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

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Abstract: *This paper investigates the theoretical problems that digital transformation poses for the professional knowledge and abilities of university teachers, and also studies the application limits of the traditional TPACK model in the era of intelligent technology. According to the explanation of the educational implications of digital transformation, this paper traces the academic lineage of AI-TPACK, puts forward framework elements for intelligent technology integration, reveals the endogenous evolution of technological knowledge, structural adjustment of pedagogical knowledge, and the integration dimension of human-machine collaboration. The AI-TPACK competence framework proposed in this paper has two dimensions: hierarchy and generation mechanism; the components, transformation process and changes will be discussed in this paper, and an evaluation index system for index screening, connotation definition and weight assignment will be developed. The goal of this paper is to provide an organised theoretical foundation for the development of university teachers' knowledge and abilities in the intelligent era, and to promote an important shift in the direction of 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 has many cognitive characteristics, so it has been applied in education at all levels and is now gradually being used to improve teaching and learning by changing how knowledge is created and spread. Therefore, the professional knowledge and abilities of university teachers need to be enhanced from the level of technical operation to include an understanding of how content representation is driven by algorithms and the organisational mode of human-machine collaborative teaching. TPACK was first proposed in the era of traditional technology, and as a result, technological knowledge has been included in the concept of instrumental cognition; thus, it is no longer suitable for dealing with the increase in complexity of artificial intelligence as an autonomous and evolving entity. When intelligent systems are given some context and can generate content, the relationship between teachers and technology will be one of cooperation and construction; thus, new theoretical problems will arise in the construction of the knowledge system. To address the problems mentioned above, this paper proposes a reconstruction of the AI-TPACK framework and investigates the generative mechanism and development path of teachers' knowledge and abilities in the era of intelligent technology. The purpose of this paper is to extend the study of teacher knowledge from the field of static factor analysis to that of dynamic generative mechanisms and to provide a conceptual basis and framework for understanding teacher professionalism in the intelligent era.

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

1.1 Educational Implications and Technological Expression of Digital Transformation

The spread of digital transformation in education is not only new technology; it is also causing significant changes in the structure of education. Digital transformation in education is not just about the rationality of tools; it has changed the form of knowledge creation and dissemination, and education is moving away from one-way transmission and standardised provision towards multi-dimensional interaction and personalised adaptation. At the core of this is that data is now a new factor of

production, algorithms have become a new form of organisation, and thus an intelligent educational ecosystem has emerged. In terms of the type of technology, digital transformation is a whole computing environment based on the cloud; the Internet of Things is the convergence of physical space and digital space; and artificial intelligence technology in education is another. The technologies mentioned above do not exist in isolation but are connected and cooperate to form a technological complex of perception, connection, computation and intelligent feedback that provides both the foundation and the environment for reconstructing the teachers' knowledge system.

1.2 The Conceptual Origins and Academic Lineage of AI-TPACK

The proposal for the AI-TPACK concept is based on the research tradition of teachers' knowledge in technology integration, and its theoretical origin can be traced back to Shulman's theory of pedagogical content knowledge; it was later extended by Mishra and Koehler to form the classic TPACK framework through the addition of the technology dimension. With the development of artificial intelligence technology, it has become a type of knowledge dissemination with cognitive abilities rather than just an external tool, and thus, the fixed and general attributes of technological knowledge in the traditional TPACK model are no longer sufficient to explain this change. Therefore, the academic lineage of AI-TPACK has been traced, and its main focus is that artificial intelligence is not a neutral technology carrier; rather, it is a knowledge-based entity with data-driven mechanisms, algorithmic decision-making and adaptability. Therefore, scholars have begun to study teachers' understanding of the operating logic of artificial intelligence, how to effectively integrate the teaching potential of intelligent tools with subject content in depth, and how to redefine their professional roles in human-machine collaboration; thus, progress has been made in the deepening of the conceptual connotation of AI-TPACK[1].

1.3 Critical Analysis of the Application of Existing Frameworks in the Digital Ecosystem

Although the traditional TPACK framework has offered a general way to study the integration of technology, some problems have arisen in its theoretical assumptions and explanatory power when applied to the digital ecosystem in the era of digital transformation. The current system of technological knowledge only lists general technological tools and does not cover the whole range of artificial intelligence as a type of technology that can develop autonomously. Intelligent systems in the digital ecosystem are no longer just means to achieve one's goals for teachers; they can now sense their surroundings, generate knowledge, offer learning support, and so on, and thus the relationship with technology has moved from "using" it to "coexisting" with it. At the same time, the separate division of knowledge elements in the traditional framework has shown some deficiencies in explaining the phenomenon of knowledge integration that occurs with the introduction of artificial intelligence. Based on the above analysis of the deficiencies in applying the current framework, a new competence system will need to be developed that is suitable for the characteristics of intelligent technology.

2. Framework Elements of AI-TPACK Orientation for Intelligent Technology Integration

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

The concept of technological knowledge in the framework of teachers' competence has changed from instrumental cognition to systemic consciousness. At the stage of traditional technology, the technological knowledge is mainly in the form of the ability to operate explicit tools, such as multimedia devices and teaching software; its type of knowledge is relatively stable and has clear boundaries. With the spread of artificial intelligence technology, the form of technological knowledge has been changing in recent years. Artificial intelligence is no longer a passive response device; now it has developed into an intelligent system that can learn knowledge from data, obtain all kinds of knowledge independently, and adjust its operation according to algorithmic learning. Teachers' knowledge of technology is changing from procedural knowledge to relational understanding; therefore, they need to learn how to use intelligent systems, and at the same time, they also need to know the data flow path in the system and the logic of algorithm decisions. The endogenous development of technological knowledge shows that the relationship between teachers and technology has changed from one of external use to that of joint construction; thus, technology is no longer external to teachers' cognition but has gradually become an intrinsic part of their professional knowledge and competence[2].

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

With the change in the internal structure of pedagogical knowledge due to intelligent technology, modifications need to be made in how this content is presented at the level of pedagogical knowledge. Traditional pedagogical knowledge is concerned with the instructional transformation of subject content; that is to say, how to change academic knowledge into a cognitive form that learners can learn and master. Based on the logic of algorithms, new technical support has been added for the presentation of content recently. Intelligent systems can modify the order, difficulty, form, etc., of the content according to the behaviour data of learners, and thus shift the organisation logic of pedagogical knowledge from presupposition to 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 know how intelligent systems find the inherent connections in the content and how to present the main ideas of a subject in a way that suits the cognitive stage of learners; this knowledge is the core content of adapted teaching knowledge.

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

The elements of the AI-TPACK framework show that this is a new kind of human-machine collaboration; that is to say, AI will no longer be an auxiliary instrument but will assume the role of an intelligent partner. Therefore, a distributed cognitive network will be established among teachers and intelligent systems, teaching tasks will be jointly carried out by people and machines, and cognitive load will be distributed dynamically between the two. As a cognitive partner, some of the cognitive functions of the AI system will be to filter information, conduct learning analytics and recommend teaching materials; thus, the workload of teachers will be reduced, and they can focus more on innovative teaching and emotional support for students. The scope of human-machine collaboration can be seen in how teachers use and are influenced by the information provided by artificial intelligence, how they verify and correct the reasons given by intelligent systems, and also in how they continuously learn and improve their own professional knowledge through interaction with AI. The new part will change the inside working mode of the teachers' competency system and raise the level of human-computer interaction from technical operation to cognitive cooperation.

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

3.1 The Constituent Dimensions and Interplay of the Competence Framework

The construction of the AI-TPACK competence framework should not only follow the classification logic of knowledge elements in the traditional TPACK framework but also redefine its constituent dimensions from the perspective of competence generation. The three parts of the framework are the intelligent technology cognition factor, the transformation mode of subject content, and the adaptation of teaching conditions. The extent to which teachers know about the operation of artificial intelligence is referred to as the dimension of awareness of intelligent technology cognition, and it includes knowledge of algorithmic mechanisms, data representation and rules for human-computer interaction. The dimension of transformation of subject content refers to teachers' ability to reconstruct knowledge representations of the subject with the help of intelligent tools, and it is shown by the deep integration of content and technology. Adaptation of Teaching Context refers to the changes teachers make in the application plan for technology due to changes in the classroom situation. The three dimensions are not independent; rather, they are related to each other in a hierarchical way. At the foundation of intelligent technology cognition is content transformation; content transformation offers the knowledge basis for context adaptation, and finally, context adaptation produces adjustment demands for technology cognition, so these three are in a cycle of self-reinforcement[3].

3.2 Transformation Mechanism of Static Knowledge into Dynamic Competence

Competence in the AI-TPACK framework is not only a collection of knowledge factors but also a change that has taken place in a particular teaching situation. The three links in this chain of events are Contextual Triggering, Cognitive Processing and Behavioural Adjustment. Contextual triggering is the activation of a teacher's existing knowledge resources and a change in their state from inactive to active due to the appearance of technological demands in a particular teaching situation. Cognitive processing is the way teachers consider all the options in response to real teaching problems, determine whether

intelligent technology is suitable, how it can be integrated with the subject content and the characteristics of learners, and then make a decision on whether to use technology. Behavioural adjustment is the modification of a teacher's teaching plan based on new information obtained during the implementation of technology, and this plan will be adjusted accordingly. The three links are connected in a circle, and the completion of each teaching task is not only the application of existing knowledge but also a test and revision of that knowledge. Static knowledge is constantly being recalled, organised and modified in this cycle, and finally it becomes dynamic ability.

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

The development of teachers' AI-TPACK competence has not been steady; instead, there have been several periods marked by considerable changes under the influence of technology. The first node in the transition path is the instrumental integration stage; at this time, teachers see artificial intelligence as a way to help achieve particular teaching goals, and the corresponding competency development can be observed in how familiar they are with and understand the functions of intelligent systems. The second node is the collaborative adaptation stage; at this time, teachers begin to learn about the cognitive features of intelligent systems, form a division of labour and cooperate with AI in the teaching process, and the development of competence is demonstrated by the understanding and application of human-machine interaction rules. The third stage is generation; here, teachers will go beyond the limitations of the current technological system to develop new teaching strategies and ways of presenting content in continuous cooperation with artificial intelligence, and competence development will be shown through the expansion and redefinition of technological possibilities. The change at each node is the result of teachers' reflective practice; that is to say, deep processing and conceptualisation of technology-using experience, and this path of change shows the qualitative development process of teachers' knowledge and abilities under the influence of technology[4].

4. 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 foundation of the construction for the evaluation index system of the reconstructed AI-TPACK framework is a deep understanding of the generation mechanism of teachers' competence. The constituent dimensions of the competence framework are a fixed structure of teachers' knowledge and abilities; the process of change from fixed knowledge to dynamic abilities shows the procedural nature of ability operation, and the path of development under technological mediation is also staged. Therefore, in building the evaluation index system, one should take into account the structural components, procedural effectiveness and development trends of teacher competence at the same time; that is to say, one needs to address the logical relationships in the framework and meet the new demands of digital transformation for teachers' professional knowledge and abilities.

Based on the above clear logical start, the Design of the index system will follow some general rules. The first is the rule of all-encompassing coverage; that is, the index system should cover the main parts of the AI-TPACK framework and show how they work together. The second is the rule of hierarchy: the index set should show the increasing logic of competence from basic to advanced, and it should be in line with the path of teachers' knowledge and ability development. The third is the principle of measurability; that is to say, the meaning of each index should be specified so that it can be easily observed in behavioural expressions or obtained by means of evidence. The fourth is the rule of openness; that is, it needs to be constantly updated to keep up with the developments in intelligent technology and changes in the educational environment[5].

4.2 The Screening and Connotation Definition of Core Indicators

According to the constituent dimensions and generation mechanism of the reconstructed AI-TPACK framework, the screening of core indicators will focus on the three dimensions and their interaction, and thus a set of indicators at the three levels will be formed. The three general indices are the three dimensions of intelligent technology cognition, subject content transformation and teaching context adaptation. The two indices in the level of intelligent technology cognition are technological literacy and data literacy and human-computer interaction. Technological literacy refers to how well teachers know the algorithms, models, functions and so on of artificial intelligence. A teacher's perception of data is their capacity to recognize and interpret teaching data in order to understand the current state of

the students. Human-machine collaboration is the organisation of teachers to divide labour and work together with intelligent systems in teaching activities. Under the dimension of transformation in the content of the subject, the two-level indicators are content deconstruction, representation reconstruction and knowledge generation.

Content deconstruction refers to the teacher's ability to find the internal links among the main ideas of a subject with the help of intelligent tools. Teacher representation reconstruction is the modification of content presentation modes in line with the cognitive traits of learners. Knowledge generation refers to teachers' creation of new teaching materials and organisation of content in cooperation with machines. The two levels of adjustment in the teaching environment are contextual awareness and modification and regulation of interaction patterns. Teachers' detailed knowledge of the class environment and how to use technology are known as contextual awareness. Strategic adjustment is to change one's plan for applying technology in teaching due to changes in circumstances. Interaction management is teachers' capacity to maintain close communication and emotional contact with students in the age of technology. Each secondary index has been broken down further into observable tertiary indices, and thus the whole hierarchy of indices has been established.

4.3 Weight Allocation and Hierarchical Model of the Indicator Structure

The distribution of weights in the index structure should reflect the relative weight of each index in the AI-TPACK competence framework and its own logical relationships. Given that the dimensions of competence are not parallel and competence generation has a hierarchy, the Analytic Hierarchy Process (AHP) is used to construct a judgment matrix and obtain the relative importance weights of indicators at all levels through expert judgment. At the top of the hierarchy is the AI-TPACK competence level of university teachers; the criteria at the second level are the three components of intelligent technology cognition, subject content transformation and teaching context adaptation; the sub-criteria at this level correspond to the second-level indicators, and specific third-level indicators are listed in the schemes.

The logical basis for the weight distribution is as follows: Intelligent technology cognition is the foundation level of competence generation in intelligent technology cognition, so it is given a basic weight; subject content transformation constitutes the core of teaching professionalism, and it is assigned a relatively high weight; teaching context adaptation serves as an important place for the externalisation of competence, and a dynamic weight will be given based on circumstances. Consistency Test: Confirm that the weight distribution is reasonable and establish a quantitative system of weight coefficients. In the construction of the hierarchy model, one can show the quantitative relationships among all the indicators and also present the intrinsic value orientation of the AI-TPACK competence framework through weight assignment. That is to say, the professional knowledge and abilities of university teachers in the intelligent era should be based on technological cognition, focus on content transformation, and aim for context adaptation; the organic integration of these three components constitutes the whole system of teachers' competence.

Conclusion

The organisation of the AI-TPACK competency framework for university teachers in the era of digital transformation is the subject of this paper. Based on the theoretical logic of this paper, we will investigate the educational connotations and technological expressions of digital transformation, trace the conceptual origin of AI-TPACK, and critique the applicability of the current framework in the digital ecosystem. At the level of framework elements, this paper finds that technological knowledge has developed endogenously from traditional tools to artificial intelligence, pedagogical knowledge has been organised according to the logic of algorithms, and the integration dimension of human-machine collaboration as a cognitive partner has been revealed. The three general ideas of intelligent technology cognition put forward in this paper are the transformation of subject content, the adaptation of the teaching context, and their interaction; it investigates how to change fixed knowledge into flexible abilities through contextual cues and changes in thinking, charts a course from tool application to teamwork and finally to idea generation. At the level of the evaluation index system, this paper offers the logical starting point and design ideas; it has completed the screening and connotation definition of the main indicators, constructed a hierarchical model, and laid out the logic for weight allocation. The combined theoretical framework for studying the professional knowledge and abilities of university teachers in the intelligent era is presented below. Future research, development and validation directions for quantitative tools of assessment index systems will track the progress of teachers'

knowledge and abilities in human-machine collaboration, compare the various effects of all kinds of intelligent technologies on the competence framework, and address the issue of reconstructing teachers' professional identity in human-machine collaborative environments. Based on the above exploration, it is hoped that research on AI-TPACK will move from framework construction to mechanism revelation and from competence description to development promotion.

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