward AI-enabled personalization and adaptive learning. The 2024–2026 period (10 studies; 28.6%) reflects a further reorientation toward generative AI, human–AI interaction, and broader pedagogical applications. Overall, the trajectory moves from establishing digital and AI foundations toward increasingly application-oriented and human-centered forms of intelligent learning, while digital transformation remains a continuing technological foundation.

2. Dominant and Emerging Themes

RQ2: What dominant and emerging themes characterize the existing research landscape?

The thematic analysis identified five interconnected clusters characterizing research on 21st-century learning technologies: (1) digital transformation and digital learning, (2) AI in education and intelligent systems, (3) personalized and adaptive learning, (4) generative AI and human–AI collaboration, and (5) implementation, readiness, and ethics. The thematic landscape spans broad digital integration, intelligent learning systems, learner personalization, generative and collaborative AI, and the organizational and ethical conditions of technology adoption. Because individual studies frequently addressed more than one theme, the clusters were treated as overlapping rather than mutually exclusive categories.

Table 2. Dominant and Emerging Research Themes

Thematic Cluster	Key Themes	Status	Author
Digital Transformation & Digital Learning	Digital transformation, digital learning, digital tools, learning environments, technology integration.	Foundational	García-Martínez et al. (2020); Timotheou et al. (2023); Zou et al. (2025)
AI in Education & Intelligent Systems	AI applications, AI adoption, intelligent tutoring, AI-enabled education, STEM applications.	Dominant	Chen et al. (2020); Ouyang & Jiao (2021); Zhang & Aslan (2021); Lin et al. (2023); Xu & Ouyang (2022)

Personalized & Adaptive Learning	Personalization, adaptive learning, learner engagement, affective feedback, learner-responsive systems	Established	Bhutoria (2022); Christodoulou & Angeli (2022); Gligorea et al. (2023); Liu et al. (2022); Sidik (2026)
Generative AI & Human-AI Collaboration	Generative AI, human-AI collaboration, teacher-AI interaction, pedagogical transformation.	Emerging	Chiu (2024); Giannakos et al. (2025); Hall (2024); Kaplan-Rakowski et al. (2023); Sharples (2023)
Implementation, Readiness & Ethics	Organizational readiness, stakeholder acceptance, teacher perspectives, ethics, responsible AI	Emerging	Mirata & Bergamin (2023); Kaplan-Rakowski et al. (2023); Abulibdeh et al. (2024); Giannakos et al. (2025)

Note. The thematic occurrences represent overlapping coding of studies and therefore do not sum to the total number of studies. Frequencies should be interpreted as approximate when based on thematic coding of the available study information.

AI in Education and Intelligent Systems emerged as the dominant thematic cluster, encompassing research on AI applications, intelligent tutoring, AI-enabled education, and technology-supported STEM learning. This cluster was accompanied by an established strand on personalized and adaptive learning, which focused on personalization, adaptive mechanisms, learner responsiveness, affective feedback, and engagement. The co-occurrence of these themes indicates that the literature increasingly connects AI capabilities with learner-centered applications, particularly through systems designed to respond to learner characteristics, performance, and learning needs.

Digital Transformation and Digital Learning constituted a foundational cluster, covering digital learning environments, technology integration, digital tools, and institutional digital capacity. Alongside this established foundation, Generative AI and Human-AI Collaboration emerged as a newer thematic direction, with increasing attention to generative systems, teacher-AI interaction, and pedagogical transformation. Implementation, Readiness and Ethics formed another emerging, cross-cutting cluster addressing organizational readiness, stakeholder acceptance, teacher perspectives, responsible AI, and ethical considerations. Together, these themes broaden the research landscape from technology integration and intelligent applications toward generative, collaborative, and contextually responsible forms of technology use in education.

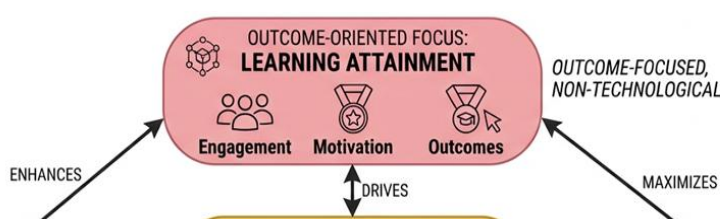


Figure 2. Thematic Structure of 21st-Century Learning Technology Research

The thematic map shows that the identified clusters are interconnected rather than isolated. AI in education and intelligent systems forms the central thematic cluster, with strong connections to personalized and adaptive learning as an application-oriented strand. Digital transformation and digital learning provide a broader technological context, while generative AI and human–AI collaboration extend the thematic landscape toward newer forms of AI-supported interaction. Implementation, readiness, and ethics function as cross-cutting themes that intersect with both technological and pedagogical dimensions. Overall, the thematic structure is characterized by a core of AI-related research connected to application, contextual, and emerging themes.

3. Conceptual Interconnections, Research Gaps, and Future Directions

RQ3: What conceptual interconnections, research gaps, and future research directions emerge from the synthesis of these interconnected domains?

The synthesis of the reviewed literature indicates that digital transformation, artificial intelligence (AI), and adaptive learning are increasingly interconnected within contemporary learning environments, while remaining conceptually distinct. Their relationship can be understood through three complementary functions: digital transformation as an enabling ecosystem, AI as an intelligent capability, and adaptive learning as a personalized application. Digital transformation establishes the technological and organizational conditions for digitally mediated learning; AI extends these environments with analytical, predictive, automated, and generative capabilities; and adaptive learning translates such capabilities into learner-responsive educational applications. Thus, the three domains are best understood as functionally interconnected rather than as a fixed linear or causal sequence.

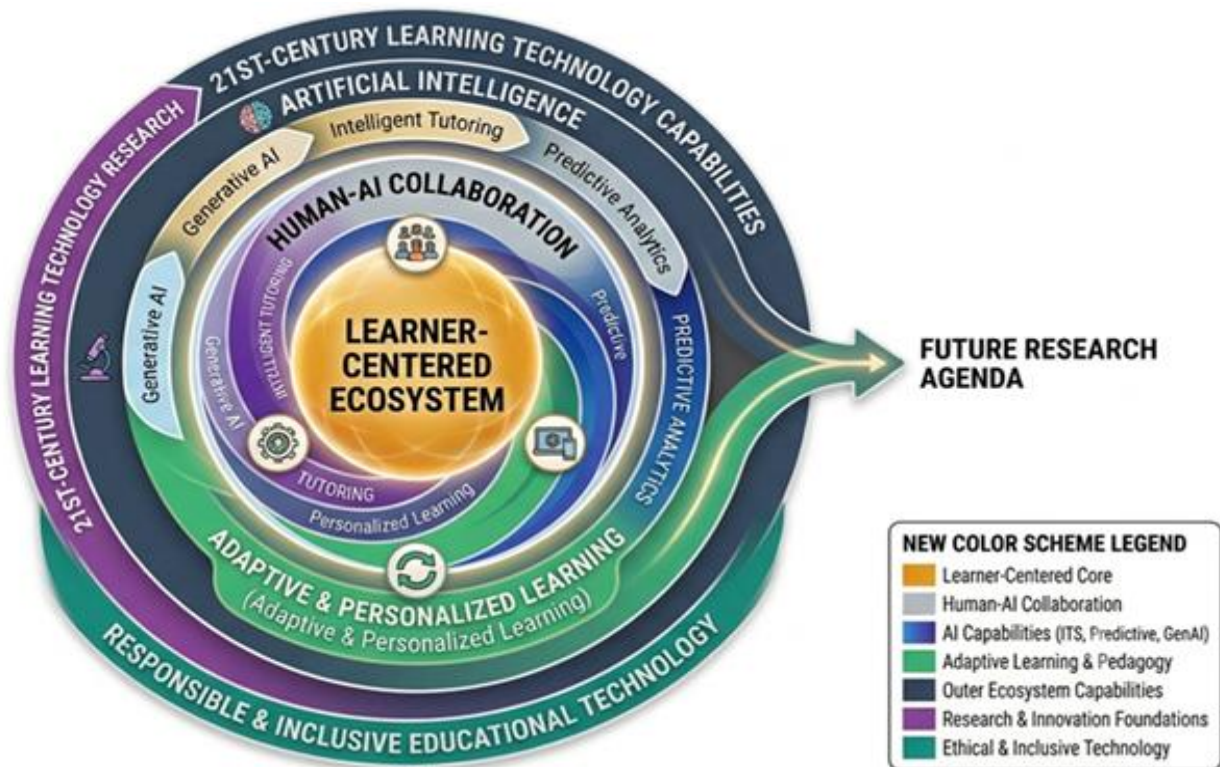


Figure 3. Interconnections of Digital Transformation, AI, and Adaptive Learning

Note. The figure represents a conceptual synthesis of the reviewed literature. The three domains are functionally interconnected but conceptually distinct. The arrows indicate enabling and functional relationships rather than a fixed linear or causal sequence.

The conceptual framework illustrates the interconnected ecosystem of 21st-century learning technologies, encompassing Artificial Intelligence (AI), Adaptive & Personalized Learning, Human–AI Collaboration, and digital transformation. AI serves as a central technological capability through Generative AI, Intelligent Tutoring, and Predictive Analytics, supporting adaptive and personalized learning. Digital transformation provides the broader context through digital platforms, data environments, and technological innovation. Overlapping areas indicate the integration and interdependence of AI, adaptive learning, pedagogy, and human–AI collaboration, while directional arrows show the contribution of AI, particularly Generative AI, to adaptive learning. Overall, the framework represents technology, pedagogy, and human–AI interaction as an interconnected and evolving educational ecosystem.

Fragmented Areas in the Existing Research

Despite increasing convergence, the literature remains fragmented across technological, pedagogical, and organizational dimensions. First, digital transformation studies primarily emphasize infrastructure, digital capacity, and institutional integration, whereas AI studies focus on technological capabilities and applications. The connection between institutional digital readiness and

effective AI-supported adaptive learning therefore remains insufficiently integrated. Second, a gap persists between AI capabilities and pedagogical adaptation: research on AI, intelligent tutoring, and generative systems emphasizes technological functions, while adaptive learning research focuses on personalization and learner responsiveness, leaving their pedagogical relationship insufficiently specified. Third, technology and learner outcomes are often examined separately through engagement, motivation, self-directed learning, or achievement, with limited integration of these outcomes into a pathway linking digital environments, AI capabilities, adaptive mechanisms, and learner development.

Conceptual, Methodological, and Empirical Gaps

The synthesis identifies three principal research gaps. Conceptually, limited research explicitly integrates digital transformation, AI, and adaptive learning as distinct yet interconnected layers. Key concepts, including personalization, adaptivity, intelligence, and digital transformation, are also inconsistently defined and operationalized, while the relationship between generative AI and established adaptive learning models remains underdeveloped. Methodologically, substantial variation in research designs, contexts, technologies, samples, durations, and outcome measures limits cross-study comparability. Longitudinal and comparative evidence remains particularly scarce for distinguishing AI-enabled adaptation from conventional digital learning and non-AI adaptive mechanisms. Empirically, limited evidence establishes which AI capabilities support particular forms of adaptation, for which learners, and under what educational conditions. Evidence is also insufficient on sustained effects and teacher roles in supervising and intervening in AI-supported adaptive processes, as well as on organizational readiness, stakeholder acceptance, data governance, transparency, bias, and ethical use (Abulibdeh et al., 2024; Mirata & Bergamin, 2023; Sharples, 2023).

Table 3. Research Gaps and Future Directions

Dimension	Research Gap	Unresolved Issue	Future Research Direction
Conceptual	Limited integration of digital transformation, AI, and adaptive learning	How can the three domains be conceptualized as distinct but interconnected layers?	Develop and test integrated ecosystem–capability–application models
Methodological	Heterogeneous designs and outcome measures; limited longitudinal evidence	What methodological approaches can establish sustained effects?	Use longitudinal, comparative, and mixed-method designs
Empirical	Limited evidence on which AI capabilities support meaningful adaptation	Which AI capabilities work for which learners and contexts?	Examine AI-enabled personalization at the learner-process level

Pedagogical	Weak connection between AI capability and pedagogical adaptation	When does AI produce meaningful rather than merely technical personalization?	Study adaptive feedback, pathways, pacing, and instructional support
Human–AI	Unclear balance between automation and human agency	What roles should teachers and learners retain?	Investigate human–AI collaborative adaptive learning
Ethical & Organizational	Fragmented attention to readiness, privacy, bias, and governance	How can intelligent learning remain responsible and equitable?	Develop responsible and sustainable intelligent learning ecosystems

Unresolved Issues

Several issues remain unresolved across the synthesized literature. A central concern is the balance between AI-driven automation and human agency, particularly the evolving roles of teachers and learners in recommendation, feedback, assessment, and content generation. Personalization also remains dependent on learner data, creating tensions involving privacy, transparency, governance, and algorithmic bias. Another unresolved issue is the distinction between content generation and genuine adaptation: generating individualized materials does not necessarily modify learning pathways, instructional strategies, feedback, pacing, or learner support. Finally, greater technological sophistication does not inherently ensure educational effectiveness, making pedagogical fit, human oversight, and implementation quality critical conditions for meaningful AI-enabled adaptive learning.

Emerging Directions for Future Research

The synthesis suggests five directions:

First, future research should develop and empirically test integrated models connecting digital transformation, AI capability, and adaptive learning, for example:



Second, research should examine AI-enabled personalization at the learner-process level, including adaptive feedback, learning pathways, pacing, content difficulty, and learner support, rather than focusing exclusively on achievement outcomes.

Third, the emergence of generative AI calls for greater investigation of human–AI collaborative adaptive learning, in which AI provides recommendations, explanations, or learning resources while teachers and learners retain meaningful decision-making authority.

Fourth, stronger longitudinal, comparative, and mixed-method research is needed to distinguish the effects of conventional digital learning, rule-based adaptive systems, and AI-driven adaptive systems.

Finally, future research should increasingly address responsible and sustainable intelligent learning ecosystems, integrating technological effectiveness with organizational readiness, teacher competence, learner agency, ethics, data governance, and equity. This direction is necessary to ensure that the integration of AI and adaptive learning is evaluated not only in terms of technological capability but also in terms of educational value and broader human consequences. Overall, the synthesis for RQ3 indicates that digital transformation, AI, and adaptive learning are functionally interconnected but conceptually distinct. Digital transformation establishes the enabling ecosystem, AI provides intelligent capabilities, and adaptive learning translates these capabilities into personalized educational applications. The principal gap lies not in the absence of research within individual domains, but in their limited integration into empirically testable models. Future research should therefore move toward integrated, longitudinal, human-centered, and responsible adaptive learning ecosystems.

4. Discussion

The synthesis indicates that digital transformation, artificial intelligence (AI), and adaptive learning represent distinct but complementary dimensions of educational technology development. Digital transformation functions as the enabling ecosystem, encompassing changes in learning environments, institutional practices, and technological infrastructures that create conditions for innovation (Bates et al., 2020; García-Martínez et al., 2020; Timotheou et al., 2023). Within this ecosystem, AI provides intelligent capabilities for processing learning data, identifying patterns, generating information, and supporting educational decisions (Chen et al., 2020; Ouyang & Jiao, 2021; Zhang & Aslan, 2021). Adaptive learning constitutes a learner-responsive application that translates such capabilities into instructional processes responsive to learners' needs, performance, feedback, and learning trajectories (Bhutoria, 2022; Christodoulou & Angeli, 2022; Gligorea et al., 2023; Liu et al., 2022). This relationship is functional rather than deterministic: digital transformation enables the ecosystem, AI provides intelligence, and adaptive learning operationalizes that intelligence for learning.

This structure is reflected in the evolution of the research landscape from technology integration toward intelligent, adaptive, generative, and collaborative applications. Earlier research emphasized digital learning environments and institutional technological capacity, followed by increasing attention to intelligent tutoring, personalization, adaptive learning, and learner-responsive feedback (García-Martínez et al., 2020; Timotheou et al., 2023; Gligorea et al., 2023; Lin et al., 2023). More

recent research on generative AI extends this trajectory toward content generation, interaction, and human–AI collaboration (Chiu, 2024; Giannakos et al., 2025; Hall, 2024; Sharples, 2023). Thus, the research agenda has shifted from whether technology can be integrated into education toward how computational capabilities can enhance responsive, interactive, and learner-centered processes, rather than simply replacing technology-centered research (Chiu et al., 2023; Crompton & Burke, 2023).

A critical implication is that AI-enabled personalization does not necessarily constitute adaptive learning. Individualized content, recommendations, or responses represent personalization, but meaningful adaptation requires continuous interpretation of learner performance, progress, needs, and feedback, followed by corresponding instructional adjustments (Bhutoria, 2022; Gligorea et al., 2023; Liu et al., 2022; Mirata & Bergamin, 2023). This distinction is particularly important with generative AI, whose individualized outputs may create an appearance of adaptivity without establishing an iterative pedagogical process. Hence, technological sophistication cannot serve as a proxy for pedagogical adaptivity; evaluation should determine whether systems detect meaningful changes in learner states and sustain appropriate instructional adaptation.

The findings therefore point toward a human-centered and responsible direction for AI-supported learning. Effective transformation depends not only on technological capability but also on organizational readiness, teacher competence, learner agency, digital and data literacy, stakeholder acceptance, data governance, and ethical accountability (Mirata & Bergamin, 2023; Abulibdeh et al., 2024; Giannakos et al., 2025; Reddy et al., 2023). Teachers increasingly act as pedagogical decision-makers and human–AI collaborators, retaining responsibility for instructional judgment (Kim et al., 2022; Kaplan-Rakowski et al., 2023). Accordingly, the future of 21st-century learning technology lies not simply in more powerful AI, but in aligning technological intelligence with adaptive pedagogy, human agency, institutional capacity, and responsible governance to establish genuinely intelligent, adaptive, and human-centered learning ecosystems.

CONCLUSION

This systematic literature review demonstrates that research on 21st-century learning technologies has evolved from technology integration toward intelligent, adaptive, generative, and human–AI collaborative learning. The synthesis positions digital transformation, artificial intelligence (AI), and adaptive learning as distinct but complementary functional levels: digital transformation provides the enabling ecosystem, AI supplies intelligent computational capabilities, and adaptive learning operationalizes these capabilities through learner-responsive applications. This trajectory reflects a broader shift from a technology-centered to a learner-centered orientation, with increasing attention to personalization, learner responsiveness, intelligent tutoring, and human–AI interaction.

A critical implication is that AI-enabled personalization should not be equated with adaptive learning. Generating individualized content or recommendations does not necessarily constitute meaningful adaptation unless systems continuously respond to learner performance, progress, feedback, and learning trajectories. The future of AI-enabled adaptive learning therefore depends not only on technological sophistication but on the alignment of AI capabilities, pedagogical design, teacher expertise, learner agency, organizational readiness, and ethical governance. The field is consequently moving toward human-centered and responsible intelligent learning ecosystems, in which AI augments rather than replaces human pedagogical judgment and supports learning that is responsive, meaningful, and educationally sustainable.

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