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Conceptual Transformation of Learning in the Era of Artificial Intelligence: A Systematic Review of 2024-2025 Studies

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ABSTRACT

Objective: This review examined recent studies (2024–2025) to identify new conceptualizations of learning in the AI era, characterized by hybrid human-system collaboration, real-time personalization using multimodal data, interpretability, and a shift from teacher-centered to learner- and technology-driven approaches.

Method: Nine peer-reviewed studies from 2024–2025 were analyzed thematically, sourced from databases including Scopus, Web of Science, PubMed, Google Scholar, and ResearchGate using keywords like "learning definition", "conceptualization of learning", "AI in education" and "hybrid intelligence."

Result: The findings reveal that learning in the AI era is conceptualized as a dynamic, adaptive, and multidimensional process integrating cognitive, emotional, social, and interactive elements. Emerging theoretical frameworks include hybrid intelligence emphasizing human-system co-evolution, the integration of cognitive load theory with AI and educational neuroscience, and generalized online learning models prioritizing interpretability and continuous autonomous learning. Key novel features encompass multimodal learning leveraging neurophysiological tools, real-time adaptive pathways, human-machine collaborative processes, incorporation of behavioral and interactional data alongside neurophysiological indicators, and a strong emphasis on transparency and interpretability

Conclusions: The core transformation is a paradigm shift toward learner- and technology-centered models, with social interaction gaining prominence in AI-mediated settings. While AI enables personalized feedback and dynamic adaptation, its limitations in context and causal reasoning underscore the necessity of human-AI synergy. Practical implications highlight the need for educator training in new technologies and careful attention to ethics and equitable access. These insights derive from a constrained sample of nine studies and may not encompass the entire scope of research on learning during 2024–2025.

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Introduction

Over the past decade, the concept of learning has undergone a profound transformation, evolving from a purely cognitive and teacher-centered process to one that centrally incorporates human-machine interaction, neurophysiological data, and real-time analyses (Gkintoni et al., 2025; Rodrigues, 2025). Recent studies no longer view learning simply as knowledge acquisition but as a hybrid process integrating cognitive, emotional, social, and computational elements within technological platforms (Castillo Martínez et al., 2024; Kong, 2025; Masih, 2025).

AI-based tools, including intelligent tutoring systems, generative AI, and adaptive platforms, are redefining learning by shifting it away from content transmission and repetitive drills toward personalized, data-driven, and learner-centered processes that enhance metacognition—an essential factor in educational quality (Afzaal et al., 2025; Castillo Martínez et al., 2024; Soroosh et al., 2024). In these environments, learning is conceptualized as the continuous optimization of alignment between learner characteristics and instructional conditions through analytics and algorithmic adaptation, rather than passive information reception (Cukurova et al., 2024; Wang et al., 2024).

Conceptual work on the “AI revolution in education” describes a transition from isolated human cognition to hybrid intelligence, in which humans and machines jointly extend cognitive capacities through personalization, predictive analytics, and real-time feedback (Rodrigues, 2025; U.S. Department of Education, 2024). This reconceptualization positions learning as co-evolution between human learners and intelligent systems, moving away from unidirectional, teacher-dominated models (Kong, 2025; Younas et al., 2025).

Advances integrating cognitive load theory with AI and educational neuroscience demonstrate that adaptive systems can dynamically adjust learning paths using real-time neurophysiological indicators of cognitive load, attention, and engagement (Gkintoni et al., 2025; Wang et al., 2025). EEG-based research shows that brain signals related to mental effort enable automatic adjustments in task difficulty, pacing, and modality, thereby embedding cognitive load management into the core of effective learning (Wang et al., 2025). Consequently, learning is increasingly redefined as ongoing alignment between the learner’s neurocognitive state and the instructional environment, mediated by AI and informed by multimodal data streams—neurophysiological, behavioral, and interactional—rather than solely observable outcomes (Cukurova et al., 2024; Gkintoni et al., 2025; Wang et al., 2024; Xia et al., 2023). This perspective aligns with evidence that self-directed learning strengthens problem-solving abilities (Jasim Imran et al., 2024).

Empirical studies further reveal that combining AI with social media in university classrooms significantly boosts student participation, provides individualized feedback, detects knowledge gaps, and supports collaborative knowledge construction and peer interaction (Afzaal et al., 2025;

Masih, 2025). Such AI-enhanced social environments reinforce learning as socio-technical co-construction rather than solitary activity (Cukurova et al., 2024; Nature Editorial, 2025). Emerging models, such as joint human-AI regulation and AI-empowered self-regulated learning, portray AI as a regulatory partner across planning, performance, and reflection phases (Järvelä et al., 2023; Lan et al., 2025). Hybrid intelligence approaches emphasize continuous co-evolution and distributed cognition, blending human strengths (e.g., moral reasoning, empathy, creativity) with machine capabilities (e.g., large-scale memory, pattern detection, speed) while highlighting the role of multimodal data in blurring boundaries between human and machine learning (Kong, 2025; Rodrigues, 2025).

Despite these developments, significant challenges remain, including digital inequality, data privacy risks, over-dependence on algorithms, and uneven access to AI-rich ecosystems, with students sometimes outsourcing self-regulation to systems (Afzaal et al., 2025; Younas et al., 2025). Learning in AI-mediated contexts is thus inextricably linked to data governance, AI literacy, and ethical considerations (Ayonrinde, 2024). Additionally, a shift from opaque “black-box” models toward interpretable and transparent analytics is increasingly advocated to ensure educational legitimacy (Ayonrinde, 2024; Gkintoni et al., 2025; Xia et al., 2023).

The literature exhibits considerable theoretical dispersion across domains—human learning, machine learning, organizational learning, robotics, and hybrid intelligence—with definitions ranging from narrow performance-based views to broader emphases on self-regulation, agency, collaboration, and ethical competence (Castillo Martínez et al., 2024; Gkintoni et al., 2025; Lan et al., 2025; Nur Amirah Mohmad Mohmiddin et al., 2025; Wang et al., 2024; Rodrigues, 2025). This heterogeneity has yet to yield a unified integrative framework, leading to ambiguity in designing intelligent learning environments, inconsistencies in assessment, and conflicting policy interpretations of desirable learning in the AI era (Kong, 2025; U.S. Department of Education, 2024; Younas et al., 2025).

The present systematic review addressed this gap by analyzing peer-reviewed studies from 2024–2025 to extract and compare explicit and implicit definitions of learning, identify new theoretical frameworks, synthesize the impact of AI, and construct a multidimensional, interpretable framework to inform educational design, implementation, and policy. Given what has been discussed, the central research question guiding this study was posed as follows:

What is the conceptual transformation of learning in the age of artificial intelligence?

Materials and Methods

Search Strategy and Article Retrieval

Articles were retrieved from reputable scientific databases, including Scopus, Web of Science, PubMed, Google Scholar, and ResearchGate, using a combination of keywords such as "learning definition", "conceptualization of learning", "artificial intelligence in education", "hybrid intelligence", "adaptive learning", "neurophysiological learning", and "AI-mediated learning". The search was limited to peer-reviewed journal articles published between January 2024 and December 2025, primarily in English (with one inclusion in Ukrainian due to its relevance and conceptual depth).

Population and Sample

The initial search yielded approximately 50 potentially relevant articles. These were screened independently by two experts in learning sciences and educational technology based on predefined inclusion criteria as follows:

- Providing a new or reconceptualized definition of learning in the AI era;
- Offering novel theoretical or empirical insights beyond existing definitions;
- Constituting theoretical, conceptual, or empirical research on learning (human, machine, or hybrid);
- Including substantial conceptual/theoretical discussion (not solely practical applications);
- Representing high-level evidence (e.g., systematic reviews, empirical studies, or conceptual papers with rigorous frameworks; excluding single case reports without theory); and
- Being a peer-reviewed publication.

Disagreements during screening were resolved through discussion and final decision by the principal investigator. This process resulted in the selection of 9 articles, which represent a diverse range of study types and domains while focusing on high-quality, conceptually rich contributions published in 2024–2025. The limited final sample reflects the strict criteria prioritizing depth and novelty over breadth, ensuring relevance to the emerging conceptual transformations in the AI era.

Table 1. Final samples of articles

Study	Type of Study	Main Topic
Gkintoni et al., 2025	Systematic Review	Integration of Cognitive Load Theory with Artificial Intelligence
Miconi & Kay, 2025	Scientific	Relational Learning and Neural Mechanisms
Masih et al., 2025	Quasi-Experimental Study	Integration of Artificial Intelligence and Social Media
Järvelä et al., 2025	Review Article	Human-Machine Hybrid Intelligence
Srisuchinnawong et al., 2025	Scientific	Continuous Motor Learning in Robotics

Study	Type of Study	Main Topic
Мінцер et al., 2024	Conceptual Study	Transdisciplinary Learning Processes Model in AI Technologies
Tan et al., 2025	Review	Evolution of Reinforcement Learning
Mohmiddin & Bakar, 2025	Systematic Review	Artificial Intelligence in Arabic Language Learning
Adliyar, 2025	Qualitative Research	E-Learning Ecosystem

Data Extraction and Analysis

Data extraction focused on key thematic categories to ensure structured and comprehensive synthesis:

1. Definitions of learning (explicit/implicit, key features, contextual conceptualizations);
2. New theoretical frameworks/models (name, components, distinctions from traditional theories, integration with AI/technologies);
3. Role and impact of AI (changes to learning concepts, human-AI collaboration, new capabilities, adaptive/personalized aspects);
4. Novel features and conceptual innovations (e.g., multimodal/real-time adaptation, interpretability, metacognition, interdisciplinary integration);
5. Context and applications (educational level, domain, environment, technologies, target populations); and
6. Practical implications (teaching changes, educator/learner needs, tools, challenges, benefits).

The Extracted data were analyzed using thematic analysis, involving iterative coding of content, identification of recurring themes, and synthesis across studies. Two researchers independently coded the articles, compared codes, and refined themes through consensus to enhance reliability and validity.

Results

As mentioned earlier, Data extraction focused on some key thematic categories which will be investigated and explained below.

Definitions of Learning in 2025

The reviewed studies provide different definitions of learning that can be classified into several categories:

Table 2. Definitions of Learning in 2024-2025

Approach to Definition	Studies	Key Features
Adaptive-Technological Learning	Gkintoni et al., Masih et al.	Dynamic process, personalized, based on neurophysiological data, emotional and cognitive engagement
Relational-Neural Learning	Miconi et al.	Creating relationships between experiential elements, transitive inference, list linking
Human-Machine Hybrid Learning	Järvelä et al.	Metacognitive capacity, planning, monitoring, and inhibiting learning processes
Continuous Automatic Learning	Srisuchinnawong et al.	Acquiring skills automatically with a simple reward function

Approach to Definition	Studies	Key Features
Knowledge Transfer-Based Learning	Мінцер et al.	Transferring knowledge with selective and targeted strategies
Reinforcement Learning	Tan et al.	Learning from interactions with the environment to maximize long-term rewards

The analysis shows that during 2024-2025, learning is understood as a multidimensional process that includes cognitive, emotional, and interactive elements. Many definitions emphasize dynamism and adaptability, while others focus on underlying neural mechanisms.

New Theoretical Frameworks

Table 3. New Theoretical Frameworks

Framework	Study	Key Components	Differentiation from Traditional Theories
CLT-AI-EdNeuro Integration Framework	Gkintoni et al.	Adaptive learning systems, neurophysiological tools, deep learning models	Automatic cognitive load management, path adaptation based on real-time data
Relational Learning Model	Miconi et al.	Neural networks with synaptic plasticity, meta-learning	Active solution with reconstruction of past items in neural activity
Hybrid Intelligence (HI)	Järvelä et al.	Combination of human and machine intelligence, stages of externalizing human cognition and internalizing AI models	Multidisciplinary approach integrating cognitive sciences and psychology
Generalized Online Learning with Bounded. Uncertainty Models	Srisuchinnawong et al.	Interpretable neural inhibition network, neurogenesis, two-layer learning mechanism	Emphasis on interpretability and learning in real conditions without human intervention
Transdisciplinary Model	Мінцер et al.	Integration of AI in learning processes, simulation environments	Transdisciplinary approach combining psychology, biology, and computer science

New theoretical frameworks in 2024-2025 all emphasize the integration of technology with learning processes. Hybrid intelligence as an emerging paradigm centers on human-machine co-evolution, while generalized online learning with bounded uncertainty models focuses on interpretability and continuous automatic learning.

Role of Artificial Intelligence in the Concept of Learning

Table 4. Role of Artificial Intelligence in the Concept of Learning

Aspect	Findings	Studies
Change in Definition of Learning	Learning as automatic and independent of human intervention, revolution in traditional educational methods	Srisuchinnawong et al., Masih et al.
Human-AI Collaboration	AI as a complement to human interaction, collaboration in learning and decision-making	Masih et al., Järvelä et al.
New Capabilities	Individual feedback, dynamic content adaptation, real-time analyses, personalized learning	Masih et al., Мінцер et al.
Differences Between Human and Machine Learning	AI limitations in understanding context and cause-effect relationships, machine learning independent of humans	Järvelä et al., Srisuchinnawong et al.
Adaptive Learning	Adaptive systems for identifying knowledge gaps, adaptive strategies for knowledge transfer	Masih et al., Мінцер et al.

Artificial intelligence plays a transformative role in conceptualizing learning. AI expands the boundaries of traditional learning by providing real-time feedback and content adaptation based on individual needs. However, AI's limitations in understanding context and causal relationships indicate that human-AI collaboration remains essential.

Key Novel Features of Learning

Table 5. Key Novel Features of Learning

Feature	Related Studies	Explanations
Metacognition and Self-Regulation	Järvelä et al., Miconi et al., Hekhand	Integration of metacognitive skills in AI systems, self-directed learning
Multimodal Learning	Gkintoni et al.,Masih et al., Мінцер et al.	Combining EEG with fMRI, ECG, and GSR, using multiple platforms
Real-Time and Adaptive Learning	Gkintoni et al.,Srisuchinnawong et al., Tan et al.	Path adaptation based on real-time data, scalable online learning
Human-Machine Collaborative Learning	Järvelä.et al., Masih et al.	Human-AI co-evolution, collaboration through social media
Emotional and Social Capabilities	Järvelä et al., Masih et al.	Integration of emotional intelligence in AI systems, 32% reduction in classroom anxiety
Transparency and Interpretability	Järvelä et al., Srisuchinnawong et al.	Need for transparency for trust, layered and columnar interpretability

Novel features of learning in 2024-2025 indicate an emphasis on combining multiple dimensions. Multimodal learning using various neurophysiological tools and real-time learning that dynamically adapts paths are among the most important features.

Conceptual Transformations

Table 6. Conceptual Transformations

Transformation	Studies	Description
From Traditional to Technology-Centered	Gkintoni et al.,Masih et al., Nur Amirah.Mohmad Mohmiddin et al.	Integration of CLT with EdNeuro and AI, use of AI and social media
From Independent to Collaborative	Järvelä et.al., Miconi et al.	Human-machine collaboration and mutual reinforcement, combining neuroscience and AI
From Black Box to Interpretable	Srisuchinnawong et al.	Use of interpretive models instead of opaque models
Role of Data and Analytics	Gkintoni et al., Järvelä et al.	Use of neurophysiological data, multimodal analytics

Conceptual transformations indicate a shift from traditional teacher-centered approaches to learner-centered and technology-centered approaches. This transformation includes the integration of various disciplines, including psychology, neuroscience, and computer science, in defining learning.

Practical Implications

Table 7. Conceptual Transformations

Aspect	Findings
Changes in Teaching Methods	Use of AI-based adaptive learning systems, reduced need for human intervention, shift from direct teaching to interactive activities
New Needs for Educators	Continuous training in using AI tools, facilitative role instead of lecturing, awareness of ethical challenges
New Needs for Learners	Digital literacy for interacting with AI content, participation in problem-solving activities
Required Tools	Neurophysiological tools (EEG, fNIRS), social media platforms (Discord, Teams), simulation environments
Implementation Challenges	Ethical challenges and data security, digital inequality (15% reduction in participation among underrepresented students), over-dependence on AI
Potential Benefits	Improved learning efficiency, reduced classroom anxiety, faster and more flexible learning, deeper understanding of content

Practical implications show that implementing new definitions of learning requires fundamental changes in educational infrastructure, educator training, and attention to ethical issues and equity of access.

Discussion

This systematic review of nine selected studies during 2024–2025 reveals a profound and multifaceted transformation in the concept of learning, primarily driven by advances in artificial intelligence. Through thematic analysis—involving iterative coding of extracted data on definitions, frameworks, AI impacts, and novel features—the findings were synthesized into three central themes that capture the dominant emerging paradigm at the intersection of human cognition, machine intelligence, and neurophysiological science.

The core shift involves moving from a static, instructor-led knowledge transfer model to a dynamic, adaptive, and co-regulated process characterized by continuous optimization between the learner's cognitive-affective state and a responsive technological environment. First, learning is increasingly reconceptualized as a hybrid and data-driven process. It transcends isolated human cognition, emerging instead from synergistic human-AI partnerships mediated by multimodal data streams (neurophysiological, behavioral, and interactional). This enables real-time personalization, adaptive cognitive load management, and a redefinition of learning effectiveness based on ongoing alignment rather than final outcomes alone.

Second, the findings underscore the centrality of human-AI synergy and interpretability. While AI offers powerful capabilities for personalization, instantaneous feedback, and analytics, its persistent limitations in contextual comprehension and causal reasoning highlight the enduring necessity of human agency. The ideal model is therefore collaborative intelligence, with AI serving as a regulatory partner in metacognitive and self-regulated processes. This collaboration requires a concurrent shift from opaque "black-box" algorithms to transparent, interpretable systems, allowing educators and learners to understand and negotiate AI-driven recommendations.

Third, the new paradigm carries inherent ethical and practical imperatives. Implementation demands substantial re-skilling of educators for facilitative, technology-literate roles. Although AI-enhanced learning shows promise in reducing anxiety and improving efficiency, these benefits are offset by risks such as widened digital inequality, data privacy violations, and over-reliance on algorithms. Equity of access, robust data governance, and critical AI literacy must thus become foundational elements of educational design and policy.

Despite these convergent themes, the reviewed studies also reveal theoretical tensions. For instance, domains differ in emphasis: robotics and reinforcement learning models prioritize autonomous, reward-based adaptation with minimal human intervention, whereas educational and neuroscientific studies stress collaborative regulation and human-centered oversight. These differences highlight an ongoing debate about the balance between AI autonomy and human control, underscoring the need for integrative frameworks that reconcile domain-specific perspectives.

Several methodological limitations should be acknowledged in this study. The approach in this study prioritizes conceptual rigor and diversity but is limited by the small sample size (9 articles), potential publication bias toward English-language sources, and focus on emerging 2024–2025 literature, which may not fully represent all domains or ongoing developments. Reproducibility is supported by the explicit search strategy, criteria, and independent screening process. Moreover, the final sample comprises only nine articles, constrained by stringent inclusion criteria prioritizing conceptual depth and novelty. This small sample—drawn primarily from English-language sources and major academic databases—may not fully represent the breadth of global research during 2024–2025, potentially introducing selection bias and limiting generalizability. Additionally, the predominance of theoretical, review, and computational studies over large-scale longitudinal empirical work restricts insights into long-term real-world outcomes. Interpretations are thus shaped by the characteristics of the selected studies and should be viewed as indicative rather than exhaustive.

Conclusion

In summary, learning in the AI era is best characterized as a technology-mediated, co-evolutionary process in which human and artificial intelligence collaboratively construct understanding through personalized, data-informed, and interpretable interactions. The integrative framework derived from this review offers a valuable lens for researchers, educational designers, and policymakers.

Future research should prioritize actionable directions, including:

- Experimental designs testing interpretable AI recommendation systems in real university classrooms (e.g., evaluating learner trust and negotiation of suggestions).
- Longitudinal studies examining AI's impact on metacognition and self-regulation among K-12 or higher education students in STEM disciplines.
- Mixed-methods investigations of human-AI collaboration in diverse cultural and socioeconomic contexts to address equity gaps.
- Development and validation of practical tools for educator training in ethical AI integration and transparent learning analytics.

Such efforts will help clarify long-term effects on human development, bridge theoretical tensions across domains, and ensure that AI-driven transformations in learning remain equitable, human-centered, and sustainable.

Conflict of interest

There are no conflicts of interest.

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