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Revisiting Teacher Cognition in the Digital Age: Intersections of Belief, Technology, and System Design

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Abstract
The rapid integration of digital technologies into education has profoundly transformed not only instructional practices but also the cognitive landscape of teaching. This integrative review revisits the concept of teacher cognition—encompassing beliefs, knowledge, and decision-making—within the context of AI-enhanced and system-driven educational environments. Drawing from educational research and systems design, the article explores how digital platforms, learning analytics, and algorithmic tools influence how teachers process information, make pedagogical decisions, and construct professional identities.
Key themes such as digital literacy, cognitive dissonance, adaptive expertise, and system usability are examined, alongside the often-overlooked impact of technological architecture on cognitive load and teacher agency. By integrating perspectives from human-computer interaction (HCI) and educational theory, this review emphasizes the need for interdisciplinary approaches in both teacher education and technological tool development. The article concludes with a call to action for the co-design of cognitively aligned technologies that empower—rather than constrain—teachers as critical decision-makers in digitally mediated classrooms.

Keywords: Teacher Cognition, Digital Education, System Design, Educational Technology, AI in Education, Cognitive Load, Human-Computer Interaction

Introduction

Teaching is not merely about delivering curricula or managing classrooms—it is, at its core, a cognitive activity. What teachers know, believe, and think profoundly influences how they plan lessons, interact with students, and respond to new instructional demands. These mental constructs, broadly defined as teacher cognition, form the foundation of educational decision-making. Borg (2003) [6] described teacher cognition as "the unobservable cognitive dimension of teaching—what teachers know, believe, and think." Over the past two decades, this concept has attracted increasing scholarly attention, with research consistently showing that teachers' beliefs and knowledge are strong predictors of their instructional practices (Fives & Buehl, 2012; Pajares, 1992) [18].

Concurrently, education systems across the globe are undergoing rapid digital transformation. Technologies such as interactive whiteboards, learning management systems, mobile applications, artificial intelligence, and virtual learning environments are no longer supplementary—they are integral to contemporary classrooms. This shift has not only changed how content is delivered but also how teachers and students interact with knowledge and learning. For many educators, it has unlocked new possibilities for creativity, accessibility, and student-centered instruction (Voogt, Fisser, Good, Mishra, & Yadav, 2015) [31]. Yet, it has also introduced significant challenges, requiring teachers to rethink their professional roles, acquire new digital competencies, and reconcile established pedagogical beliefs with rapidly evolving technological expectations (Howard, Chan, & Caputi, 2015).

The intersection of teacher cognition and digital education is particularly complex. Research shows that the mere introduction of technology into classrooms does not guarantee meaningful integration or improved learning outcomes. What matters most is how teachers perceive and respond to technology. According to Ertmer and Ottenbreit-Leftwich (2010), teachers' beliefs about the value and usability of digital tools significantly influence whether those tools are embraced or rejected. Educators who perceive technology as aligned with their instructional goals tend to innovate, while those who view it as burdensome or incompatible with their teaching philosophy often resist its use—even when institutional mandates encourage or require it.

Moreover, the digital age has introduced new cognitive demands. Today's teachers must manage complex digital ecosystems, interpret real-time data from learning platforms, and sustain engagement across both physical and virtual learning spaces. These are not merely technical challenges—they are cognitive ones, requiring flexible thinking, reflective decision-making, and continuous professional learning (Koehler & Mishra, 2009) [15].

Understanding how teacher cognition evolves in response to digital transformation is essential for the development of effective teacher education and professional development strategies. As educational technologies continue to advance, so too must our understanding of the cognitive frameworks that shape teachers' instructional choices. This article aims to explore how the digital age is reshaping teacher cognition, focusing on beliefs, knowledge structures, and decision-making processes. By synthesizing recent research, it seeks to illuminate the opportunities and tensions teachers navigate within this shifting educational landscape.

Methodologically, this article employs an integrative literature review to synthesize diverse perspectives from education and computer systems design. It draws on peer-reviewed journal articles, theoretical models, and interdisciplinary research in teacher cognition, educational technology, human-computer interaction (HCI), and artificial intelligence in education. Rather than analyzing empirical data, this review constructs a conceptual framework that maps the cognitive, pedagogical, and technical dimensions shaping teacher experience in digitally mediated environments. This approach allows for the identification of emergent themes, contradictions, and design opportunities at the intersection of cognition and system architecture.

Theoretical foundations of teacher cognition

The study of teacher cognition emerged as a response to earlier behaviorist models that focused solely on teachers' observable behaviors, largely ignoring the mental processes behind those actions. Beginning in the 1970s and 1980s, influenced by advances in cognitive psychology, researchers shifted their attention to the internal world of teachers—what they know, believe, and think—and how these internal processes shape their classroom practices (Clark & Peterson, 1986) [9]. This marked a pivotal shift in educational research, recognizing teachers as complex decision-makers with rich cognitive lives rather than just performers of prescribed behaviors.

Borg's (2003) influential framework remains foundational today, defining teacher cognition as a broad umbrella encompassing beliefs, knowledge, attitudes, assumptions, images, metaphors, and perspectives that teachers hold about their work. Importantly, these cognitive constructs are not fixed. They evolve through personal experiences, formal education, the culture of the school, and the daily realities teachers face in classrooms. Borg emphasized that teacher cognition and classroom practice are interdependent—teachers' thoughts shape their actions, which in turn feed back into their cognition in a dynamic cycle.

Research in traditional face-to-face classrooms has consistently shown that deeply held personal beliefs often guide instructional decisions, sometimes even overriding evidence-based teaching strategies (Pajares, 1992; Richardson, 1996) [18]. This illustrates why changing teaching practices can be so challenging: cognitive frameworks are resistant to change because they are intertwined with a teacher's identity and experience (Kagan, 1992). Understanding these mental models is therefore essential to any effort aimed at improving teaching quality.

With the rapid rise of digital technologies in education, this foundational understanding of teacher cognition is being revisited and expanded. New technologies require teachers to rethink their pedagogical approaches, assessment methods, and modes of classroom interaction. The cognitive demands now include mastering online platforms, integrating multimedia content, managing virtual classrooms, and interpreting data from digital assessments (Koehler & Mishra, 2009) [15]. These challenges are reshaping the very definition of teacher competence in the 21st century.

The integration of digital tools also highlights new tensions. Teachers must negotiate between their established beliefs about teaching and the often unfamiliar requirements of technology-enhanced learning environments. As Ertmer (1999) argued, "first-order barriers" such as access to technology can be overcome, but "second-order barriers" related to teachers' beliefs and attitudes are much harder to change. This complexity underscores the need for professional development that addresses both skills and underlying cognition.

Although there is a wealth of research separately on teacher cognition and educational technology, a comprehensive synthesis connecting these fields is still needed. Understanding how teachers' internal cognitive frameworks adapt—or resist adapting—to technological change is vital for designing effective teacher education and ongoing support systems in the digital age.

This review article aims to map out the current landscape of teacher cognition in digitally transformed education. It will explore key themes such as digital literacy, pedagogical adaptation, resistance, and cognitive challenges posed by online teaching. By doing so, it provides valuable insights for researchers, teacher educators, and policymakers committed to fostering teacher growth in contemporary learning environments. To better understand the complex and dynamic nature of teacher cognition, especially as it interacts with the demands of digital education, table 1.1 summarizes the key cognitive components, their influencing factors, and the new challenges teachers face in the digital age.

Table 1: Key Components and Influencing Factors of Teacher Cognition in the Digital Age

Teacher Cognition Component	Description	Influences	Digital Age Challenges
Beliefs	Deeply held convictions about teaching and learning	Prior experience, culture, training	Conflict between traditional beliefs and technology use
Knowledge	Content, pedagogical, and technological knowledge	Formal education, professional development	Need to integrate technological knowledge (TPACK framework)
Attitudes	Feelings and dispositions toward teaching and tools	Personal motivation, school environment	Attitudes toward digital tools shape adoption or resistance
Metaphors and Images	Conceptualizations of teaching roles and practices	Cultural narratives, personal experience	Shifts needed to include new digital teaching identities
Assumptions and Perspectives	Underlying assumptions about learners and learning processes	Classroom realities, policy contexts	Adapting assumptions to online/blended learning environments

This table highlights how the internal beliefs, knowledge, and attitudes of teachers are deeply intertwined with their professional contexts and experiences. It also illustrates the additional cognitive load placed on educators as they adapt to rapidly evolving technologies, underscoring the importance of addressing both skills and mindsets in teacher education and support programs.

How Digital Transformation is Reshaping Teacher Cognition

The rapid expansion of digital technologies has not simply altered the tools used in classrooms; it has fundamentally reconfigured the knowledge, beliefs, and cognitive processes that underpin effective teaching. In today's digital era, educators are expected to master a multifaceted skill set that includes not only subject matter expertise and pedagogical knowledge, but also a high level of digital fluency. This fluency enables teachers to design, manage, and assess learning in increasingly hybrid, online, and technology-rich environments (Koehler & Mishra, 2009; Howard, Tondeur, Siddiq, & Scherer, 2021) [15].

One of the most influential conceptual models in this context is the Technological Pedagogical Content Knowledge (TPACK) framework, introduced by Mishra and Koehler (2006) [16]. TPACK emphasizes the integration of three core knowledge domains—technological, pedagogical, and content knowledge—as essential for effective teaching in the digital age. From a teacher cognition perspective, TPACK reframes the cognitive architecture required of educators. It situates technological knowledge not as an optional supplement, but as a central element of teachers' evolving mental schemas. Mastery of this triadic framework empowers teachers to make informed decisions about when, how, and why to use specific technologies in pedagogically sound and contextually appropriate ways (Koehler, Mishra, & Cain, 2013).

However, the process of cognitive adaptation to digital tools is far from uniform. Teachers' beliefs and prior experiences play a critical role in shaping their engagement with technology. Numerous studies have demonstrated that attitudes, confidence levels, and contextual exposure significantly influence how educators perceive and implement digital tools (Ertmer & Ottenbreit-Leftwich, 2010; Inan & Lowther, 2010). For instance, teachers who view digital tools as catalysts for student engagement and deeper learning are more likely to embrace constructivist, student-centered pedagogies (Tondeur, van Braak, Ertmer, & Ottenbreit-Leftwich, 2017). In contrast, those who experience anxiety or skepticism may restrict technology use or revert to teacher-centered approaches, even in resource-rich environments.

The cognitive shift necessitated by digital transformation also compels a re-evaluation of long-established pedagogical constructs such as classroom management, formative assessment, and communication. In virtual or blended learning contexts, educators often face diminished physical presence, delayed feedback loops, and unfamiliar tools for tracking student understanding (Trust & Whalen, 2020). These challenges impact not only instructional strategies but also teachers' sense of professional identity and efficacy. Many educators report experiencing a destabilization of their roles, prompting reflection, uncertainty, and at times resistance as they navigate these new realities (Philipsen, Tondeur, Roblin, Vanslambrouck, & Zhu, 2019) [19].

Another critical dimension involves the cognitive tension between institutional mandates and individual beliefs. Technology integration policies often fail to account for the deeply held pedagogical convictions of teachers. When top-down directives conflict with educators' values, they may trigger cognitive dissonance—a psychological discomfort that can impede meaningful adoption unless mitigated by contextualized support (Fullan, 2007; Hermans, Tondeur, van Braak, & Valcke, 2008).

To address these challenges, research highlights the value of professional learning communities, peer mentoring, and continuous training. These support structures help educators develop not only technical competencies but also the cognitive agility to reframe their beliefs and practices. Reflective practice—facilitated through collaborative dialogue and inquiry-based learning—has proven effective in helping teachers manage the complex emotional and cognitive demands of technology integration (Prestridge, 2012) [20].

In sum, digital transformation in education is not merely a matter of tool acquisition; it represents a profound process of cognitive reconstruction. Teachers must expand their knowledge bases, reexamine their pedagogical assumptions, and cultivate adaptive thinking. Recognizing and supporting these cognitive shifts is essential for the design of effective teacher education and professional development initiatives that reflect the realities of 21st-century classrooms.

Table 2: Cognitive Shifts in Teacher Cognition due to Digital Transformation

Traditional Cognition (Pre-Digital Era)	Cognitive Changes in the Digital Era
Focus on face-to-face instruction	Competence in hybrid/online learning
Stable teaching roles and identity	Evolving roles and flexible identity
Limited reliance on technology	Integration of multiple digital tools
Teacher-centered pedagogy	Learner-centered digital pedagogy
Assessment based on physical cues	Use of analytics and digital feedback

Emerging Themes in the Literature

In technology-rich classrooms, teacher cognition is shaped by multiple interrelated dimensions—digital literacy, cognitive dissonance, identity negotiation, and adaptive expertise—that collectively influence how educators define their professional identity and adapt their practice. Digital literacy now functions as a broad cognitive competency encompassing not only technical know-how but also critical evaluation and ethical use of technology (Ng, 2012). This deep integration of digital literacy into teachers' thinking shapes how they incorporate tools into pedagogy and guide students in online environments. At the same time, the introduction of new technologies can trigger cognitive dissonance (Ertmer, 2005) when long-held beliefs about "good teaching" clash with unfamiliar digital practices. Such tensions often manifest as resistance or discomfort, and resolving them requires reflection and support to realign one's beliefs with innovative methods. As teachers work through these challenges, they engage in identity negotiation, revising their professional self-concept to accommodate new roles afforded by digital education. Technology integration frequently prompts a shift from being solely content deliverers to becoming facilitators or designers of learning experiences, a process that can both challenge and enrich teachers' sense of purpose (Beijaard *et al*., 2004) [4]. This identity transformation is dynamic and context-dependent: in supportive school cultures, technology serves as a catalyst for renewing professional purpose, whereas inadequate support may lead to stress or fragmentation. Adaptive expertise then emerges as a critical capacity enabling continuous professional growth. It refers to the ability to keep learning, think flexibly, and solve novel problems—qualities that allow teachers to reinterpret challenges as opportunities and remain resilient amid rapid technological change (Hatano & Inagaki, 1986) [13]. Together, these cognitive dimensions operate in tandem to reshape teacher cognition, empowering educators to continually reconstruct their identity and practice in response to the evolving demands of digital education.

Developing Adaptive Expertise in the Digital Age

In today's fast-evolving digital educational landscape, adaptive expertise has emerged as a critical competency for teachers. Unlike routine expertise, which involves applying well-established knowledge and procedures in familiar contexts, adaptive expertise refers to the ability to think flexibly, navigate ambiguity, and respond to novel situations with creativity and reflection (Hatano & Inagaki, 1986; Bransford *et al*., 2005) [13,5]. This dynamic form of professional judgment is essential for educators striving to integrate new technologies meaningfully while addressing the diverse and ever-changing needs of their students. Teachers with adaptive expertise are not merely efficient users of digital tools; they are critical thinkers, reflective practitioners, and lifelong learners who continually refine their instructional strategies based on feedback, data, and contextual shifts. They understand that digital environments are not static—they evolve rapidly, often presenting unfamiliar challenges such as changing platform capabilities, emerging pedagogical trends, or shifts in student engagement patterns (Mishra & Koehler, 2006) [16]. In such environments, adaptive expertise allows teachers to pivot from one approach to another while maintaining pedagogical coherence and purpose. Importantly, the development of adaptive expertise is deeply intertwined with teacher cognition. It involves the capacity to monitor one's thinking, recognize knowledge gaps, and seek out new solutions—a process known as metacognitive regulation (Schraw & Moshman, 1995) [25]. Teachers demonstrating adaptive expertise are more likely to engage in ongoing inquiry, whether through action research, collaborative professional learning communities, or informal experimentation with digital tools (Timperley, 2011) [28]. They are also more resilient in the face of uncertainty, viewing challenges not as threats but as opportunities for professional growth and innovation. However, adaptive expertise does not develop in isolation. It thrives in supportive institutional cultures that value experimentation, reflection, and risk-taking. Professional development programs that focus on problem-solving, peer learning, and authentic technology integration have been shown to foster this mindset (Darling-Hammond *et al*., 2017; Dede, 2010) [10]. Encouraging teachers to co-design digital learning environments, share best practices, and engage with emerging research can help cultivate a sense of agency and intellectual curiosity—two hallmarks of the adaptive expert. Ultimately, adaptive expertise represents an advanced stage of cognitive and professional development—one that enables teachers to go beyond applying knowledge to actively reshaping it. In doing so, they not only enhance their own teaching practices but also contribute to more responsive, inclusive, and innovative learning environments. The four cognitive dimensions explored—digital literacy, cognitive dissonance, professional identity, and adaptive expertise—represent interconnected yet distinct areas of transformation within teacher cognition. The following infographic provides a concise visual synthesis of these themes, highlighting their relevance to teaching in digitally mediated environments.

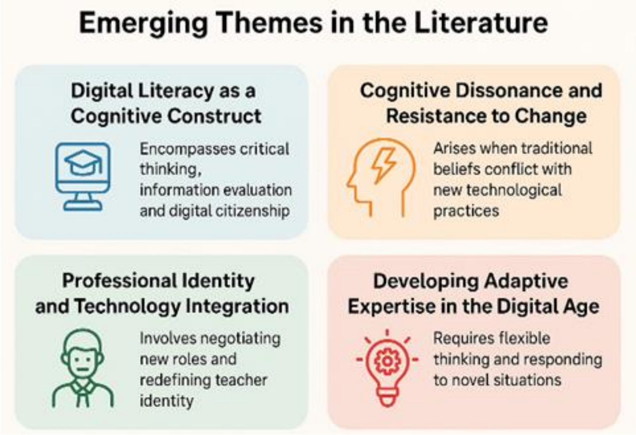

Fig 1: Four Cognitive Dimensions of Teacher Adaptation in the Digital Age"

Implications for Teacher Education and Professional Development

The dynamic shifts in teacher cognition prompted by digital transformation necessitate a reimagining of both initial teacher education and ongoing professional development. Technological fluency should not be treated as an isolated skill but integrated into the broader cognitive and reflective development of educators. To prepare pre-service teachers for complex, technology-enhanced environments, teacher education programs must move beyond fragmented models by embedding digital technologies into core pedagogical discussions and practical coursework. Frameworks such as TPACK offer valuable structure for engaging future educators in exploring the interplay between pedagogy, content, and technology through collaborative learning, critical reflection, and hands-on projects that challenge beliefs and promote adaptive thinking. For in-service teachers, professional development must align with existing cognitive structures and provide iterative learning opportunities centered on critical reflection, real-time experimentation, and peer collaboration. Effective programs go beyond generic tool training to focus on the pedagogical rationale behind technology use, anchoring decisions in instructional intent and cognitive outcomes while fostering a culture that values teacher agency and risk-taking. As teachers adapt to digital change, they must also renegotiate their professional identities. Education and PD programs should therefore create spaces for identity exploration and renewal, empowering teachers to lead change, personalize technology use, and co-construct learning environments. Mentoring, storytelling, and reflective community practices can help affirm evolving identities while reinforcing core professional values. Moreover, the increasing cognitive demands of digital teaching call for a renewed emphasis on well-being and resilience. Teachers must be supported in developing strategies for managing cognitive load, setting boundaries, and maintaining mental clarity in tech-saturated environments. This holistic approach to teacher development promotes not only digital competence but also the cognitive and emotional capacity to thrive in evolving educational landscapes. To complement this discussion, the accompanying visual presents four interrelated domains—preparation, continuous growth, agency and identity, and well-being—that together support educators' shifting cognitive needs in the digital age.

Fig 2: Core Implications for Teacher Education and Professional Development in the Digital Age

The Technological Architecture of Digital Tools and Its Cognitive Implications

While much research on teacher cognition in the digital age has focused on pedagogical adaptation and professional beliefs, relatively little attention has been given to the underlying technological architecture of the tools teachers use daily. Digital platforms, learning management systems (LMS), and AI-powered educational applications are not neutral instruments; they are engineered systems whose design choices directly influence how teachers think, make decisions, and manage cognitive load. This section explores how structural and algorithmic elements of educational technology shape teacher cognition, with particular emphasis on system architecture, human-computer interaction (HCI), and artificial intelligence (AI).

Beyond Interfaces: Teachers as End-Users of Complex Systems

As digital technologies become deeply embedded in education, teachers increasingly rely on platforms that appear user-friendly but are driven by complex and largely opaque technical infrastructures. Learning Management Systems (LMS) such as Google Classroom, and data analytics tools like Microsoft Insights, now routinely offer predictive alerts and behavioral flags based on real-time data. Yet, these platforms rarely make transparent the algorithmic assumptions, threshold criteria, or data pipelines underlying such insights, leaving teachers to interpret system outputs without a clear understanding of their origins (Ndukwe & Daniel, 2020).

This disconnect creates what Norman (2013) [17] describes as cognitive friction—the mental strain that arises when users must work around systems that don't align with their intuitive workflows or mental models. For example, when a teacher receives an "at-risk" alert for a student based on limited or poorly contextualized engagement data, they may struggle to determine whether to trust that alert or rely on their own professional judgment. This tension is exacerbated when teachers are not equipped with the data literacy needed to interpret or question the output (Ifenthaler & Yau, 2020).

The introduction of AI-driven tools, such as ChatGPT, adds another layer of complexity. Increasingly, teachers are experimenting with these generative AI systems to draft lesson plans, create differentiated tasks, or streamline administrative work. While these tools promise efficiency, they also produce highly plausible but potentially inaccurate content, and they operate on probabilistic models that lack transparency or curricular specificity (Giannoutsou *et al*., 2024). The risk is that teachers may adopt AI-generated outputs without fully understanding their limitations or pedagogical implications, especially if they feel time-constrained or lack confidence in their ability to scrutinize the technology's output critically.

In such contexts, the design opacity of digital tools doesn't merely inconvenience teachers—it reshapes their cognitive environment. When decisions are increasingly guided by algorithms that provide recommendations without explainability, teacher autonomy and agency may be subtly eroded. This shift from informed decision-making to data-led compliance has implications for both pedagogy and professional identity.

Addressing these concerns requires more than improving interface usability. It calls for cognitively aligned system design—technological tools that match teachers' decision-making processes, offer transparency into how insights are generated, and allow meaningful human intervention. Moreover, professional development programs must move beyond technical training to include critical platform literacy, enabling teachers to question the affordances and limitations of the tools they use daily (Ndukwe & Daniel, 2020; Ifenthaler & Yau, 2020).

Ultimately, for educational technologies to genuinely support teacher cognition, they must be designed not only for functionality but for interpretability, adaptability, and professional trust. Teachers are not passive users but expert decision-makers; systems that fail to reflect this reality risk undermining the very work they aim to support.

AI-Powered Tools and Teacher Cognition

AI-powered educational technologies—including adaptive learning platforms (e.g., DreamBox Learning, ALEKS), automated feedback systems (e.g., Gradescope, Turnitin), and conversational agents (e.g., Khanmigo, ChatGPT)—are becoming central to how teachers plan, instruct, and assess. These tools do not merely extend teacher capacity; they reshape how teachers perceive student learning, allocate attention, and evaluate instructional decisions. As such, their cognitive impact is profound, affecting key mental processes such as judgment, attention, and trust calibration (Holmes *et al*., 2021; Luckin *et al*., 2016).

A critical cognitive shift involves automation bias—the tendency to over-rely on algorithmic suggestions, even when they conflict with expert knowledge (Mosier & Skitka, 1996). For instance, when an adaptive learning platform recommends a remediation path based on student performance patterns, teachers may accept the recommendation without sufficiently interrogating its fit with classroom dynamics. Alternatively, algorithmic aversion may arise when teachers distrust the system due to a lack of transparency, leading them to disregard useful recommendations (Dietvorst *et al*., 2015). Both tendencies illustrate how AI can alter teacher decision-making by shaping the degree of cognitive effort and scrutiny they apply to instructional choices.

Scenario Example:

Imagine a middle school teacher using an AI-powered tool to group students for collaborative reading based on recent quiz data. The system recommends four heterogeneous groups, flagging some students as "struggling readers." However, the teacher, recalling a recent classroom discussion, notices that one student flagged as "struggling" had demonstrated advanced comprehension verbally. Here, the teacher must reconcile system-generated data with situational judgment, requiring cognitive negotiation between external analytics and internal professional memory.

This cognitive tension points to the importance of trust calibration—the ability to regulate one's reliance on AI tools by evaluating their accuracy, contextual fit, and alignment with pedagogical goals (Kizilcec, 2016). Teachers with high trust calibration can balance automation benefits with critical oversight, whereas those without such skills may either over-delegate or reject useful assistance.

Furthermore, LMS platforms like Canvas or Moodle structure not just workflow but also cognitive framing—how teachers interpret student behavior through analytics dashboards. These visualizations influence how teachers prioritize interventions, monitor progress, and identify learning gaps. However, this constant stream of data can also contribute to data fatigue or increase cognitive load, particularly when interfaces are cluttered, unfiltered, or lack actionable insight (Sailer & Homner, 2020).

To maximize the cognitive benefits of AI in education, systems must be designed with explainability, customizability, and feedback loops that align with teachers' cognitive workflows. Equally, teacher training should extend beyond technical proficiency to include metacognitive strategies for evaluating AI input and maintaining pedagogical agency.

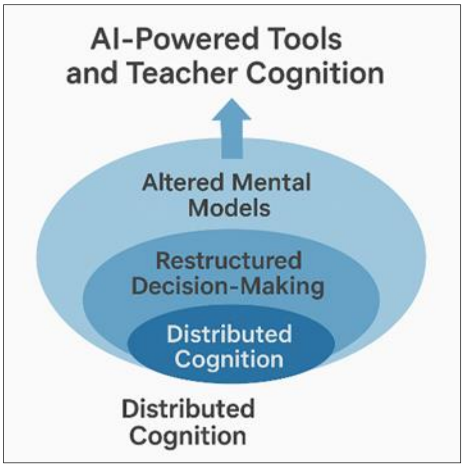

Fig 3: AI-Powered Tools and Teacher Cognition: A Layered Model of Interaction and Influence"

System Design, Cognitive Load, and Usability

Effective system design plays a pivotal role in supporting teacher cognition, particularly within the cognitively demanding landscape of technology-enhanced education. Poorly designed digital interfaces—marked by cluttered dashboards, inconsistent navigation, or delayed feedback—can overwhelm teachers with redundant or disjointed information, heightening cognitive strain and diminishing instructional effectiveness (Suh *et al*., 2021; Adesope *et al*., 2017).

This phenomenon is well-explained by Cognitive Load

Theory (Sweller, 1988), which distinguishes between intrinsic load (task complexity), germane load (cognitive effort beneficial for learning), and extraneous load (inefficient processing caused by poor design). When educational tools impose excessive extraneous load—such as through fragmented data displays or unclear interaction sequences—they interfere with teachers' cognitive resources, detracting from their core pedagogical tasks (Paas *et al.*, 2003).

Human-Computer Interaction (HCI) frameworks offer practical solutions to these design challenges. Nielsen's usability heuristics (1994) and the ISO 9241-210 standard for human-centered design (ISO, 2010) provide evidence-based guidelines for minimizing interaction costs and enhancing user control. Effective design elements include predictable navigation paths, informative feedback, reduced steps for routine tasks, and coherent visual organization—all of which help teachers maintain cognitive focus and situational awareness during complex instructional decision-making (Shneiderman *et al.*, 2017).

Equally important is how digital platforms structure and prioritize information in real-time. Systems that offer customizable, integrated dashboards empower teachers to monitor student progress, identify trends, and adjust instruction without mental overload (Lee & Hsieh, 2019; Park *et al.*, 2020). In contrast, tools that require excessive context-switching or fragment user interactions can elevate cognitive load, leading to fatigue, frustration, and decreased instructional performance (Chen *et al.*, 2021).

Integrating insights from both Cognitive Load Theory and HCI is essential for designing AI-powered educational technologies that enhance rather than hinder teacher cognition. A user-centered approach—anchored in cognitive psychology and iterative design—ensures that tools present information in ways that are intuitive, supportive, and aligned with teachers' decision-making processes. In doing so, designers can build systems that foster clarity, efficiency, and professional trust, empowering teachers to engage more deeply with their instructional goals (Wickens *et al.*, 201

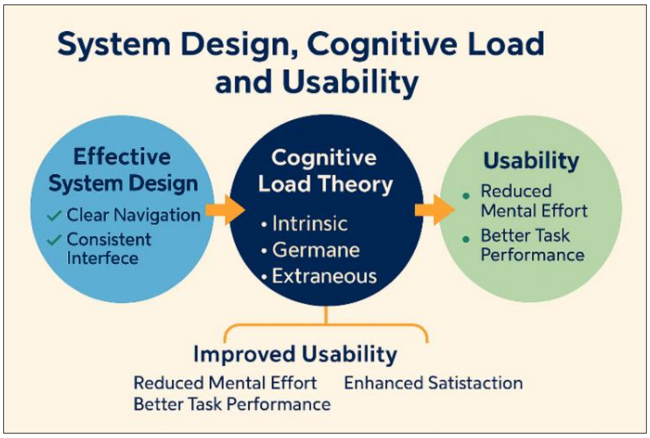

Fig 4: Cognitive Load, Interface Design, and Instructional Usability in Educational Technology

Algorithmic bias and ethical system design

Algorithms embedded within educational platforms rely heavily on historical data, pre-determined weightings, and complex decision pathways, which may unintentionally perpetuate existing biases and inequities (Baker *et al.*, 2019; Holstein *et al.*, 2019). Without sufficient transparency, these systems risk unfairly flagging students or recommending interventions that overlook vital contextual factors unique to each classroom environment (Suresh & Guttag, 2021). Consequently, teachers may come to accept algorithmic outputs as authoritative, despite limited awareness of the algorithms' underlying assumptions and constraints, which can undermine critical pedagogical judgment (Williamson & Eynon, 2020).

To mitigate these challenges, the field of Explainable Artificial Intelligence (XAI) has emerged, emphasizing the importance of systems that clearly articulate the rationale behind algorithmic decisions (Adadi & Berrada, 2018). XAI techniques facilitate greater teacher agency by enabling educators to interrogate recommendations, understand potential biases, and exercise professional discretion, including the option to override or opt out of algorithmic suggestions (Doshi-Velez & Kim, 2017). For example, systems designed with interactive explanation modules can reveal how data inputs influence output predictions, fostering trust while promoting ethical engagement (Raji *et al.*, 2020). Ethical system design must therefore prioritize transparency, fairness, and accountability throughout the AI development lifecycle (Jobin *et al.*, 2019). This includes rigorous bias audits, inclusive training datasets, and ongoing stakeholder involvement—especially educators who directly mediate algorithmic influence in classroom settings (Holstein *et al.*, 2019). By embedding ethical principles into AI tools, developers can support teachers in making informed decisions that align with diverse learner needs and uphold educational equity (Binns, 2020).

In summary, addressing algorithmic bias and fostering ethical AI deployment in education demands an integrative approach combining explainability, teacher empowerment, and continuous ethical oversight. Only then can AI systems serve as supportive partners in pedagogy rather than opaque authorities with hidden, potentially harmful biases.

Toward Collaborative Design: Engineering for Cognition

Effectively addressing the challenges of AI integration in education demands a collaborative, multidisciplinary approach that actively involves educators, cognitive scientists, and system engineers throughout the design process (Fischer *et al.*, 2018; Suthers *et al.*, 2020). Teachers, as domain experts and end-users, must serve as central stakeholders to ensure that educational platforms align with authentic cognitive workflows and pedagogical practices (D'Mello & Graesser, 2015). Participatory design methodologies, which foster iterative co-creation and sustained teacher engagement, help surface usability requirements and inform the development of system features—such as intuitive data visualizations, contextualized AI recommendations, and adaptive pacing controls—that promote rather than diminish teacher agency (Spinuzzi, 2005; Muller *et al.*, 2017).

From an engineering perspective, building cognitively aligned educational technologies requires the integration of backend algorithmic logic with frontend usability considerations in a holistic, user-centered manner (Norman, 2013; Johnson *et al.*, 2021) [17]. This entails optimizing not only the predictive accuracy and fairness of AI models but also designing interfaces and interactions that accommodate human cognitive limitations and promote seamless decision-making in complex classroom environments (Wickens *et al.*, 2015). For example, embedding real-time teacher feedback loops and customizable AI interventions allows systems to dynamically adapt to teacher preferences and contextual nuances, strengthening trust and collaborative use (Holmes *et al*., 2021).

In sum, a collaborative design framework that unites cognitive science insights with engineering rigor and teacher expertise is essential for developing educational technologies that genuinely enhance teacher cognition and pedagogical effectiveness. Such integrative design approaches advance system usability while respecting the professional autonomy of educators, ultimately fostering more equitable and impactful AI adoption in education (Fischer *et al*., 2018; Suthers *et al*., 2020).

Table 3: The Technological Architecture of Digital Tools and Its Cognitive Implications

Subsection	Focus Area	Key Implication
Beyond Interfaces: Teachers as End-Users of Complex Systems	Opaque system infrastructure and data interpretation challenges	Enhance transparency and platform literacy
AI-Powered Tools and Teacher Cognition	Cognitive shifts due to adaptive platforms and AI feedback tools	Foster critical engagement with AI tools and maintain pedagogical control
System Design, Cognitive Load, and Usability	Interface design impacts on cognitive load and instructional clarity	Minimize extraneous cognitive load through usability standards
Algorithmic Bias and Ethical System Design	Unintended bias and the importance of explainability and ethics in AI	Ensure fairness, explainability, and teacher oversight in AI systems
Toward Collaborative Design: Engineering for Cognition	Collaborative, multidisciplinary design approaches for cognitive alignment	Integrate teacher input with cognitive science and engineering principles

Conclusion

The digital transformation of education has redefined not only the tools and platforms teachers use but also the underlying cognitive processes that shape their instructional decision-making, professional identity, and pedagogical engagement. This integrative review has illuminated how teacher cognition in the 21st century is increasingly shaped by a constellation of evolving beliefs, digital literacies, cognitive tensions, and interactions with complex system architectures.

One of the central contributions of this article is its interdisciplinary lens—bringing together educational psychology, system design, and AI ethics to show that technology integration is not merely a technical challenge, but a cognitive one. Teachers must continually negotiate between professional judgment and algorithmic outputs, often under conditions of opacity and high cognitive load. Poorly designed systems may compromise teacher agency and increase friction, while cognitively aligned tools can foster adaptive expertise and support reflective, context-sensitive practice.

By mapping key cognitive dimensions—such as digital literacy, cognitive dissonance, identity negotiation, and adaptive expertise—and linking them to technological affordances and constraints, this review offers a conceptual framework for understanding how system design and teacher thinking co-evolve. It also underscores the ethical imperative for greater transparency, explainability, and collaboration in the development of educational technologies.

However, as a conceptual synthesis, this review is limited by its lack of empirical validation. Future research should explore how specific design features influence teacher cognition in practice, using mixed-methods approaches that capture both cognitive outcomes and user experiences. Further investigation is also needed into how diverse educational contexts—culturally and institutionally—shape the interplay between cognition and technology use.

Ultimately, if teacher agency and expertise are to be preserved and empowered in digitally mediated classrooms, educational technologies must be co-designed with teachers, for teachers. This demands not only technical innovation but sustained dialogue between educators, researchers, and developers to ensure that emerging systems genuinely align with pedagogical values, cognitive needs, and ethical responsibilities.

References

1. Albion PR, Ertmer PA. Beyond the foundations: The role of vision and belief in teachers' preparation for integration of technology. TechTrends 2002;46(5):34–38. https://doi.org/10.1007/BF02778299.
2. Balfour SP. Assessing writing in MOOCs: Automated essay scoring and calibrated peer review™. Research & Practice in Assessment 2013;8:40–48.
3. Beauchamp C, Thomas L. Understanding teacher identity: An overview of issues in the literature and implications for teacher education. Cambridge Journal of Education 2009;39(2):175–189. https://doi.org/10.1080/03057640902902252.
4. Beijaard D, Meijer PC, Verloop N. Reconsidering research on teachers' professional identity. Teaching and Teacher Education 2004;20(2):107–128. https://doi.org/10.1016/j.tate.2003.07.001.
5. Benjamin R. Race after technology: Abolitionist tools for the new Jim code. Polity Press; 2019.
6. Borg S. Teacher cognition in language teaching: A review of research on what language teachers think, know, believe, and do. Language Teaching 2003;36(2):81–109. https://doi.org/10.1017/S0261444803001903.
7. Bransford J, Darling-Hammond L, LePage P. Introduction. In: Darling-Hammond L, Bransford J, editors. Preparing teachers for a changing world: What teachers should learn and be able to do. Jossey-Bass; 2005. p. 1–39.
8. Bulger M. Personalized learning: The conversations we're not having. Data & Society Research Institute; 2016. https://datasociety.net/pubs/ecl/PersonalizedLearning_primer_2016.pdf.
9. Clark CM, Peterson PL. Teachers' thought processes. In: Wittrock MC, editor. Handbook of research on teaching. 3rd ed. Macmillan; 1986. p. 255–296.
10. Darling-Hammond L, Hyler ME, Gardner M. Effective teacher professional development. Learning Policy Institute; 2017.
11. Day C, Gu Q. The new lives of teachers. Routledge;

2010.
12. Gunning D. Explainable artificial intelligence (XAI). DARPA; 2017. https://www.darpa.mil/attachments/XAIProgramUpdate.pdf.
13. Hatano G, Inagaki K. Two courses of expertise. In: Stevenson H, Azuma H, Hakuta K, editors. Child development and education in Japan. W.H. Freeman; 1986. p. 262–272.
14. Kelchtermans G. Who I am in how I teach is the message: Self-understanding, vulnerability and reflection. Teachers and Teaching: Theory and Practice 2009;15(2):257–272. https://doi.org/10.1080/13540600902875332.
15. Koehler MJ, Mishra P. What is technological pedagogical content knowledge (TPACK)? Contemporary Issues in Technology and Teacher Education 2009;9(1):60–70.
16. Mishra P, Koehler MJ. Technological pedagogical content knowledge: A framework for teacher knowledge. Teachers College Record 2006;108(6):1017–1054.
17. Norman DA. The design of everyday things. Revised and expanded edition. Basic Books; 2013.
18. Pajares MF. Teachers' beliefs and educational research: Cleaning up a messy construct. Review of Educational Research 1992;62(3):307–332. https://doi.org/10.3102/00346543062003307.
19. Philipsen B, Tondeur J, Roblin NP, Vanslambrouck S, Zhu C. Improving teacher professional development for online and blended learning: A systematic meta-aggregative review. Educational Technology Research and Development 2019;67:1145–1174. https://doi.org/10.1007/s11423-019-09645-8.
20. Prestridge S. The beliefs behind the teacher that influences their ICT practices. Computers & Education 2012;58(1):449–458. https://doi.org/10.1016/j.compedu.2011.08.028.
21. Ribble M. Digital citizenship in schools: Nine elements all students should know. 2nd ed. ISTE; 2011.
22. Sachs J. Teacher education and the development of professional identity: Learning to be a teacher. In: Denicolo P, Kompf M, editors. Connecting policy and practice: Challenges for teaching and learning in schools and universities. Routledge; 2005. p. 5–21.
23. Sahmaniasl R. EFL educators' perceptions of AI-driven assessments: A systematic review. [Journal Name] 2025;[Volume(Issue)]:[Page range].
24. Sahmaniasl R, Ersanlı CY. Secondary school students' language learning motivation and perceptions about English as a lingua franca in Iran. ELT Research Journal 2024;13(2):167–204.
25. Schraw G, Moshman D. Metacognitive theories. Educational Psychology Review 1995;7(4):351–371. https://doi.org/10.1007/BF02212307.
26. Spante M, Hashemi SS, Lundin M, Algers A. Digital competence and digital literacy in higher education research: Systematic review of concept use. Cogent Education 2018;5(1):1519143. https://doi.org/10.1080/2331186X.2018.1519143.
27. Sweller J, Ayres P, Kalyuga S. Cognitive load theory. Springer; 2011.
28. Timperley H. Realizing the power of professional learning. McGraw-Hill Education; 2011.
29. Valizadeh S. Digital literacy practices of pre-service EFL teachers: A case study of private language schools; 2024.
30. Valizadeh S, Valizadeh G. Digital storytelling for intermediate EFL learners: Enhancing narrative skills and cultural awareness.
31. Voogt J, Fisser P, Good J, Mishra P, Yadav A. Computational thinking in compulsory education: Towards an agenda for research and practice. Education and Information Technologies 2015;20(4):715–728. https://doi.org/10.1007/s10639-015-9412-6.