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Bridging Pedagogy and Computation: A Theoretical Framework for AI in Educational Systems

Houda BOUMEDIENE[1], Ouafa OUARNIKI[2]
[1]*AILE Laboratory, Amar Telidji University of Laghouat, Algeria*
[2]*SIGMA Laboratory, Ziane Achour University of Djelfa, Algeria*

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ABSTRACT

Introduction

Today the integration of Artificial Intelligence (AI) in education systems is a paradigm shift in in building, delivering, and assessing knowledge. Though many studies address AI applications and implications, their theoretical underpinnings are scattered across disciplines. AI-powered adaptive learning software, intelligent tutoring systems, automated grading, and predictive analytics are being used in educational institutions increasingly, generally without an explanatory theoretical understanding of how these technologies alter learning processes.

Objectives:

This paper synthesizes key theoretical perspectives of constructivism, cognitive load theory, personalized learning, and socio-technical systems theory, to build an integrative framework explaining AI's pedagogical role. It also addresses how AI-backed systems operate and confront learning theories, focusing on the interplay among technological affordances, learner agency, and institutional dynamics.

Methods:

An extensive review of the literature was conducted across learning sciences, cognitive psychology, information systems, and critical theory, including articles published between 2013 and 2025. Adaptive learning systems, intelligent tutoring systems, and AI-based personalisation models are discussed to reveal cognitive processes and implementation implications at individual, social, and institutional levels.

Results:

Five theoretical frameworks were recognized as fundamental: constructivism for AI-enhanced learning environments, cognitive load theory for the design of intelligent systems, connectivism and networked intelligence, adaptive personalization theory, and socio-technical systems theory. Main results suggest that AI can be a cognitive tool, instructional mediator, social agent, and institutional technology, yet a multi-level theoretical appreciation of its educational use is required.

Conclusions:

AI learning needs to be envisioned through a composite theory model that combines cognitive, social, and institutional aspects. The model suggested here focuses on personalized scaffolding, transparent and explainable algorithms, equitable and bias-aware design, and alignment between technological efficacy and genuine learning objectives. The study finally underscores the imperatives of theory-driven innovation where pedagogical theory would inform AI innovation for improving learning without undermining human agency and equity**.**

Keywords: *artificial intelligence, educational theory, personalized learning, cognitive systems, learning analytics, adaptive systems, socio-technical systems, intelligent tutoring*.

INTRODUCTION

The fast-paced development of artificial intelligence (AI) in schools has preceded the theoretical models for understanding its teaching impacts [1]. Educational institutions have increasingly come to depend on AI-based

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technologies, including adaptive learning platforms, smart tutoring systems, computerized assessment, and predictive analytics, yet without a systematic theoretical model to inform their construction and assessment [2]. This disconnection presents challenges for researchers, educators, and policymakers attempting to gauge the real educational effectiveness of AI. Established learning theories, much developed in pre-digital settings, thus need to be reassessed to speak to AI-mediated contexts in which algorithms co-participate with teachers and learners as co-producers of instruction. This shift away from pedagogies centered on the teacher or student to heterodox human–AI partnerships demand novel theoretical underpinnings that cover algorithmic decision-making and pedagogical influence. The latest from education technology insiders' marks how AI continues to redefine personalization, learner engagement, and institutional practice.

AI integration addresses various learning issues, such as learner diversity, cognitive overload, feedback constraints, and teacher workload [3]. Drawing upon adaptive learning model paradigms and cognitive load theory, AI systems adjust instruction, regulate task difficulty, and provide instant feedback to optimize engagement and knowledge retention [6]. The Adaptive Personalization Theory of Learning (APT) captures the innovation by its AI-based learner modeling, adaptive testing, cognitive scaffolding, and ethical safeguarding to create adaptive learning pathways for individuals. There are indeed real concerns, however, in terms of algorithmic bias and explainability behind the demand for fair and interpretable AI systems [1]. This article responds to these challenges by integrating pedagogical, cognitive, and information systems theories to create a theoretical framework that integrates into a coherent foundation for imagining the transformative potential of AI in education. It also focuses on how smarter systems engage with existing learning principles as they create new potential for theory-informed, ethically driven innovation in education.

OBJECTIVES

The main objectives of this study are:

1. To integrate fundamental learning and education theories, such as constructivism, cognitive load, connectivism, and self-regulated learning, to guide the composition of how they holistically influence AI-mediated learning environments.
2. To analyze the pedagogy and ethics of AI personalization and how learner modeling, adaptive algorithms, and socio-cultural contexts shape pedagogy, learner agency, and transparency and bias issues.
3. To integrate these elements into a unified, holistic theoretical framework that combines pedagogical and computational viewpoints, which, by extension, catalyzes the creation of fair, explainable, and future-proof AI systems that incorporate next-generation paradigms like embodied and generative intelligence.

METHODS

This research adopts an extensive theoretical synthesis method that includes a systematic literature review with framework integration across disciplines. There are different, interconnected aspects of the method whose final objective is to build up a robust theory for conceptualizing AI in educational settings.

Literature Choice and Review

The review integrates learning sciences, cognitive psychology, educational technology, information systems, and critical pedagogy literature between 2013 and 2025. Literature curation favors peer-reviewed journal articles, official reports of educational institutions, and classic theory textbooks, creating foundational frameworks. Specific focus is given to recent research from 2024–2025 documenting ongoing progress in AI applications in education and new directions in theory [5][8]. Database searching concentrated on the most significant scholarly repositories: Scopus, Web of Science, and subject-specific educational technology databases. Search terms combined AI-relevant terms (artificial intelligence, machine learning, intelligent tutoring, adaptive systems) with learning theory-related concepts (constructivism, socio-technical systems, cognitive load, personalized learning). The systematic process yielded 69 core articles spanning AI methods, personalized learning concepts, and theoretical models, augmented by classic theoretical papers setting fundamental learning science principles.

Theoretical Framework Integration

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Research Article

The approach incorporates theoretical models at various levels of analysis in acknowledging AI systems as intricate phenomena to be understood in a multi-faceted manner. The cognitive integration considers:

- **Cognitive Level Analysis:** Theoretical explanations of AI influences on individual learning processes, founded on constructivist epistemology, cognitive load theory [13], and models of self-regulated learning. This level considers how AI systems support cognitive processes, deal with working memory limitations, and facilitate metacognitive development.
- **The Social Level Analysis:** Mediation of social interaction and knowledge construction in collaboration from a social learning theory, computers-as-social-actors paradigm, and computer-supported collaborative learning research-based perspective. This phase inquires whether AI systems are good representations of society and to what degree algorithmic mediation contributes to the construction of social knowledge.
- **Institutional Level Analysis:** Analysis of AI adoption problems at organizational- and system-level, based on socio-technical systems theory and technology acceptance models. It meets adoption requirements, organizational change needs, and technical competence with educational purpose.
- **Critical Analysis:** Although critical pedagogy questions of concern critically explore power relations, algorithmic justice [10], and effects of AI instructional technology on equity, this aspect is tasked with the responsibility of ensuring theory models consider social justice issues in addition to the potentialities of reifying injustice.

Synthesis Methodology

This is a step-by-step process:

1. Construct Identification: Systematic identification of the chosen theoretical concepts, propositions, and disciplinary tradition literature constructs.
2. Pattern Analysis: Convergent theme identification, complementary mechanisms, and contradictory claims between theoretical frameworks.
3. Integration Development: Development of integrated frameworks incorporating varied perspectives with theoretical consistency and explanatory power.
4. Principle Derivation: Derivation of concrete design principles and implementation guidelines for AI education systems, from abstract theoretical findings.
5. Gap Analysis: Theoretical gaps, unexplained phenomena, and areas of future theoretical development.

This pluralistic approach enables rigorous theoretical analysis to be undertaken while being pragmatic and flexible enough to handle the rapidly changing AI educational technology context. Synthesis is biased toward theoretically worked-out frameworks but is receptive to new ideas solving new challenges of AI opportunities, not foreseen by conventional learning theory.

RESULTS

The analysis identifies five complementary theoretical perspectives: constructivism, cognitive load theory, connectivism, adaptive personalization, and socio-technical systems theory. In fact, all these theories together provide a comprehensive understanding of AI's pedagogical impact. In addition, each framework contributes to explaining how AI transforms learning processes at the cognitive, social, and institutional levels.

Constructivism and Cognitive Mediation

By constructivist epistemology, AI is both a tool for constructing knowledge and an active contributor to the construction of knowledge. Intelligent tutoring systems realize Vygotsky's zone of proximal development through content difficulty that constantly adjusts and provides feedback [7]. Algorithmic control of the learning path does, however, problematize the agency role and the teacher's correspondingly diminishing role as broker [8]. AI also enables constructionist learning by allowing students to externalize meaning through generative AI tools for rapid prototyping and reflection. These bolster constructivist theory but require ongoing watchfulness regarding the way meaning-making happens in human–AI collaboration.

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Research Article

Cognitive Load Optimization and Metacognitive Support

In Cognitive Load Theory (CLT), AI maximizes learning efficiency via a balance of working memory capacity and control of intrinsic, extraneous, and germane cognitive loads [13]. Adaptive learning environments monitor performance to manage instructional complexity so as not to induce overload and sustain motivation [6]. However, new cognitive challenges also arise due to AI systems, since students need to process algorithmic suggestions and decide on AI-created content. Processes like these emphasize the necessity of theoretical ideas considering the distributed cognitive load among human and AI systems.

Connectivism and Networked Intelligence

Connectivism describes learning as network building and navigation through nodes of knowledge in the online world [12]. AI illustrates this with recommender systems that link learners to suitable content and peers, creating personal intelligence networks far more sophisticated than human capability. But the more AI queries and harvests rich data ecologies automatically, the less the distinction between algorithmic pattern-matching and human sense-making can be maintained. This conflict calls for a new examination of how knowledge harvesting by AI enhances or degrades true learning and intellectual diversity.

Adaptive Personalization and Learner Modeling

AI applies personalized learning theory via iteratively updating learner models and data-driven adaptation. The Adaptive Personalization Theory of Learning (APT) advocates for this shift using real-time feedback, tracking engagement, and cognitive scaffolding [2]. Machine learning enables aptitude–treatment interaction, instructional style correspondence with learner profiles, and generates differentiated recommendations that improve over time. Algorithmic black boxing constrains interpretability, however, and teachers cannot readily see behind how or why adaptive decisions are being made. Balancing pedagogic autonomy and predictive precision is a key theoretical and moral dilemma [14].

Self-Regulation and Learner Agency

From the self-regulated learning perspective, AI systems facilitate metacognition through analytics dashboards and feedback mechanisms that assist learners in planning, monitoring, and self-assessing [11]. Excessive dependence on algorithmic cues, however, might close off self-regulatory agency. Future designs need to clarify how AI scaffolding can initiate, not substitute, learner agency, progressively relinquishing control with growing mastery.

Sociocultural and Critical Dimensions

AI systems increasingly operate as social actors in the form of conversational interfaces, embodied agents, and collaborative robots aligned with social learning theory and the computers-as-social-actors paradigm. From a critical pedagogy perspective, however, these systems contain power relationships, bias, and neoliberal values prioritizing efficiency over humanistic learning [10][15]. Machine learning algorithms capture algorithmic bias rooted in historical data that perpetuates disparities on the basis of race, gender, or socioeconomic status. Thus, theoretical reflections have to embody equity, and social justice concerns right from the start so that personalization brings more opportunity and not marginalization.

Socio-Technical and Institutional Views

Both AI adoption and success in education rely on technological design as well as organizational alignment. The Unified "Theory of Acceptance and Use of Technology (UTAUT) " outlines performance expectancy, effort expectancy, social influence, and facilitating conditions as fundamental drivers of uptake that now need to be supplemented by trust, transparency, and algorithmic fairness [4]. Likewise, socio-technical systems theory points out that schools need to coordinate social subsystems (teachers, students, administrators, policymakers) and technical subsystems (algorithms, data infrastructure, interfaces) at the same time in order to exert meaningful impact [14]. Effective AI integration demands a balance of pedagogical purpose and technological capability.

Towards an Integrated Theoretical Framework

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Synthesizing the lessons of the above approaches, the research imagines an integrated framework that considers AI as cognitive, social, and institutional technology. At the cognitive plane, AI supports learning and cognitive load management; at the social plane, it supports collaboration and participation; and at the institutional plane, it supports organizational change and policy reform.

Out of this union emerge several theory-based design principles for AI systems:

- Explainability and transparency to enable calibrated trust;
- Adaptive scaffolding calibrated to learners' zones of proximal development;
- Preserving human agency in automated systems;
- Equity-sensitive design reducing bias; and
- Pedagogical alignment to ensure that optimization measures serve to support real learning goals.

DISCUSSION

The synthesis reveals both convergence and tension across the frameworks addressing AI's role in education. First, constructivist and cognitive theories both think that AI can act like a helpful tool that gets you to build your own knowledge while keeping things from getting too overwhelming. Also, systems like smart tutoring systems try to find a sweet spot between letting you learn on your own and giving you help from a program. Most importantly, finding that balance brings up questions like: Are we relying on these things too much? Are we losing our own ability to think for ourselves? Plus, when you mix ideas about connecting with others and making learning personal, you see that AI has this interesting ability to put together learning info from all over the place while still teaching each person in a way that fits them. This is both great and potentially not so great: pooling knowledge can make learning accessible to everyone, but if things become too standardized, we might lose unique ways of learning. Additionally, sociocultural and critical approaches enhance the discussion by repositioning AI not as a tool but as a socio-technical artifact with embedded values, biases, and power relations. Leading among findings of algorithmic bias summon equity-centered design and theoretical frameworks with justice, inclusivity, and transparency incorporated from the outset. Basically, AI's capacity to expand personalized learning must be weighed against its potential to amplify structural inequities if not ethically governed.

From an information system's viewpoint, successful educational AI adoption depends not only on robust design but also on teacher acceptance, institutional readiness, and alignment with pedagogical missions. The socio-technical systems approach confirms that human and technological subsystems must be coordinated so that educational effects are derived from their mutual optimization rather than technological innovation per se. The literature on generative AI introduces a new twist into the argument. Multimodal and large language models increasingly engage with creative, discursive, and affective aspects of learning, forcing classical claims of human cognitive exclusivity to be reevaluated. Large Language Models (LLMs) also develop constructivist and socio-technical principles by functioning as dialogical co-builders of knowledge, encouraging exploration and thought through mutual dialogue. However, on a constructivist basis, they are adaptive scaffolding that foster learner agency, yet on a socio-technical basis, they are the intermingling of human cognition and algorithmic intelligence in mutual networks of sense-making. Theory reflection should therefore be capable of making distinctions between AI as co-creator, facilitating creativity and higher-order thinking, and AI as surrogate, one which threatens to undo learner autonomy and critical thinking.

Theoretical development soon needs to investigate embodied and affective AI in the service of emotional interaction, collective intelligence from large-scale learner data, lifelong learning environments that combine formal and informal learning, and pedagogy enriched by reframing teacher competencies for human–AI interaction. Empirical testing is still important: longitudinal studies need to investigate how AI shapes learning processes, cognitive development, and institution-wide practices over time. Briefly put, while AI brings with it the unprecedented possibilities of personalizing, scaling, and humanizing learning, its success hangs in the balance—on the one hand between innovation and ethics, automation and autonomy, efficiency and equity. Only by theoretically informed, empirically tested, and ethically sound models can AI realize its innovative potential in learning.

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CONCLUSIONS

This way of analysis gives important highlights on how AI is changing education. It uses ideas from different learning theories like constructivism, cognitive, sociocultural, critical, and information systems. The whole idea sees AI as a thing with many parts. It's like a thinking helper, a way to connect with others, and a tool in schools. This gives us one clear way to see how it changes teaching and the whole education system. Five interconnected perspectives are revealed: constructivism in AI-facilitated learning, cognitive load optimization system design, connectivism and networked intelligence, adaptive personalization, and socio-technical systems theory. Together, they call out the promise of AI to transform teaching practices and raise issues of autonomy, transparency, and equity. From such a confluence arises necessary design principles: transparency and explainability to build trustworthiness and accountability, adaptive scaffolding to support learners' growth, safeguarding human agency, equity-based design, and close alignment between pedagogical intent and technology deployment.

Theory construction in the coming years must be kept abreast of AI advances so that the philosophy of education advances, and does not fall behind, technological development. Construction of new paradigms on the basis of breakthrough concepts like embodied and generative AI, collective intelligence, and systems of lifelong learning will be essential. In short, ongoing empirical research and theory construction should be complementary for AI to emerge as a powerful vehicle for inclusive, human-centered, and pedagogically oriented education.

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