Research Postprint on the Technological Pedagogical Content Knowledge (TPACK) Model

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Abstract

[Purpose/Significance] The TPACK framework does not describe the hierarchical levels of knowledge, knowledge generation and transformation processes, etc. This paper constructs a TCP teacher knowledge system model that more comprehensively describes the structure of teachers' TPACK. [Method/Process] Based on the TPACK framework, three dimensions—knowledge domain, knowledge hierarchy, and knowledge correlation degree—are added to construct a three-dimensional TCP teacher knowledge system model. Drawing on principles from systems science and knowledge theory, deductive thinking and derivation are performed, and the relationships among variables in the system are analyzed using three-dimensional geometric forms. [Result/Conclusion] The analysis reveals that TPACK changes under the influence of the knowledge domain, knowledge hierarchy, and knowledge correlation degree of TK, PK, and CK. Improvements in knowledge domain, knowledge hierarchy, and knowledge correlation degree promote TPACK integration, and four approaches to promoting teachers' TPACK integration are proposed.

Full Text

Preamble

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Technological Pedagogical Content Knowledge (TPACK) of Teachers
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Abstract

[Purpose/Significance] The TPACK framework does not describe the hierarchical levels of knowledge, nor the processes of knowledge generation and transformation. This paper constructs a TCP teacher knowledge system model to provide a more comprehensive description of teachers' TPACK structure. [**Method/Process**] Based on the TPACK framework, three dimensions—knowledge domain, knowledge level, and knowledge correlation degree—are added to construct a three-dimensional TCP teacher knowledge system model. Drawing on principles from systems science and knowledge science, the study employs deductive reasoning and derives relationships among variables within the system using solid geometry. [**Result/Conclusion**] The analysis reveals that TPACK is influenced by changes in the knowledge domain, knowledge level, and knowledge correlation degree of TK, PK, and CK. Improvements in these three dimensions promote the integration of TPACK. Four approaches to facilitating teachers' TPACK integration are proposed.

Keywords: Technological Pedagogical Content Knowledge; TPACK; teacher knowledge model
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1 Overview of TPACK Theoretical Framework Development

The "Technological Pedagogical Content Knowledge" (TPCK) theoretical framework was proposed by P. Mishra and M. J. Koehler in 2006 [?]. This theory reveals what knowledge teachers should possess in the information age and what forms of knowledge can most effectively support teaching, providing explanations for knowledge components within teacher knowledge frameworks and offering directions for teacher knowledge research. Mishra and Koehler argue that TPCK represents the most effective form of knowledge for supporting teachers' instructional activities, and that developing TPCK should become an extremely important goal of teacher education.

From a systems science perspective, the TPACK framework constitutes a system. Technological Knowledge (TK), Content Knowledge (CK), and Pedagogical Knowledge (PK) form the overall system. Their pairwise intersections constitute three dual-interactive knowledge forms: Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK), as well as one triple-interactive knowledge form: Technological Pedagogical Content Knowledge (TPCK). These three knowledge types are not simple additive combinations but rather form new knowledge structures through mutual connections and dynamic interactions. To facilitate pronunciation and memorization, the American Association of Colleges for Teacher Education changed "TPCK" to "TPACK," emphasizing its holistic nature [?]. The TPACK framework is illustrated in Figure 1 [Figure 1: see original paper].

The TPACK framework attends to all knowledge elements within it, but it has certain limitations, such as blurred conceptual boundaries, unclear relationships among various knowledge types, and ambiguous mechanisms of interaction and integration. C. Angeli and N. Valanides [?] replaced technology (T) with Information and Communication Technology (ICT) in TPACK, added learner knowledge and learning context knowledge, and proposed the ICT-TPCK framework. This model focuses on the integrated knowledge form of technological pedagogical content knowledge rather than knowledge formed by combining basic components [?], and its fusion of five knowledge components makes the framework more complex and relationships among elements more difficult to analyze. Yan Zhiming et al. [?] proposed the Technological Pedagogical Content Knowledge Network model (TCPNet), distinguishing knowledge components and their relationships, shifting the focus of teacher knowledge research from parts to the whole, and further enriching the explanatory power of the TPACK theoretical framework. Liu Zhe [?] validated through path analysis models and structural equation models the relationships among one-dimensional, two-dimensional integrated knowledge and TPACK: one-dimensional core knowledge in the TPACK framework positively influences two-dimensional interactive knowledge but does not directly affect TPCK; two-dimensional interactive knowledge positively influences TPCK, with the most significant impact.

However, the current TPACK framework can only be considered a top-level schematic diagram of teacher knowledge. It represents the composition of teacher knowledge and explains knowledge types and two-dimensional relationships, but it does not describe hierarchical levels of knowledge nor explain the cognitive transformation processes in TPACK development. Without in-depth research into the integration mechanisms of TK, PK, and CK, the broad and vague use of the TPACK concept will weaken its theoretical significance and consequently affect its guiding role in practice [?]. To address these issues, this study constructs a TCP teacher knowledge system model to conduct more detailed deconstruction of the mutual influences among TPACK's internal elements, analyze the influence relationships of TK, PK, and CK on PCK, TPK, TCK, and TPCK, and attempt to describe teachers' TPACK structure more comprehensively. Based on the TPACK framework, three dimensions—knowledge domain, knowledge level, and knowledge correlation degree—are added to clarify the mutual relationships and integration mechanisms of the three knowledge types within the teacher knowledge system.

2 Logical Levels and Generative Mechanisms of Knowledge

2.1 Understanding of Knowledge

Knowledge is a composite phenomenon with multiple facets. Therefore, the TCP teacher knowledge system model employs a three-dimensional diagram instead of TPACK's original two-dimensional framework, enabling knowledge description to be presented at a three-dimensional level. Knowledge also possesses logical hierarchies. The creation and development of knowledge is a logical process of transforming data into information and information into knowledge, forming a spirally ascending unity [**?**]. Consequently, the TCP teacher knowledge system model reflects changes in logical levels of knowledge to further reveal the true nature of facts.

2.2 Logical Levels of Knowledge

From a cognitive perspective, the processes of knowledge generation, transformation, dissemination, and utilization occur at several different levels. The lower level forms the foundation and material for the upper level, while the upper level represents the organization and sublimation of the lower level. The higher the level, the greater the difficulty and the more complex the content. The logical hierarchy of knowledge constitutes a "cognitive continuum" composed of data—information—knowledge—wisdom, forming a complex recursive system from low to high, shallow to deep, and easy to difficult. While hierarchical levels have progressive relationships, they are not linearly arranged but rather mutually overlapping, intersecting, and multi-dimensionally coupled (see Figure 2 [Figure 2: see original paper]).

The implications of knowledge science theory for the TPACK model are that knowledge is established and accumulated over long periods, involving not only quantitative accumulation but also qualitative improvement. Therefore, knowledge is not a planar element but a multi-dimensional three-dimensional structure with logical hierarchies.

3 System Characteristics of the TPACK Knowledge Framework

A system is a universal form of material existence. An organic whole composed of two or more interdependent and interacting elements (or variables) with certain functions is called a system. The TPACK knowledge framework possesses system characteristics, summarized as follows:

3.1 Holistic Nature

A system is composed of more than two elements, but not as a random 堆砌 of these elements; rather, they are organized according to a certain structure. A change in one element of a system will cause changes in other elements, while any element's change also depends on changes in other elements. The three core elements in TPACK have dynamically interactive and mutually influential relationships. If any of these elements changes, the other two elements will change to "compensate" [?].

3.2 Openness

Knowledge exists and is generated within certain semantic environments. The environment and conditions upon which this process depends constitute the knowledge field. Knowledge achieves information acquisition, aggregation, and transformation through interaction with the knowledge field (environmental conditions). TPACK is an open system, and constructing a benign, information-rich environment is crucial, directly affecting system input and internal transformation.

3.3 Dynamic Nature

Knowledge is a dynamic mixture of experience, values, contextual information, expert opinions, and basic intuition [?], whose spatial structure continuously changes over time. Teachers' knowledge domains, knowledge levels, and knowledge correlation degrees are constantly developing and changing, affecting the knowledge structure. In different contexts, the three elements of TK, PK, and CK play different roles, making the integration of education and technology highly variable and producing diverse system outputs.

3.5 Self-Organization

The hierarchical structure of a system is its fundamental nature. Knowledge hierarchies resemble a pyramid: moving upward, the knowledge space gradually narrows while the complexity level gradually increases. The lower level is the foundation, while the upper level represents enhancement. TK, PK, and CK are all hierarchical knowledge. For example, TK includes two meanings: materialized technology and intelligent methods and skills [?]. When TK integrates with PK and CK, it also exhibits hierarchical characteristics. The lowest level of integrating information technology with teaching is the renewal of instructional media, where technology serves merely as a materialized tool, generating new teaching media during integration.

The "self-organization" process refers to spontaneous transformation from disorder to order, and from one ordered state to a higher ordered state. Order and disorder both represent certain system structures. For instance, when students cannot understand the teacher's lecture, it indicates disorder in their knowledge organization. The essence of knowledge organization is implementing a series of ordering activities to address the disorderly state of objective knowledge [?]. The knowledge integration process also advances spirally through chaos—order—chaos—order. We expect teachers' knowledge structures to be self-organizing systems with higher degrees of order. When internal system elements reach certain threshold conditions (such as knowledge quantity accumulation and knowledge level improvement), they can spontaneously transform toward order or greater order.

4 TCP Teacher Knowledge System Variables and Relationships

This study defines elements of the TCP teacher knowledge system using solid geometry and visualizes relationships among elements. The effect produced after elements form a system is called organizational effect, which is influenced by the nature of element attributes, system structure, and the strength of internal system synergy. Therefore, this study decomposes knowledge into three elements: knowledge attributes (type and domain), knowledge structure (organizational hierarchy), and knowledge interaction (correlation effect).

4.1 Definition of Main Variables

Based on the logical levels of knowledge and the factors involved in the TPACK knowledge model, this study proposes a TCP teacher knowledge system model with systematic structure that can visually represent the three-dimensional space and hierarchical structure of knowledge. As shown in Figure 3 [Figure 3: see original paper], TPACK is generated within an open semantic environment, achieving information acquisition and aggregation from the environment and transforming it into knowledge. TPACK emerges from the multiple interactive integration of three knowledge types; knowledge is hierarchical, with the knowledge space gradually narrowing and complexity levels gradually increasing from bottom to top; different knowledge types influence each other through dynamic interaction; when TPACK elements and external environmental changes reach certain threshold conditions, they trigger "self-organization," promoting knowledge transformation toward order or greater order.

Three cones are used to represent the three different types of knowledge entities: TK, PK, and CK. The base area of a cone represents the knowledge domain, expressing the scope of knowledge; the height of a cone represents knowledge depth, expressing logical levels of knowledge; the distance between cones represents the degree of knowledge convergence, expressing knowledge correlation degree. The TCP teacher knowledge system is a three-dimensional representation of the TPACK theoretical framework, as shown in Figure 4 [Figure 4: see original paper].

This study assumes that factors such as knowledge failure rate and knowledge acquisition efficiency remain unchanged in the short term. To emphasize the equality and unity of the three core elements, it assumes the three core elements are equal (i.e., the three cones are identical in size).

(1) Knowledge is unstable and treated as a variable. Cones represent the three variables of first-order knowledge TK, PK, and CK, which pairwise

integrate to generate second-order interactive knowledge PCK, TCK, and TPK, and integrate at the center to generate third-order interactive knowledge TPCK.

(2) Each knowledge entity corresponds to a knowledge domain, represented by the cone's base area S. The larger S is, the broader the knowledge domain scope and the greater the quantity of horizontal knowledge.

(3) A cone consists of different hierarchical levels, representing logical levels of knowledge. From bottom to top, levels gradually increase, and knowledge complexity levels also gradually increase. The cone's height h represents the depth of vertical knowledge. The larger h is, the higher the knowledge level, the more optimized the knowledge structure, the more organized the knowledge, and the greater the knowledge difficulty.

(4) The cone's volume V represents knowledge space. The larger V is, the greater the knowledge space and the richer the knowledge quantity. $V = sh$.

(5) The distance d between cones represents the correlation degree among knowledge types. The smaller d_{first}-order is, the closer the cones are, the higher the correlation degree among knowledge types, the easier it is to establish connections between knowledge, and the more readily knowledge integrates.

4.2 Relationships Among Variables

Using deductive reasoning and solid geometry, this study derives relationships among variables:

(1) When the knowledge domain changes—for example, when horizontal knowledge accumulates to a certain extent—the knowledge level will increase, meaning knowledge depth improves. Geometric analysis shows that when S_{first}-order increases, S_{second}-order and S_{TPCK} increase, h_{second}-order and h_{TPCK} also increase, thereby V_{second}-order and V_{TPCK} also increase. This demonstrates that increases in the knowledge domains of TK, PK, and CK lead to increases in the knowledge spaces of second-order and TPCK knowledge, improving the degree of TPACK integration.

(2) As the depth of TK, PK, and CK increases, the depth of integrated second-order knowledge also increases, thereby affecting the depth of TPCK. Improvements in knowledge levels promote knowledge sublimation, generating larger knowledge spaces, and the integrated second-order and TPCK knowledge spaces also increase, thereby improving TPACK integration levels. Geometric analysis shows that when h_{first}-order increases, h_{second}-order and h_{TPCK} increase, thereby V_{second}-order and V_{TPCK} also increase.

(3) The closer the connections among knowledge types, the more easily knowledge fuses and develops toward greater order. Improvements in knowledge correlation degree promote knowledge generation and development, thereby enhancing knowledge depth and levels. Geometric analysis shows that when d_{first}-order decreases, cones converge more closely, S_{second}-order and S_{TPCK} increase, h_{second}-order and h_{TPCK} also increase, thereby V_{second}-order and V_{TPCK} increase. This indicates that greater knowledge convergence and higher correlation degree lead to larger integrated knowledge spaces and higher degrees of TPACK integration.

The general patterns are: TPACK is dynamically changing knowledge, and its generation is influenced by the knowledge domain, knowledge level, and knowledge correlation degree of its constituent elements. Second-order knowledge is directly influenced by first-order knowledge, and TPCK is influenced by second-order knowledge. Increases in knowledge domain, improvements in knowledge level, and enhancements in knowledge correlation degree all improve the degree of knowledge integration, playing a promoting role in TPACK integration. Although knowledge domain, knowledge level, and knowledge correlation degree do not have a proportional linear relationship with knowledge integration degree, they exhibit a positive correlation in overall interaction.

5 Approaches to Promoting Teacher TPACK Integration

Integration refers to combining scattered elements to form a valuable and efficient whole. This study treats the knowledge integration process as knowledge innovation, which must involve human self-construction to be completed. The above TCP teacher knowledge system analysis concludes that increases in knowledge domain, improvements in knowledge level, and enhancements in knowledge correlation degree all improve the degree of knowledge integration and optimize integration effects. Therefore, four key approaches to promoting TPACK integration can be identified:

(1) **Extensively acquire information, excavate knowledge, expand the knowledge domains of TK, PK, and CK, and balance self-development across knowledge areas.** Larger knowledge domains lead to higher degrees of knowledge integration. Sufficient quantitative accumulation of data and information is necessary for effective knowledge generation. According to systems theory, only when internal elements reach certain threshold conditions can self-organization form, promoting transformation from disorder to order. This requires teachers to extensively learn various types of knowledge, expand knowledge domains, complete the accumulation of original knowledge, and strengthen their ability to excavate knowledge, enabling them to extract sufficient effective information from massive data. Among the three core elements of TPACK, TK changes most dramatically. With rapid technological iteration, technology has become a significant and active element in modern education.

Technology is no longer merely a means of information transmission but serves as a cognitive tool to enhance students' higher-order cognition and extend users' thinking processes [**?**]. From traditional blackboards and chalk to today's intelligent terminals, interactive whiteboards, and digital schoolbags, technology has become dominant knowledge in the new era. TPACK essentially represents teachers' "ability to effectively integrate technology with subject teaching (PCK)." Therefore, teachers must continuously pay attention to and update their technological knowledge. Regarding subject content, teachers must not only master the curriculum materials students are currently learning but also be familiar with other subjects students are simultaneously studying. Furthermore, as defects in system parts affect overall function—the "barrel effect" where the shortest board determines water storage capacity—teachers must balance their knowledge development and promptly identify and fill knowledge gaps.

(2) **Improve the hierarchical levels of TK, PK, and CK knowledge, continuously summarize patterns, extract strategies, and promote the transformation of knowledge into wisdom.** Higher knowledge levels lead to higher degrees of knowledge integration. Knowledge creation undergoes the process of "information—knowledge—wisdom—creation," requiring teachers to classify and assign meaning to extracted information, establish connections, correspond to specific contexts, and elevate knowledge levels from "knowing" to "wisdom." Teachers must continuously summarize patterns, extract strategies, and transform "knowledge" into "ability" applied in "action." Regarding technology levels, R. R. Puentedura proposed the SAMR model focusing on the depth of technology integration, dividing technology application levels into "substitution—augmentation—modification—redefinition" [**?**]. The lowest level of technology use is as a direct tool substitute without functional change; the next level is as a tool for improvement and functional enhancement; then comes redesign for modification; the highest level is creative function exertion. Technology tools should first be used effectively for their conventional functions, becoming habitual through frequent application. Second, based on technology's affordances, teachers should apply technology creatively, breaking its original "functional fixedness." Reconfiguring and repurposing existing technology functions for teaching represents an approach to improving technological knowledge levels. In the digital age, teachers must strive to elevate their technological knowledge levels, pursue immersive technology experiences and innovative applications, and become wise individuals in the digital era.

(3) **Establish connections among TK, PK, and CK knowledge, improve knowledge correlation degree, and enhance knowledge fusion and fitting abilities.** Higher knowledge correlation degree leads to higher degrees of knowledge integration. The key to knowledge integration lies in establishing connections among knowledge types. TPACK is not only a knowledge form but also a thinking strategy and high-level abil-

ity. To achieve TPACK integration, teachers must deeply understand CK, PK, TK, and the tensions among them, and continuously establish connections and rebalance according to changes in the three elements. Knowledge creation principles tell us that to integrate new knowledge into existing knowledge and fuse different knowledge into a unified whole, teachers must make knowledge into interconnected knowledge chunks, then connect these fused chunks through fitting to form an orderly and systematic whole that promotes knowledge development. In the TCP teacher knowledge system, TPACK integration degree is affected by knowledge correlation degree, which is related to knowledge fusion degree. Therefore, teachers must possess knowledge fusion and fitting abilities. Additionally, teachers should increase contextual connections among subject content, pedagogy, and technology knowledge, strengthening connections between their disciplines and social practice and with other subject content.

(4) **Obtain integration experience and improve knowledge integration ability through autonomous inquiry, self-construction, and repeated practice.** TPACK belongs to "ill-structured" knowledge, and the problems it addresses are "wicked problems." Therefore, solutions can only be found through teachers' cognitive flexibility in combining and intersecting the three knowledge types [**?**]. Improving teachers' own knowledge integration ability is the fundamental approach to addressing the variable combinations of TK, CK, and PK. Integrated knowledge requires teachers to personally experience the complete integration process, establishing and strengthening knowledge connections through autonomous inquiry, self-construction, and repeated practice to gain TPACK integration experience. Therefore, content materials in teacher education should be "incomplete" and require "integration," rather than being pre-integrated, otherwise teachers lose opportunities to imagine various "possibilities," open their thinking, and train their knowledge integration abilities. The so-called "construction" precisely addresses the "incompleteness" in knowledge formation processes. Element "absence" in the TPACK system allows teachers to recognize defects caused by this absence and then rethink and establish new connections based on this "defect." It also enables the integrated knowledge to have extensive diversity, not limited by fixed objects, facilitating exploratory learning beyond conventional boundaries. Element "absence" essentially resets variables in the system, as shown in Figure 5 [Figure 5: see original paper].

When one element of the system changes, to maintain dynamic balance of the overall system, the other two elements also change to "compensate." Element "absence" creates weak connections among system elements, a structural relationship that facilitates information acquisition because weak connections link two different categories of knowledge with different information sources, which is conducive to transmitting fresh or heterogeneous information and knowledge. Figure 5(a) shows content materials lacking TK, thus TK and PK, TK and CK form weak connections. Teachers need to acquire new information to supplement the missing parts and re-establish and strengthen connections. In this system, the original three knowledge variables become PK and CK as known independent variables, with TK becoming a dependent variable (changing according to PK and CK combinations). Teachers must design the "missing" part—specifically, concrete technological solutions—based on known content to adapt to specific content objectives and contexts, repurposing technology functions according to teaching goals to improve technology application levels. In Figure 5(b), CK is absent; when PK and TK are independent variables, CK can produce multiple outcomes based on different combinations of PK and TK. For the same teaching content, when technology serves as demonstration presentation, expression communication, information processing, cognition, collaboration, or research and development tools, correspondingly different teaching methods can be employed. In Figure 5(c), when two elements are absent, there are more variable factors, more complex integration methods, and higher integration difficulty, making it suitable for advanced teacher training. By supplementing the "missing" parts, teachers continuously excavate knowledge, establish connections among knowledge types, and fuse and fit knowledge during self-construction, thereby improving knowledge integration ability.

6 Conclusion

Current digital technology has penetrated every aspect of people's learning and lives—progress without technology is nearly impossible. However, in the specific domain of teacher professional knowledge, technology is mostly treated as an external tool without being deeply "integrated." TPACK is the pyramid of teacher professional knowledge and a core component of teacher qualification certification and cultivation orientation. "Decoding" it helps better reveal the true nature of practice. The TCP teacher knowledge system model makes the systematic structure of TPACK more visualized, providing direction for how teachers can meaningfully integrate technology into specific subject domain teaching and offering theoretical support and inspiration for further research in teacher education. Future research should focus on methods and strategies for TPACK integration, particularly integrating technology and content knowledge (TCK)—that is, how to use technology to solve teaching problems in modern teaching environments (TPK).

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Note: Figure translations are in progress. See original paper for figures.