

Research on the Reconstruction of University Teachers' AI-TPACK Competence Framework in the Context of Digital Transformation

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Abstract: This study focuses on the theoretical challenges posed by digital transformation to the professional knowledge and competence of university teachers and examines the applicability limitations of the traditional TPACK framework under the integration of intelligent technology. On the basis of explaining the educational implications of digital transformation, this study reviews the academic lineage of AI-TPACK, proposes the framework elements oriented toward intelligent technology integration, and reveals the endogenous evolution of technological knowledge, the structural adjustment of pedagogical knowledge, and the integration dimension of human-machine collaboration. Furthermore, this study constructs the AI-TPACK competence framework from the perspectives of hierarchical structure and generative mechanism, analyzes its constituent dimensions, transformation mechanisms, and transition pathways, and on this basis establishes an evaluation index system, completing index screening, connotation definition, and weight allocation. This research aims to provide a systematic theoretical framework for the development of university teachers' knowledge and competence in the intelligent era and to promote a deep shift in teacher knowledge research from technology integration to human-machine collaboration.

Keywords: Digital Transformation; University Teachers; AI-TPACK; Competence Framework; Generative Mechanism; Evaluation Index System

Introduction

Artificial intelligence, with its cognitive attributes, deeply embeds itself into the educational process, evolving from a teaching assistance tool into a core element, and thus drives a transformation in the modes of knowledge production and dissemination. This transformation requires university teachers' professional knowledge and competence to transcend the technical operation level and extend to the understanding of the content representation mechanism driven by algorithms and the organizational mode of human-machine collaborative teaching. However, the TPACK framework, which was formed in the traditional technological environment, defines technological knowledge within the confines of instrumental cognition, and thus it fails to accommodate the complexity brought by artificial intelligence as an autonomously evolving entity. When intelligent systems possess the potential to perceive contexts and generate content, the relationship between teachers and technology shifts toward a two-way constructive relationship, which raises theoretical demands for the reconstruction of the knowledge framework. This study aims to address this gap by reconstructing the AI-TPACK framework, revealing the generative mechanism and development paths of teachers' knowledge and competence under the integration of intelligent technology. The significance of this study lies in promoting teacher knowledge research from static factor analysis to the exploration of dynamic generative mechanisms, and in providing a conceptual basis and framework reference for understanding teacher professionalism in the intelligent era.

1. The Theoretical Logic of Digital Transformation and University Teachers' Knowledge Base

1.1 The Educational Implications and Technological Representations of Digital Transformation

The penetration of digital transformation into the education field is not a mere technological overlay, but it triggers deep structural changes in the educational system. From the perspective of educational implications, digital transformation transcends the scope of instrumental rationality, reshapes the forms

of knowledge production and dissemination, and drives education from one-way transmission toward multi-dimensional interaction and from standardized provision toward personalized adaptation. The core of this process lies in the fact that data becomes a new production factor and algorithms become a new organizational logic, thereby giving rise to an intelligent educational ecosystem. At the level of technological representations, digital transformation manifests itself in the ubiquitous computing environment constructed by cloud computing, the integration of physical space and digital space achieved by the Internet of Things, and the deep involvement of artificial intelligence technology in the educational process. These technological forms do not exist in isolation, but they intertwine with one another to jointly build a technological complex of perception, connection, computation, and intelligent feedback, thus providing both a fundamental technological premise and a contextual constraint for the reconstruction of teachers' knowledge system.

1.2 The Conceptual Origins and Academic Lineage of AI-TPACK

The proposal of the AI-TPACK concept is rooted in the research tradition of teachers' knowledge in technology integration, and its theoretical origin can be traced back to Shulman's pedagogical content knowledge theory, which was later extended by Mishra and Koehler through the integration of the technology dimension to form the classic TPACK framework. As artificial intelligence technology gradually evolves from an external assistive tool into a teaching intermediary with cognitive attributes, the static and general nature of technological knowledge in the traditional TPACK framework faces challenges to its explanatory power. The academic lineage of AI-TPACK thus unfolds, and its core concern lies in the fact that artificial intelligence is not a neutral technological carrier, but it is a knowledge-based entity characterized by data-driven mechanisms, algorithmic decision-making, and adaptability. Within this lineage, scholars begin to explore how teachers understand the operational logic of artificial intelligence, how they deeply couple the pedagogical possibilities of intelligent tools with subject content, and how they reposition their professional roles in human-machine collaboration, thereby forming a progressive deepening of the conceptual connotation of AI-TPACK^[1].

1.3 A Critical Examination of the Applicability of Existing Frameworks in the Digital Ecosystem

The classic TPACK framework provides a fundamental analytical category for understanding technology integration, but when scholars examine it within the digital ecosystem under the background of digital transformation, its theoretical presuppositions and explanatory framework reveal several points worth questioning. The existing framework defines technological knowledge primarily based on general technological tools, and it fails to fully accommodate the complexity brought by artificial intelligence as a technological form with autonomous evolutionary capabilities. In the digital ecosystem, intelligent systems are no longer merely the executors of teachers' will, but they possess the potential to perceive contexts, generate content, and even provide teaching suggestions, which shifts the relationship between teachers and technology from "use" toward "collaboration." Meanwhile, the clear boundary delineation among knowledge elements in the traditional framework faces certain constraints on its explanatory power when confronted with the phenomenon of knowledge fusion triggered by the penetration of artificial intelligence. This critical examination of the applicability of existing frameworks reveals the academic necessity of constructing a new competence framework that can respond to the characteristics of intelligent technology.

2. Framework Elements of AI-TPACK Oriented Toward Intelligent Technology Integration

2.1 The Endogenous Evolution of Technological Knowledge: From Traditional Technology to Artificial Intelligence

The connotation of technological knowledge in teachers' competence framework has undergone an evolutionary process from instrumental cognition to systemic understanding. In the traditional technology stage, technological knowledge is mainly embodied in the ability to manipulate explicit tools such as multimedia devices and teaching software, and its knowledge form remains relatively stable with clear boundaries. With the penetration of artificial intelligence technology, the nature of technological knowledge has undergone a qualitative change. Artificial intelligence is no longer a passively responding tool, but it is a technological entity equipped with data perception, pattern recognition, and autonomous evolution, and its operational logic is based on the continuous iteration of algorithms and the dynamic optimization of models. This transformation requires teachers'

technological knowledge to shift from static procedural knowledge to dynamic relational understanding, which means that teachers not only need to master the operating interface of intelligent systems, but they also need to gain insight into the underlying data flow mechanisms and algorithmic decision-making logic. The endogenous evolution of technological knowledge signifies that the relationship between teachers and technology shifts from one-way use to two-way construction, and technology is no longer external to teachers' cognition, but it gradually becomes an integral part of teachers' professional knowledge and competence^[2].

2.2 Structural Adjustment of Pedagogical Knowledge: Content Representation Under Algorithmic Logic

The integration of intelligent technology exerts a profound impact on the internal structure of pedagogical knowledge, prompting corresponding adjustments in pedagogical knowledge at the level of content representation. Traditional pedagogical knowledge focuses on the instructional transformation of subject content, that is, how to convert academic knowledge into a cognitive form acceptable to learners. Under the intervention of algorithmic logic, the mode of content representation gains a new technical support dimension. Intelligent systems can dynamically adjust the presentation order, difficulty level, and representation form of content based on learners' behavioral data, thus shifting the organizational logic of pedagogical knowledge from presupposition toward generation. Meanwhile, the algorithmic labeling and relational mining of massive subject content provide teachers with a knowledge organization path that transcends the linear textbook structure. Teachers need to understand how intelligent systems identify the intrinsic connections within content and how to present the core concepts of a discipline in a manner adapted to learners' cognitive states, and this understanding constitutes the core connotation of the adjusted pedagogical knowledge.

2.3 The Integration Dimension of Human-Machine Collaboration: AI's Integration as a Cognitive Partner

The integration of the AI-TPACK framework elements points to a new form of human-machine collaboration, in which the role of artificial intelligence shifts from an assistive tool to a cognitive partner. This transformation means that a distributed cognitive network is formed between teachers and intelligent systems, teaching tasks are jointly undertaken by humans and machines, and the cognitive load is dynamically allocated between the two. As a cognitive partner, the AI system can undertake cognitive tasks such as information filtering, learning analytics, and resource recommendation, thereby freeing teachers from tedious routine work and allowing them to focus on creative teaching decisions and emotional teacher-student interactions. The integration dimension of human-machine collaboration is embodied in teachers' critical acceptance and creative reorganization of AI-generated information, in teachers' examination and calibration of the reasoning logic of intelligent systems, and moreover, in teachers' iteration and updating of their own professional cognition through continuous interaction with AI. This integration dimension reconstructs the internal logic of the teachers' competence framework and elevates human-machine interaction from the technical operation level to the cognitive collaboration level.

3. The Hierarchical Structure and Generative Mechanism of the AI-TPACK Competence Framework

3.1 The Constituent Dimensions and Interactive Relationships of the Competence Framework

The construction of the AI-TPACK competence framework needs to transcend the classification logic of knowledge elements in the traditional TPACK framework and redefine its constituent dimensions from the perspective of competence generation. The framework consists of three core dimensions: the intelligent technology cognition dimension, the subject content transformation dimension, and the teaching context adaptation dimension. The intelligent technology cognition dimension refers to the extent of teachers' understanding of the operational logic of artificial intelligence, including their grasp of algorithmic mechanisms, data representation, and human-machine interaction rules. The subject content transformation dimension involves teachers' ability to reconstruct subject knowledge representation with the help of intelligent tools, which is embodied in the deep coupling of content and technology. The teaching context adaptation dimension focuses on teachers' sensitivity in adjusting technology application strategies within a dynamically changing classroom

ecology. These three dimensions are not arranged in parallel, but they form interactive relationships in a nested manner. Intelligent technology cognition provides a technological prerequisite for content transformation, content transformation in turn provides knowledge support for context adaptation, and context adaptation in turn imposes adjustment requirements on technology cognition, thus forming an internally reinforcing cyclical relationship among the three^[3].

3.2 The Transformation Mechanism from Static Knowledge to Dynamic Competence

The competence within the AI-TPACK framework is not a simple accumulation of knowledge elements, but it is a dynamic product generated through a transformation mechanism in specific teaching contexts. This transformation mechanism involves three key links: contextual triggering, cognitive processing, and behavioral adjustment. Contextual triggering refers to the process in which the technological demands embedded in specific teaching tasks activate teachers' existing knowledge reserves, thereby shifting them from a latent state to an activated state. Cognitive processing refers to the process in which teachers, when facing real teaching problems, comprehensively weigh the possibilities of intelligent technology, the constraints of subject content, and the characteristics of learners, and thus form teaching decisions for technology integration. Behavioral adjustment refers to the process in which teachers fine-tune their teaching strategies based on real-time feedback during technology application, thereby transforming decisions into appropriate teaching actions. These three links form a continuous circular loop, and the completion of each teaching task is not only an application of existing knowledge but also a test and revision of that knowledge. Static knowledge is continuously activated, reorganized, and updated within this cycle, and it finally settles into dynamic competence.

3.3 The Transition Path of Teachers' Knowledge and Competence Under Technological Mediation

The generation of teachers' AI-TPACK competence is not a linear accumulation process, but it achieves staged transitions through key nodes under the mediation of technology. The first node of the transition path is the instrumental integration stage, in which teachers regard artificial intelligence as an operational tool for completing specific teaching tasks, and the competence development is embodied in the familiarity with and mastery of the functions of intelligent systems. The second node is the collaborative adaptation stage, in which teachers begin to understand the cognitive attributes of intelligent systems and form a division of labor and collaboration with AI in the teaching process, and the competence development is embodied in the grasp and application of human-machine interaction rules. The third node is the generative creation stage, in which teachers transcend the constraints of existing technological frameworks and generate new teaching strategies and content organization methods through continuous interaction with AI, and the competence development is embodied in the expansion and redefinition of technological possibilities. The transition between each node depends on teachers' reflective practice, that is, the deep processing and conceptual refinement of technology use experience, and this transition path reveals the qualitative change process of teachers' knowledge and competence under technological intervention^[4].

4. The Construction of the Evaluation Index System for the Reconstructed AI-TPACK Framework

4.1 The Logical Starting Point and Design Principles of the Evaluation Index System

The construction of the evaluation index system for the reconstructed AI-TPACK framework has its logical starting point derived from a deep grasp of the generative mechanism of teachers' competence. The constituent dimensions of the competence framework reveal the static structure of teachers' knowledge and competence, while the transformation mechanism from static knowledge to dynamic competence presents the procedural characteristics of competence operation, and the transition path under technological mediation further demonstrates the staged nature of competence development. Therefore, the construction of the evaluation index system needs to simultaneously accommodate the structural elements, procedural performances, and developmental traits of competence, which not only responds to the logical relationships within the framework but also aligns with the new requirements imposed by digital transformation on teachers' professional knowledge and competence.

Based on this clear logical starting point, the design of the index system follows several fundamental principles. The first principle is the principle of comprehensiveness: the index system

should cover the core dimensions of the AI-TPACK framework and reflect the interactive relationships among these dimensions. The second principle is the principle of hierarchy: the index setting should embody the progressive logic of competence from basic to advanced levels, which corresponds to the transition path of teachers' knowledge and competence. The third principle is the principle of measurability: the connotation of each index should be clearly defined, so that it can be easily measured through observable behavioral performances or obtainable evidence. The fourth principle is the principle of openness: the index system should possess the flexibility for dynamic adjustment, in order to adapt to the iteration of intelligent technology and the evolution of educational scenarios^[5].

4.2 The Screening and Connotation Definition of Core Indicators

Based on the constituent dimensions and generative mechanism of the reconstructed AI-TPACK framework, the screening of core indicators focuses on the three dimensions and their interactive relationships, and this process forms an indicator set composed of three levels of indicators. The first-level indicators correspond to the three dimensions of intelligent technology cognition, subject content transformation, and teaching context adaptation. Under the dimension of intelligent technology cognition, the second-level indicators include technological understanding, data perception, and human-machine collaboration. Technological understanding refers to the depth of teachers' cognition regarding the algorithmic logic, model characteristics, and functional boundaries of artificial intelligence. Data perception refers to teachers' ability to identify and interpret teaching data and to infer learners' states accordingly. Human-machine collaboration refers to teachers' organizational ability to divide labor and collaborate with intelligent systems to jointly complete teaching tasks. Under the dimension of subject content transformation, the second-level indicators cover content deconstruction, representation reconstruction, and knowledge generation.

Content deconstruction refers to teachers' ability to analyze the intrinsic relationships among core concepts of a subject with the help of intelligent tools. Representation reconstruction refers to teachers' ability to adjust the content presentation mode according to learners' cognitive characteristics. Knowledge generation refers to teachers' ability to create new teaching resources and content organization patterns through human-machine interaction. Under the dimension of teaching context adaptation, the second-level indicators include contextual perception, strategic adjustment, and interaction management. Contextual perception refers to teachers' acute awareness of classroom dynamics and the effects of technology integration. Strategic adjustment refers to teachers' flexibility in revising technology integration strategies based on real-time feedback. Interaction management refers to teachers' ability to sustain deep dialogue and emotional connection with learners under technological mediation. Each second-level indicator is further refined into observable third-level indicators, thus forming a complete hierarchical system of indicators.

4.3 Weight Allocation and Hierarchical Model of the Indicator Structure

The weight allocation of the indicator structure needs to reflect the relative importance of each indicator in the AI-TPACK competence framework and the inherent logical relationships among them. Considering the non-parallel nature of the competence dimensions and the hierarchical nature of competence generation, the weight allocation adopts the analytic hierarchy process to establish the judgment matrix, and it obtains the relative importance values of indicators at each level through expert evaluation. In the hierarchical model, the target level is set as the AI-TPACK competence level of university teachers, the criterion level consists of the three dimensions of intelligent technology cognition, subject content transformation, and teaching context adaptation, the sub-criterion level corresponds to each second-level indicator, and the scheme level consists of specific third-level indicators.

The logical basis for weight allocation is as follows: intelligent technology cognition, as the fundamental dimension of competence generation, is assigned a basic weight; subject content transformation, as the core embodiment of teaching professionalism, is assigned a relatively higher weight; teaching context adaptation, as the key field for competence externalization, is assigned a dynamically adjustable weight to reflect its contextual dependence. The consistency test ensures the rationality of the weight allocation, and this process ultimately forms a quantitative weight coefficient system. The construction of the hierarchical model not only presents the quantitative relationships among the indicators, but it also highlights the intrinsic value orientation of the AI-TPACK competence framework through weight allocation. That is, the professional knowledge and competence of university teachers in the intelligent era should take technological cognition as the foundation, content

transformation as the core, and context adaptation as the ultimate goal, and the organic integration of these three elements jointly constitutes a complete structure of teachers' competence.

Conclusion

This study systematically explores the reconstruction of the AI-TPACK competence framework for university teachers in the context of digital transformation. At the level of theoretical logic, this study clarifies the educational implications and technological representations of digital transformation, traces the conceptual origins of AI-TPACK, and critically examines the applicability of existing frameworks in the digital ecosystem. At the level of framework elements, this study reveals the endogenous evolution of technological knowledge from traditional tools to artificial intelligence, the structural adjustment of pedagogical knowledge under algorithmic logic, and the integration dimension of human-machine collaboration as a cognitive partner. At the level of hierarchical structure and generative mechanism, this study establishes three core dimensions of intelligent technology cognition, subject content transformation, and teaching context adaptation along with their interactive relationships, elucidates the transformation mechanism from static knowledge to dynamic competence through contextual triggering, cognitive processing, and behavioral adjustment, and delineates the transition path from instrumental integration to collaborative adaptation and then to generative creation. At the level of the evaluation index system, this study clarifies the logical starting point and design principles, completes the screening and connotation definition of core indicators, constructs a hierarchical model, and establishes the logic of weight allocation. This research provides an integrated theoretical analytical tool for understanding the professional knowledge and competence of university teachers in the intelligent era. Future research can be deepened along the following directions: developing and validating quantitative tools for the evaluation index system, tracing the evolutionary trajectory of teachers' knowledge and competence in human-machine collaboration, comparing the differential impacts of different types of intelligent technologies on the competence framework, and attending to the reconstruction of teachers' professional identity in human-machine collaborative contexts. Through these explorations, it is expected that AI-TPACK research can advance from framework construction to mechanism revelation and from competence description to development promotion.

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