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Constructing an Application Framework for Educational AI Agents to Promote Deep Integration of Teacher TPACK

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Abstract

As artificial intelligence technology permeates the educational landscape, the autonomous and adaptive characteristics of Educational AI Agents present new opportunities for teacher professional development. However, current technological applications often remain superficial, failing to effectively promote the deep integration of teachers' Technological Pedagogical Content Knowledge (TPACK). This study, grounded in a deep analysis of the TPACK theoretical construct and a deconstruction of the core capabilities of Educational AI Agents, aims to construct an application framework for Educational AI Agents oriented towards deep TPACK integration (the AIA-TPACK Framework). This framework is centered on "Teacher-Agent Collaboration" and unfolds across three dynamic stages: "Contextual Awareness and Diagnosis," "Scaffolding-in-Practice," and "Reflective Practice and Iteration." The framework delineates the multifaceted roles of Educational AI Agents in assisting instructional design, coordinating classroom practice, empowering teaching assessment, and guiding professional reflection. This study posits that the implementation of this framework can help shift AI technology from merely empowering singular knowledge domains to facilitating the systematic integration and co-evolution of all TPACK elements, thus providing a theoretical model and practical pathway for future teacher professional development.

Keywords

Educational AI Agents, TPACK, Teacher Professional Development, Deep Integration, Application Framework

1. Introduction

Artificial intelligence is rapidly reshaping educational systems worldwide [1]. Educational AI Agents, with their capacity to perceive environments, make autonomous decisions, and provide proactive services, offer learners high-quality, personalized learning experiences and meet their individualized needs [2], driving the renewal of educational concepts, the transformation of models, and the restructuring of systems. Against this backdrop, the roles, competencies, pedagogical understanding, and self-worth of teachers are facing profound challenges [3]. Teachers are no longer mere transmitters of knowledge or "users" of technology; they must become "designers" and "facilitators" who collaborate with AI in complex instructional environments.

"Educational intelligent agents are profoundly intervening in the entire process of how teachers understand, reconstruct, and impart specific subject content" [1], posing entirely new pedagogical challenges to teacher professional development. The TPACK (Technological Pedagogical Content Knowledge) framework, as a core theory describing the knowledge system required for effective teaching in technological environments, is a "theoretical framework for exploring the relationships among cutting-edge technology, teaching methods, and subject matter content" [4]. TPACK emphasizes the complexity, situatedness, and dynamic nature of the three core components—Technology (TK), Pedagogy (PK), and Content (CK)—as well as their intersections (TCK, TPK, PCK) and their ultimate integration (TPACK) [5]. However, in practice, the application of AI technology often exhibits a "technology-pedagogy" separation. While the intervention of AI tools may enhance TK to some extent, a lack of organic integration with PK and CK can easily lead to a "high-tech, low-efficacy" predicament, or even rigidify existing teaching models. As Li Rui (2025) points out, "The development of AI technology brings multiple challenges and impacts to teaching philosophies, content, resources, and models." [6].

The emergence of Educational AI Agents, with their "human-like" interaction and autonomous service characteristics, offers new possibilities for the deep integration of TPACK. These agents have the potential to transcend the limitations of traditional tools, acting as teachers' "cognitive partners" or "instructional assistants" to provide immediate, personalized support in authentic teaching contexts, targeting the weaker aspects of TPACK.

Despite this promising outlook, how Educational AI Agents can systematically promote the deep integration of teacher TPACK, rather than superficial technological overlay, remains the core issue of this study. For the purposes of this framework, "deep integration" is operationally defined as a cyclical process where technology, pedagogy, and content knowledge are not merely co-existent, but mutually shape and transform one another within authentic practice, leading to the development of new, resilient pedagogical schemata in the teacher. That is, how can an application framework be constructed that uses Educational AI Agents as a medium to guide and support teachers in achieving a transition from separated

elements to integrated knowledge, and from surface-level application to deep fusion, within their authentic professional practice?

Based on this, the present study attempts to build a connection between TPACK theory and the technical characteristics of Educational AI Agents, constructing an "Application Framework for Educational AI Agents for Deep Integration of Teacher TPACK" (the AIA-TPACK Framework). The academic value of this research lies in its attempt to move beyond the instrumentalist perspective of "What can AI do?" and shift towards an educational perspective of "How can AI promote the development of teachers' core competencies?" providing guidance for the deep application of Educational AI Agents in the field of teacher professional development.

2. Theoretical Basis: The Coupling Mechanism of Educational AI Agents and Deep TPACK Integration

The prerequisite for constructing the AIA-TPACK framework is a deep understanding of how the core characteristics of Educational AI Agents (AI Agents) couple with the complex constructs of TPACK. The essence of deep integration is that the AI Agent does not merely act on a single element of TPACK, but rather becomes a systematic force that catalyzes the evolution of its internal structure.

TPACK, as a form of situated, integrative, and practical knowledge, does not develop through the linear accumulation of TK, PK, and CK. Instead, it is a process whereby teachers dynamically and synthetically invoke and reconfigure these three knowledge types within specific teaching contexts to address concrete instructional problems. Mishra & Koehler (2008) emphasized that the essence of TPACK lies in the "transformation" and "integration" of knowledge [5]. Therefore, the key to promoting deep TPACK integration is the ability to support teachers in continuously experiencing these cognitive processes of "transformation" and "integration" in authentic practice (e.g., instructional design, classroom interaction, post-lesson reflection).

The core characteristics of Educational AI Agents—namely Autonomy, Adaptivity, and Interactivity [2]—equip them with the potential to deeply intervene in teachers' practical cognitive processes.

First, the autonomy and adaptivity of Educational AI Agents enable them to provide "context-aware" support. Traditional TPACK training is often "decontextualized." In contrast, an Educational AI Agent can be embedded into a teacher's daily workflow, such as lesson planning systems, classroom management platforms, or online professional learning communities. It can proactively analyze the alignment among the current instructional content (CK), the intended pedagogical goals (PK), and the available technological tools (TK), alerting the teacher to potential integration challenges. For example, while a teacher is preparing a lesson, the agent could analyze whether the chosen technology (TK) aligns with the requirements of "inquiry-based learning" (PK) and whether it can accurately represent "abstract physics concepts" (CK), thereby stimulating the teacher's re-

flection at the TPACK level.

Second, the interactivity of Educational AI Agents allows them to serve as scaffolds "during practice." TPACK development is inseparable from practice. An Educational AI Agent can act as a "teaching co-pilot" or a "cognitive scaffold," providing real-time feedback during classroom implementation. For instance, if the agent perceives that classroom interaction is deviating from the pedagogical design (TPACK), it can offer non-intrusive prompts (to the teacher, not the students), such as suggestions to adjust questioning strategies or technology use. This immediate, concurrent support helps teachers engage in "reflection-in-action" [7], reinforcing the application of TPACK in authentic situations.

Furthermore, the data analysis capabilities of Educational AI Agents act as a catalyst for "reflective practice." The enhancement of TPACK relies on "reflective practice" post-implementation. Educational AI Agents can collect and analyze data from the entire teaching process (e.g., student learning behaviors, classroom discourse, resource utilization efficiency) and present it visually to the teacher. More importantly, the agent can "translate" this data based on the TPACK framework, linking "student points of confusion" to deficiencies in the teacher's "content representation (TCK)" or "learning activity organization (TPK)." This enhances teaching reflection [8] and guides teachers toward deeper, structured reflection oriented at TPACK integration, rather than superficial instructional tweaks.

3. Research Design: Principles for Constructing the AIA-TPACK Framework

To ensure the framework's theoretical rigor and practical feasibility, its construction adheres to the core principles of "Teacher-Centered, Practice-Oriented, and Iterative-Evolution."

Methodologically, the construction of this framework primarily employed Theoretical Synthesis and the logic of Design-Based Research (DBR). First, through a systematic review of literature on TPACK theory and Educational AI Agents, key nodes for their coupling were distilled to form the framework's theoretical prototype. Second, the framework is explicitly grounded in the iterative logic of DBR, which is uniquely suited for developing both theory and practical interventions simultaneously in real-world settings. This study's "Design-Practice-Reflect-Redesign" cycle (as detailed in Principle 4) directly embodies the core DBR tenet of iterative refinement based on practical feedback, aiming to develop both a robust theoretical model and a functional pedagogical intervention.

The framework construction adheres to the following principles:

1. Principle of Teacher Agency: The Educational AI Agent is a supporter and collaborator, not a substitute or decision-maker. The framework's design must always place the teacher at the core of professional judgment. All agent functions must serve to stimulate teacher autonomy and creativity, avoiding "technological alienation" or "black-box algorithms" that erode teachers' professional autonomy.

2. Principle of Situated Practice (Context-Situated): TPACK is highly contextualized. The framework must be able to adapt to the differentiated needs of various subjects (CK), grade levels, and pedagogical methods (PK). Therefore, the framework's design is not a "one-size-fits-all" solution but rather provides a flexible, configurable structure that allows the agent to adjust its support strategies based on specific contexts.

3. Principle of Integrative Development: The framework's objective is not to enhance TK, PK, or CK in isolation, but to promote their "deep integration." The design and application of the agent must always be directed at the intersections of TPACK (TCK, TPK, PCK) and its core (TPACK), guiding teachers to consider "how to use 'this' technology (TK) to teach 'this' content (CK) to achieve 'that' pedagogical (PK) goal."

4. Principle of Reflective Iteration: TPACK development is a spiraling, cyclical process. The framework must include a closed-loop feedback mechanism. That is, the Educational AI Agent must not only support "pre-practice" instructional design and "in-practice" classroom implementation but also, crucially, support "post-practice" deep reflection, feeding the results of that reflection back into the next round of instructional design to form an iterative cycle of "Design-Practice-Reflect-Redesign."

4. The Application Framework for Educational AI Agents for Deep TPACK Integration (AIA-TPACK)

Based on the theoretical analysis and construction principles outlined above, this study proposes the "Application Framework for Educational AI Agents for Deep TPACK Integration" (AIA-TPACK, see **Figure 1**). This framework is a dynamic, cyclical structure, with its core composed of the "Teacher-Agent Collaboration Interface," the "TPACK Integration Practice Field," and the "Three-Stage Dynamic Support System."

The core of the framework is the "Teacher-Agent Collaboration Interface," which serves as the medium for interaction between the teacher and the Educational AI Agent. It is not a singular piece of software, but an intelligent service layer embedded across the teacher's entire workflow (lesson planning, instruction, assessment, and reflection). Practically, this interface could be actualized in several forms, such as: (a) a plugin for widely-used Learning Management Systems (LMS), (b) a standalone desktop or web application, or (c) an advanced interactive chatbot integrated with school data systems. Regardless of its form, its function is to serve as the practical nexus for interaction and reflection.

The practical foundation of the framework is the "TPACK Integration Practice Field," referring to the authentic teaching contexts where the teacher applies TPACK, including instructional design, classroom implementation, and professional workshops.

The operating mechanism of the framework is the "Three-Stage Dynamic Support System," in which the Educational AI Agent plays different roles to systematically intervene in the TPACK integration process. For the AI agent within this

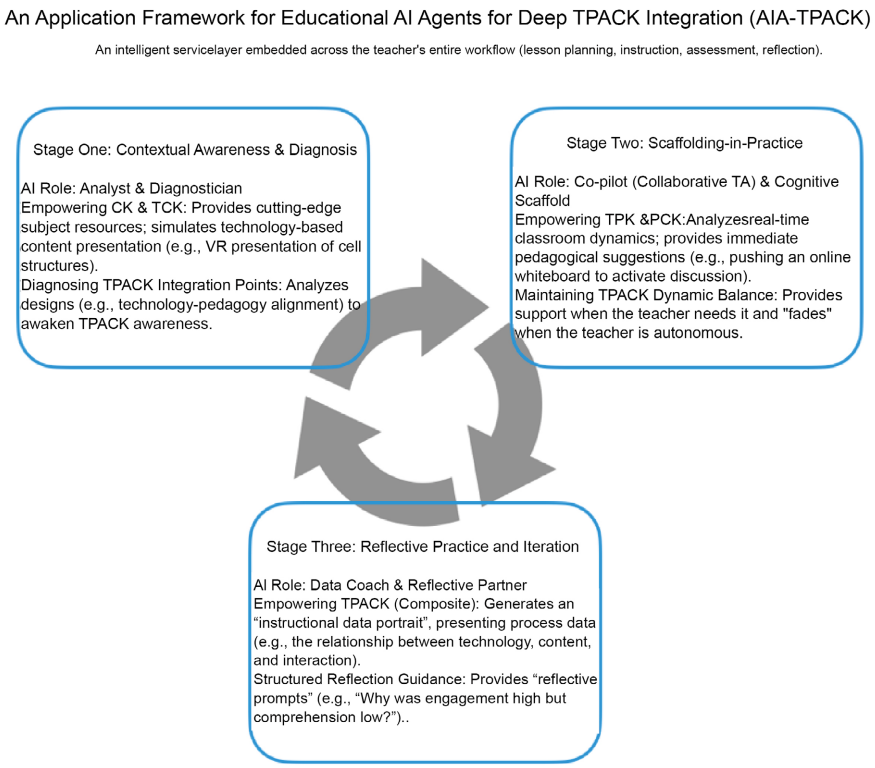

Figure 1. The application framework for educational AI agents for deep TPACK integration (AIA-TPACK).

system to function effectively across these stages, it requires robust and diverse data. This includes: (1) Static Foundational Data, such as the school's curriculum standards, approved textbooks, and institutional policies; (2) Dynamic Interaction Data, encompassing teacher-generated prompts and their subsequent edits to AI-generated content; and (3) Verification-Loop Data, which logs the verification behaviors teachers engage in. This data grounds the AI in the specific educational context and enables personalized, adaptive support.

Stage One: Contextual Awareness & Diagnosis In this stage, the primary roles of the Educational AI Agent are "Analyst" and "Diagnostician." When a teacher begins an instructional task (such as unit planning), the agent rapidly "perceives" the context through natural language dialogue or by analyzing the teaching materials provided.

- Empowering CK & TCK: The agent leverages its vast knowledge base to provide the teacher with cutting-edge, structured subject content (CK) resources. More importantly, it can recommend and simulate various technological means (TK) for presenting specific subject content (TCK), such as using VR to present "cell structures" (Biology CK) or data visualization to show "historical changes" (History CK).
- Diagnosing TPACK Integration Points: Based on the TPACK theoretical model, the agent analyzes the teacher's preliminary design. For example, if the teacher selects "Project-Based Learning" (PK), the agent might proactively ask:

"What technology (TK) do you plan to use to support student 'collaboration' (a PK element) during the project?" This guides the teacher to consider the TPK connection. This stage aims to "awaken" the teacher's TPACK awareness and expose potential integration blind spots.

Stage Two: Scaffolding-in-Practice When the teacher implements the design (e.g., in classroom teaching or online tutoring), the Educational AI Agent transforms into a "Co-pilot" or "Cognitive Scaffold." Support in this stage is immediate and non-intrusive, designed to help the teacher maintain a state of TPACK integration within the authentic, high-cognitive-load flow of teaching.

- Empowering TPK & PCK: In the classroom, the agent can analyze classroom dynamics in real-time (such as student engagement levels or participation distribution). When it perceives a deviation from the intended pedagogy (PK) (e.g., a quiet small group discussion), the agent can push an instant suggestion to the teacher (via a personal device), such as, "Try using the online collaborative whiteboard (TK) to activate the discussion (PK)." Simultaneously, by capturing typical student errors (CK difficulties), the agent prompts the teacher to adjust pedagogical strategies (PCK), for instance, "Most students are confused about this concept; suggest using an 'analogy' (PCK)."
- Maintaining TPACK Dynamic Balance: The challenge in this stage is to ensure that the intervention of technology (TK) does not disrupt the pedagogical flow (PK) or the depth of the content (CK). The agent's "scaffolding" role is dynamic; it provides support when the teacher needs it and "fades" when the teacher can integrate autonomously, thereby preserving teacher agency.

Stage Three: Reflective Practice and Iteration After the teaching practice concludes, the Educational AI Agent transitions into a "Data Coach" and "Reflective Partner." The deep integration of TPACK is ultimately realized through in-depth post-practice reflection.

- Empowering TPACK (Composite): The agent automatically generates an "instructional data portrait." This includes not just "outcome data" like student scores, but also crucial "process data," such as, "When the teacher used Technology B (TK) to explain Knowledge Point A (CK), students' Category C (PK) interaction behaviors increased by X%."
- Structured Reflection Guidance: The agent moves beyond simple data presentation to offer "reflective prompts" based on the TPACK framework. For example: "Data shows that while student engagement was high when you used the simulation software (TK), the accuracy of their conceptual understanding (CK) did not improve. Do you think this might be related to its alignment with your pedagogy (PK)?" Through this structured dialogue, the agent guides the teacher from a TK-centric mindset ("Was the tech good to use?") to a TPACK integration mindset ("Did the technology, pedagogy, and content align?").
- Forming an Iterative Loop: The outcomes of this reflection (e.g., new insights into TPK) are recorded by the agent and "activated" during the next "Contextual Awareness and Diagnosis" (Stage One), helping the teacher optimize their TPACK practice and forming a spiral of professional development.

5. Challenges and Ethical Considerations of the Framework's Application

The implementation of the AIA-TPACK framework is not without obstacles; it poses challenges to technology, teachers, and organizations.

First, the challenge at the technical level lies in the "educational wisdom" of the AI Agent. Current AI performs strongly at the Content (CK) and Technology (TK) levels, but it is still deficient in deeply understanding Pedagogy (PK) and its situated nature. The agent needs to evolve from a "language model" to an "educational model," one that truly comprehends the complex dynamics of the classroom and the subtleties of TPACK integration. This requires that the algorithm design deeply incorporates educational and psychological theories.

Second, the challenge at the teacher level involves "human-agent trust" and "role adjustment." Teachers need to transition from being traditional knowledge authorities to "learning designers" who collaborate with AI. If teachers lack trust in the agent or view it as a "monitor" rather than a "collaborator," the framework cannot operate effectively. Therefore, cultivating teachers' "AI literacy" and "critical technological thinking" (i.e., the 'T' in TPACK) becomes paramount. To make this challenge actionable, the framework proposes specific strategies to foster "calibrated trust." First, ensuring Algorithmic Transparency, where the interface articulates why it suggested a resource or flagged a potential issue. Second, guaranteeing Teacher-in-the-Loop Control, which ensures the teacher always retains ultimate professional autonomy. The interface presents suggestions and warnings, not directives, positioning the AI as a co-pilot, not an auto-pilot, and requiring explicit teacher approval before any content is used.

Finally, there are ethical considerations. The Educational AI Agent needs to collect vast amounts of teaching process data during the "Contextual Awareness" and "Reflective Support" stages, raising serious concerns about student and teacher privacy and data security. Chen Yongwei (2023) noted the significant impact of AI on security and privacy [9], while Guo Leilei (2025) identified risks such as "knowledge authenticity, value deviation, cognitive agency attenuation, and information security risks" in AI [10]. Will the agent's "suggestions" imperceptibly rigidify a certain "optimal" TPACK model, thereby stifling teachers' pedagogical diversity and creativity? Is it possible that the agent's algorithms contain biases, exacerbating educational inequities?

Addressing these challenges requires establishing transparent algorithm review mechanisms, robust data governance regulations, and always adhering to a "Human-in-the-Loop" design philosophy. This ensures that the Educational AI Agent remains a "tool" and "partner" that assists teachers' professional judgment, rather than an "authority" that supplants it.

6. Research Limitations and Future Outlook

The AIA-TPACK framework proposed in this study, as a theoretical exploration, has certain limitations. First, the framework is currently based primarily on theo-

retical deduction and logical construction. Although it strives to be practice-relevant, it has not yet undergone large-scale, multi-context empirical validation. The framework's applicability and effectiveness across different disciplines (e.g., humanities vs. sciences) and educational stages (e.g., K-12 vs. higher education) require further in-depth empirical investigation.

Second, this study focuses on the mechanism by which Educational AI Agents promote TPACK "integration," but the measurement and assessment of "deep integration" remains a difficult problem in the field. The developmental assessment of TPACK itself is complex; evaluating TPACK development under the intervention of AI Agents will require innovative evaluation methods and tools.

Looking ahead, this study provides direction for subsequent empirical exploration and technological development. First, future research should adopt Design-Based Research (DBR) or Action Research (AR) methodologies to apply and iteratively optimize the AIA-TPACK framework in real teaching environments, collecting empirical evidence of teachers' TPACK evolution under the framework's support. Second, the design of Educational AI Agents themselves needs to be more refined. Future agents should possess greater "educational emotional intelligence," "paying attention to the coordination and balance of the agent's affective and cognitive functions" (Xu Zhenguo et al., 2021), and be capable of understanding the subtle balance of TPACK to provide "subtle and silent" support. Third, as the framework is applied, the very connotation of teacher TPACK may evolve; for example, "pedagogical knowledge for collaborating with AI" (AI-TPACK) may become a new direction in the development of TPACK theory.

7. Conclusions

In the era of artificial intelligence, the development of teacher TPACK faces new implications and requires new pathways. Educational AI Agents, with their autonomy, adaptivity, and interactivity, provide an unprecedented technological lever for moving TPACK from "elemental separation" to "deep integration." This study moves beyond the limitation of viewing AI as a singular technology (TK), positioning it instead as a "catalytic environment" and "intelligent partner" that promotes the evolution of the entire TPACK construct.

The AIA-TPACK framework constructed in this study—through the three dynamic stages of "Contextual Awareness and Diagnosis," "Scaffolding-in-Practice," and "Reflective Practice and Iteration"—delineates how Educational AI Agents can systematically intervene in teachers' instructional design, classroom practice, and professional reflection. It guides teachers, within a "practice-reflect-redesign" cycle, to achieve the dynamic integration and deep fusion of technology, pedagogy, and content.

This study argues that the true value of Educational AI Agents lies not in replacing teachers, but in unleashing their potential. The core purpose of the AIA-TPACK framework is to use the "intelligence" of AI Agents to serve and enhance the "wisdom" of teachers, ultimately realizing the educational ideal of human-

agent collaborative education. This exploratory framework is intended to provide a starting point for discussion and critique in subsequent research and practice in this field.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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