



Innovation in Teacher Education in the Artificial Intelligence Era: Reimagining Pedagogical Preparation through Adaptive Technologies and Ethical Governance

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DOI: <https://doi.org/10.5281/zenodo.22900609>

Abstract

Artificial intelligence (AI) is transforming teaching, learning, and educational decision-making, yet many teacher education programs remain insufficiently prepared to develop the knowledge, skills, and ethical judgment required in AI-enabled classrooms.

This conceptual paper reimagines pedagogical preparation as a human-centered, adaptive, and ethically governed process. It examines how adaptive learning platforms, intelligent tutoring systems, learning analytics, generative AI, and simulation environments can personalize teacher candidates' learning, strengthen reflective practice, and enhance their capacity to design inclusive and responsive instruction. The paper proposes an integrated framework combining AI literacy, pedagogical content knowledge, data literacy, critical digital competence, and professional judgment. It argues that innovation should not be evaluated solely through technological adoption, but through its contribution to teacher agency, educational equity, learner well-being, and instructional quality. Ethical governance is positioned as foundational, with particular emphasis on transparency, privacy, accountability, bias mitigation, accessibility, academic integrity, and meaningful human oversight. The discussion further identifies essential institutional conditions, including faculty development, adequate digital infrastructure, participatory policy design, and continuous evaluation. By connecting adaptive technologies with ethical and pedagogical principles, the paper offers a roadmap for preparing teachers to use AI critically, creatively, and responsibly while preserving the relational and human core of education.

Objectives: The study examines transformative innovations emerging at the intersection of artificial intelligence and teacher education, identifies systemic opportunities and ethical challenges accompanying these technologies, and proposes a conceptual framework for their sustainable integration within pre-service and in-service teacher preparation programs.

Methods: A qualitative document analysis methodology was employed to systematically review 65 peer-reviewed empirical studies, policy documents, and institutional reports published between 2018 and 2025. Data were analyzed using reflexive thematic analysis to identify recurrent patterns regarding AI adoption, pedagogical transformation, and structural barriers across diverse geographical and institutional contexts.



Results: The findings indicate that AI innovations, including adaptive learning platforms, intelligent tutoring systems, generative AI conversational agents, and immersive virtual reality simulations, are fundamentally altering the landscape of teacher preparation. While these technologies afford personalized learning pathways, enhanced formative assessment capabilities, and expanded access to clinical teaching experiences, significant challenges persist concerning data privacy, algorithmic bias, digital inequity, and faculty resistance to pedagogical change.

Conclusions: To harness the transformative potential of AI in teacher education, stakeholders must adopt an ethics-centered, equity-driven framework that prioritizes critical digital literacy, continuous professional development, and participatory governance structures. The study recommends the mandatory integration of AI-literacy competencies into teacher education curricula and the adoption of human-in-the-loop pedagogical models that position AI as a complement to, rather than a replacement for, the relational dimensions of teaching.

Keywords: Artificial Intelligence; Teacher education; pre-service training; Digital pedagogy; Algorithmic ethics

Introduction

Artificial intelligence has emerged as one of the most disruptive forces reshaping professional practice across the twenty-first century (Holmes, Bialik, & Fadel, 2019; Luckin, 2016). Within education, AI applications have shifted from peripheral administrative tools to central features of pedagogical strategy, a trend accelerated by the public release of large language models and generative AI applications in 2022 (Chiu, 2023; Trust, Whalen, & Mouza, 2023). Despite this momentum, the scholarly discourse has concentrated overwhelmingly on AI as a tool for student learning rather than on the foundational preparation of teachers who must deploy these technologies ethically and effectively (Zawacki-Richter, Marín, Bond, & Gouverneur, 2019). This imbalance represents a critical gap because teacher education institutions bear primary responsibility for cultivating the pedagogical judgment, subject-matter expertise, and ethical dispositions required for professional practice (Darling-Hammond, Hyler, & Gardner, 2017).

Historically, teacher preparation programs have been critiqued for sluggish responsiveness to technological innovation, often adopting a reactive rather than proactive stance toward emerging digital practices (Tondeur, van Braak, Ertmer, & Ottenbreit-Leftwich, 2017). The traditional architecture of teacher preparation, built upon transmission-oriented coursework and standardized clinical experiences, now confronts a profound challenge. AI technologies are not merely augmenting existing educational tools; they are introducing new epistemological possibilities, automating evaluative functions previously considered uniquely human, and generating novel ethical dilemmas that demand sophisticated professional reasoning (Selwyn, 2016). Consequently, the gap between the technological realities of contemporary classrooms and the preparatory experiences offered within teacher education programs has widened into a chasm that threatens the professional relevance of graduating teachers (Seufert, Guggemos, & Sailer, 2021).



The implications of this disjuncture are particularly acute within contexts characterized by infrastructural constraints, including many institutions across Sub-Saharan Africa and the global South. In Nigeria, for instance, where basic digital connectivity remains unevenly distributed and educational funding is severely constrained, the integration of AI into teacher education might appear a distant luxury. However, such a view risks consigning Nigerian educators and their students to peripheral positions within global knowledge economies (Zhao & Frank, 2003). Moreover, as multinational technology corporations and international development agencies increasingly promote AI-driven educational solutions across African markets, local teacher educators must possess the critical literacies necessary to evaluate, adapt, and govern these technologies within culturally resonant pedagogical frameworks. The stakes, therefore, are not merely technological but deeply political and epistemological.

Against this backdrop, the present study is guided by three interrelated research questions:

1. What specific AI innovations are currently reshaping the landscape of teacher education globally?
2. What opportunities and challenges accompany the integration of AI within pre-service and in-service teacher training programs?
3. What conceptual framework can guide the sustainable, ethically grounded integration of AI into teacher education curricula across diverse institutional contexts?

By addressing these questions, the study seeks to contribute a theoretically informed, critically oriented analysis that moves beyond instrumentalist celebrations of educational technology to consider the structural, ethical, and pedagogical conditions necessary for transformative integration. The significance of this inquiry lies in its potential to inform policy deliberation, curriculum redesign, and professional development architectures within teacher education institutions striving to navigate the complexities of the AI era.

Literature Review

Historical and Theoretical Foundations

The relationship between educational technology and teacher preparation has long been characterized by cycles of enthusiasm, partial adoption, and tempered disappointment. From the introduction of radio and television broadcasts in the mid-twentieth century to the proliferation of computer-assisted instruction in the 1980s and the embrace of virtual learning environments in the early twenty-first century, each technological wave has generated predictions of revolutionary change that have rarely materialized in full (Cuban, 1986, 2001). Cuban famously documented this pattern, arguing that teachers have consistently adapted new technologies to existing pedagogical routines rather than transforming their practice in response to technological affordances. Within teacher education specifically, this pattern has manifested in the tendency to treat technology as an add-on component rather than an integral dimension of pedagogical reasoning (Mishra & Koehler, 2006).



The emergence of more integrative theoretical models marked a significant advancement in conceptualizing technology within teacher education. The Technological Pedagogical Content Knowledge (TPACK) framework, developed by Mishra and Koehler (2006), represented a paradigmatic shift by arguing that effective technology integration requires the dynamic interplay of technological knowledge, pedagogical knowledge, and content knowledge. This framework has profoundly influenced teacher education curricula worldwide, prompting programs to attend to the contextual, relational nature of technology-mediated teaching (Grossman, 2018). Nevertheless, the TPACK framework predated the contemporary AI revolution and was developed in reference to relatively stable digital tools such as learning management systems, multimedia presentations, and web-based resources. The autonomous, adaptive, and often opaque characteristics of contemporary AI systems introduce qualitatively different challenges that demand an extension or reconceptualization of existing theoretical architectures (Chiu, 2023).

Contemporary AI Innovations in Teacher Preparation

Recent literature reveals a rapidly expanding array of AI applications specifically targeting the domain of teacher education. Intelligent tutoring systems (ITS), once deployed almost exclusively for student learning in domains such as mathematics and language acquisition, are now being adapted to support pre-service teachers' pedagogical reasoning (Zawacki-Richter et al., 2019). These systems can simulate student responses to instructional strategies, providing novice teachers with low-stakes environments in which to practice questioning techniques, error diagnosis, and adaptive instruction. Complementing these developments, immersive virtual reality (VR) and mixed-reality simulations, exemplified by platforms such as Teach LivE and Mursion, have gained substantial traction within teacher education research (Holmes et al., 2019). Such environments allow pre-service teachers to engage in repeated clinical rehearsals with artificially generated student avatars, receiving immediate feedback on their classroom management, discourse moves, and content representations without the ethical and logistical complexities of practicing on actual school pupils.

Adaptive learning platforms represent another significant frontier. Unlike earlier digital resources that presented static content to all users, AI-driven adaptive systems analyze pre-service teachers' interaction patterns, assessment performances, and self-reported confidence levels to personalize learning pathways through complex pedagogical content (Luckin, 2016). For instance, a teacher candidate struggling with formative assessment strategies might be automatically directed to targeted micro-learning modules, simulated classroom scenarios, and reflective prompts calibrated to their specific developmental needs. Furthermore, learning analytics dashboards are increasingly being integrated into teacher education programs to visualize pre-service teachers' engagement trajectories, collaborative interaction patterns, and competency development over time, thereby enabling more data-informed mentoring and program evaluation (Williamson & Eynon, 2020).

The advent of generative AI, particularly large language models, has introduced perhaps the most immediately disruptive set of innovations. Pre-service teachers now utilize conversational AI agents to generate lesson plan drafts, differentiate instructional materials for diverse learners, produce formative assessment items, and receive feedback on their written reflections (Trust et



al., 2023). These capabilities have democratized access to instructional design expertise while simultaneously raising profound questions about originality, pedagogical ownership, and the development of professional judgment. Recent policy documents from UNESCO (2023) have acknowledged both the transformative potential and the significant risks of generative AI in education, urging institutions to develop governance frameworks that harness these tools without undermining the development of autonomous professional capability.

Critical Perspectives and Ethical Challenges

Alongside instrumentalist accounts of AI in teacher education, a robust critical literature has emerged warning against the unexamined adoption of algorithmic systems within educational contexts. Selwyn (2016, 2010) has consistently argued that educational technologies are never politically neutral; rather, they embed particular assumptions about knowledge, learning, and social order that privilege certain groups while marginalizing others. Applied to teacher education, this critical lens illuminates the ways in which AI systems developed within specific cultural and linguistic contexts, predominantly North American, European, and East Asian, may propagate normative pedagogical models that conflict with local educational traditions and epistemologies.

The issue of algorithmic bias constitutes a particularly pressing concern. AI systems trained on historical educational data may replicate and amplify existing patterns of inequality related to race, gender, socioeconomic status, and linguistic background (Williamson & Eynon, 2020). When such systems are deployed within teacher education, for example to evaluate teaching simulations or recommend learning resources, they risk encoding discriminatory standards of “effective teaching” that disadvantage minority teacher candidates or devalue culturally responsive pedagogies. Moreover, the data-intensive nature of AI applications raises significant privacy and surveillance concerns. The continuous monitoring of pre-service teachers’ digital interactions, biometric responses within simulations, and competency metrics generates vast repositories of personal data that may be exploited by commercial vendors or state agencies in ways that compromise academic freedom and professional autonomy (Selwyn, 2016).

Williamson and Eynon (2020) have further cautioned that the rhetoric of AI-driven personalization in education often masks a deeper tendency toward the automation and standardization of professional practice. Within teacher education, there is a tangible risk that AI systems designed to streamline assessment, provide standardized feedback, and ensure uniform competency benchmarks may inadvertently erode the improvisational, relational, and contextually sensitive dimensions of teaching that constitute the core of professional expertise. The deskilling of teacher educators, who may come to rely upon algorithmic recommendations rather than exercising their own pedagogical judgment, represents a subtle but consequential long-term risk. These critical perspectives underscore the imperative that AI integration in teacher education be governed by robust ethical frameworks that prioritize human dignity, professional agency, and social justice over operational efficiency and technological spectacle.



Theoretical Framework

The integration of artificial intelligence into teacher education demands a theoretical architecture capable of accommodating technologies that are not merely instrumental but generative, adaptive, and epistemologically disruptive. The original TPACK framework remains indispensable for understanding how teachers negotiate relationships among content knowledge, pedagogical knowledge, and technological knowledge (Mishra & Koehler, 2006). Yet TPACK was theorized during an era of relatively stable digital tools whose operations were transparent and whose outputs were deterministic. Contemporary AI systems differ qualitatively: they are probabilistic, opaque in their decision-making, capable of autonomous content generation, and trained on corpora that embed specific cultural and historical biases. These characteristics mean that AI does not simply intersect with content and pedagogy; it reconfigures what counts as knowledge, redistributes cognitive labor between human and machine, and introduces ethical dilemmas that existing TPACK intersections cannot adequately capture. Consequently, this study mobilizes an integrated framework that extends TPACK through AI literacy while embedding both within a sociotechnical ecology that treats teacher education as a complex system rather than a collection of individual practitioners.

The Extended AI-TPACK Architecture

The first pillar of the framework extends TPACK by installing AI literacy as a meta-competency that undergirds all technological, pedagogical, and content interactions. Drawing upon Ng et al. (2021), AI literacy is operationalized across four interrelated dimensions, each adapted here to the specific context of teacher preparation. Conceptual understanding refers not merely to surface-level awareness of machine learning or neural networks, but to a situated grasp of how AI systems produce probabilistic outputs, the role of training data in shaping recommendations, and the phenomenon of algorithmic hallucination. For teacher candidates, this means recognizing that an intelligent tutoring system's feedback on their simulated teaching is statistically generated rather than pedagogically ordained, and therefore subject to error. Functional competence denotes the ability to operate AI tools for professional purposes, including generating differentiated materials, analyzing learning analytics, and navigating simulated classrooms, but insists that such competence is always pedagogically situated rather than technically abstract. A teacher candidate must learn to use generative AI not as a generic user, but as a curriculum-maker who evaluates output against disciplinary accuracy and developmental appropriateness.

Critical evaluation constitutes the third dimension, requiring teacher candidates to interrogate the ethical, social, and political implications of AI deployment in educational settings. This dimension directly addresses algorithmic bias, data privacy, and the commodification of teaching by cultivating capacities for skepticism and ethical reasoning. Finally, design thinking and creative innovation position teacher candidates not as passive consumers of AI tools but as active designers of human-AI pedagogical collaborations. This dimension emphasizes the ability to imagine novel instructional configurations that leverage AI affordances while preserving the relational and improvisational core of teaching.



The second pillar reconceptualizes the intersections of TPACK for an AI-mediated environment. AI-Content Knowledge (AI-CK) involves understanding how AI transforms disciplinary knowledge representation, such as the ways generative AI reconfigures writing instruction or mathematical problem-solving. AI-Pedagogical Knowledge (AI-PK) concerns the use of adaptive systems to differentiate instruction, provide automated feedback, and manage classroom dynamics. AI-TPACK represents the pinnacle of this architecture: the capacity to make contextually grounded decisions about when AI enhances, hinders, or fundamentally alters learning objectives, and when human judgment must supersede algorithmic recommendation.

Sociotechnical Ecological Dimension

The third pillar embeds the AI-TPACK architecture within a sociotechnical ecology that recognizes teacher education as a complex system nested within institutional, cultural, and political environments (Bronfenbrenner, 1979; Zhao & Frank, 2003). This ecological perspective holds that AI integration cannot succeed through individual teacher educator initiative alone; rather, it requires aligned infrastructure, policy support, professional learning communities, and governance structures. At the microsystem level, individual programs must provide access to devices, platforms, and mentoring. At the mesosystem level, partnerships between universities and school districts must ensure that AI-enhanced preparation translates into classroom practice. At the macrosystem level, national policies and accreditation standards must mandate AI literacy while protecting against surveillance capitalism and digital colonialism. This ecological dimension ensures that the framework does not collapse into individualistic skill-building but instead targets systemic transformation.

Methodology

Research Design

This study employed a qualitative document analysis (QDA) methodology to systematically examine the landscape of AI in teacher education. QDA is an established qualitative method for interrogating written materials, including scholarly articles, policy documents, and institutional reports, to derive empirical meaning and identify patterned phenomena (Bowen, 2009). This approach was selected because it allows for rigorous analysis of publicly available texts without the ethical complexities of human subjects research, while nevertheless generating theoretically rich insights into emerging educational trends.

Data Sources and Selection Criteria

The corpus comprised 65 peer-reviewed empirical studies, policy documents, and institutional reports published between 2018 and 2025. Documents were sourced through systematic searches of ERIC, Web of Science, Scopus, and Google Scholar using combinations of the following search terms: artificial intelligence, teacher education, pre-service teacher, intelligent tutoring systems, generative AI, adaptive learning, teacher preparation, and algorithmic ethics. Inclusion criteria required that documents (a) addressed AI applications or implications specifically within pre-service or in-service teacher education, (b) were published in English, and (c) offered empirical, conceptual, or policy-oriented analysis rather than purely promotional or commercial content. Exclusion criteria eliminated documents focused exclusively on K-12 student learning



without reference to teacher preparation, as well as non-peer-reviewed blog posts and news articles lacking analytical depth.

Data Analysis

Data were analyzed using reflexive thematic analysis following Braun and Clarke (2006, 2019). This six-phase approach involves familiarization with the data, generation of initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final analysis. The researcher engaged in iterative reading of the full document set, maintaining an analytic journal to track interpretive decisions, reflexive positionings, and emergent patterns. Particular attention was paid to tensions between instrumentalist and critical accounts of AI in teacher education, as well as to geographical disparities in AI adoption. Trustworthiness was supported through prolonged engagement with the data, peer debriefing with colleagues in educational technology, and maintenance of a detailed audit trail.

Results

The analysis generated four overarching themes that map onto the research objectives: (1) the proliferation of adaptive and immersive simulation technologies; (2) generative AI as a disruptive instructional design resource; (3) structural and ethical barriers to equitable implementation; and (4) emergent governance frameworks and policy responses.

Proliferation of Adaptive and Immersive Simulation Technologies

The most frequently documented innovations across the corpus involved adaptive learning platforms, intelligent tutoring systems, and immersive VR simulations. These technologies were consistently reported to expand pre-service teachers' access to repeated, low-stakes clinical practice. For example, multiple studies documented that VR simulations such as Mursion and TeachLive enabled candidates to rehearse classroom management strategies with diverse student avatars, thereby developing procedural fluency before entering live classrooms. Similarly, adaptive platforms were found to personalize coursework trajectories based on real-time performance data, allowing teacher candidates to focus on specific pedagogical skills such as formative assessment or differentiated instruction. Nevertheless, the corpus revealed significant variability in implementation quality, with well-resourced institutions leveraging these tools for transformative practice while under-resourced programs struggled with basic access and technical support.

Generative AI as a Disruptive Instructional Design Resource

Generative AI emerged as the most rapidly expanding and contested theme within the recent literature. Documents published after 2022 documented widespread experimentation with large language models for lesson planning, rubric generation, and reflective writing support. Teacher candidates reported that these tools democratized access to instructional design expertise, particularly for those in rural or internationally isolated contexts. However, a parallel stream of scholarship raised alarms regarding plagiarism, cognitive offloading, and the erosion of professional judgment. Several studies noted that candidates who relied heavily on generative AI for lesson planning often produced technically proficient but pedagogically thin artifacts,



suggesting that functional competence without critical evaluation undermines preparation quality.

Structural and Ethical Barriers

Across geographical contexts, the data consistently identified structural barriers including inadequate digital infrastructure, faculty resistance, and misalignment between AI tools and accreditation standards. Ethical barriers were equally prominent. Algorithmic bias was documented in several studies where AI-powered evaluation systems disproportionately flagged non-native English speech patterns or culturally specific discourse norms as “ineffective teaching.” Data privacy concerns intensified as platforms collected biometric and interaction data from pre-service teachers without transparent governance protocols. These findings suggest that AI integration in teacher education is not merely a technical challenge but a deeply ethical and political one.

Emergent Governance Frameworks and Policy Responses

The final theme identified a nascent but growing body of policy and institutional responses aimed at governing AI in teacher education. UNESCO’s (2023) guidance figured prominently, alongside national initiatives in Finland, Singapore, and South Korea that embed AI literacy within teacher accreditation standards. Notably absent from the corpus were governance models tailored to the infrastructural and linguistic realities of Sub-Saharan Africa and South Asia. This gap underscores the need for context-sensitive policy architectures that prioritize local pedagogical values over the wholesale importation of Northern technological solutions.

Discussion

The findings of this study confirm that AI is no longer a peripheral concern for teacher education but a central force reshaping curriculum, pedagogy, and professional identity. The extended AI-TPACK framework proposed here offers a theoretically grounded mechanism for navigating this transformation without surrendering to technological determinism. By positioning AI literacy as a meta-competency, the framework insists that teacher candidates must understand not only how to use AI but how AI functions, how it fails, and how it encodes particular worldviews (Ng et al., 2021). This moves beyond the tool-training orientation that has historically dominated technology integration in teacher preparation (Cuban, 2001; Mishra & Koehler, 2006).

The sociotechnical ecological dimension is equally vital. The finding that AI adoption varies sharply across institutional and national contexts aligns with Zhao and Frank’s (2003) ecological perspective on educational technology, which emphasizes that innovation succeeds only when technological, pedagogical, and organizational conditions align. In the context of this study, that alignment is missing in many programs, particularly those in under-resourced settings. Consequently, recommending AI integration without simultaneously addressing infrastructure, funding, and faculty development constitutes a hollow gesture that risks exacerbating existing inequities (Selwyn, 2016).



The ethical challenges documented here, algorithmic bias, data surveillance, and deskilling, demand governance structures that are participatory and context-responsive. A human-in-the-loop pedagogical model, as recommended in the conclusions below, does not simply mean retaining human oversight as a procedural check. Rather, it requires institutionalizing teacher educator judgment as the primary evaluative authority while deploying AI to augment rather than replace relational practice (Williamson & Eynon, 2020). This distinction is crucial for protecting the improvisational expertise that defines excellent teaching.

Finally, the geographical unevenness of AI governance frameworks identified in the results signals an urgent need for Southern epistemologies in teacher education technology policy. As multinational corporations market AI solutions across African and Asian markets, local teacher educators must possess the critical literacies to evaluate these tools against culturally resonant pedagogical standards. The framework advanced here is offered as a contribution to that project: it is not a universal blueprint but a flexible architecture that institutions can adapt to their specific ecological conditions.

Conclusion

This study has argued that the AI era demands a fundamental reimagining of teacher education, one that transcends both technophobic resistance and uncritical techno-optimism.

Through systematic analysis of contemporary literature, the study identified adaptive simulations, generative AI, and learning analytics as transformative innovations currently reshaping teacher preparation. Simultaneously, it documented profound risks related to algorithmic bias, data privacy, digital inequity, and the deskilling of professional judgment. To navigate this terrain, the study proposed an extended AI-TPACK framework embedded within a sociotechnical ecology, foregrounding AI literacy, ethical reasoning, and systemic alignment as foundational pillars.

Three concrete recommendations follow from this analysis. First, accreditation bodies and program leaders should mandate the integration of AI-literacy competencies across all teacher preparation curricula, ensuring that candidates graduate with conceptual understanding, functional competence, critical evaluation skills, and design thinking capacities. Second, institutions should adopt human-in-the-loop pedagogical models that position AI as a complement to, rather than replacement for, the relational dimensions of teaching. Third, policymakers must develop participatory governance structures that include teacher educators, candidates, and community stakeholders in decisions about AI procurement, data management, and ethical oversight. Only through such deliberate, equity-centered action can teacher education fulfill its obligation to prepare educators for an algorithmically mediated society without sacrificing the human core of the profession.



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