

From Components to Configurations: A Systematic Review of Design Approaches in TPACK-Based Teacher Professional Development

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ABSTRACT:

This study examines how design approaches in TPACK-based teacher professional development are structured and enacted, addressing a key limitation in existing research that predominantly catalogs discrete components without explaining how they are organised into coherent learning sequences. Drawing on a PRISMA-guided systematic review of empirical studies, the analysis adopts a structural perspective to investigate how learning activities are configured, sequenced, and integrated. The findings indicate that commonly emphasised features, such as technology-related input, become meaningful only when embedded within coherent configurations. Across studies, professional development is better understood as a configuration of interdependent components organised into four recurring design patterns—technology-focused, design-oriented, practice-based, and integrated modular—providing a systematically derived typology of learning configurations in the TPACK literature. These patterns reflect varying degrees of structural integration and help explain previously inconsistent findings regarding the effectiveness of similar professional development elements. In addition, the analysis identifies iteration as a generative mechanism through which design, implementation, and reflection are recursively linked, enabling the progressive integration and refinement of teachers' technological, pedagogical, and content knowledge over time. By shifting the analytical focus from component inclusion to structural configuration and iterative enactment, this study offers a configuration-based and process-oriented framework for understanding TPACK-based professional development, contributing to explaining variation across studies and informing the design of coherent and sustainable professional learning programmes.

Keywords: TPACK; teacher professional development; design approaches; systematic review; modular design.

1. Introduction

The integration of digital technologies into classroom teaching has become an essential component of contemporary education systems worldwide. Schools increasingly expect teachers to incorporate digital tools and technological resources into their instructional practices in order to enhance student engagement, support diverse learning needs, and promote twenty-first century competencies. Despite this growing emphasis, the effectiveness of technology integration in classroom practice remains uneven, and many teachers continue to experience difficulties in using digital technologies in pedagogically meaningful ways (Abedi, 2024; Tondeur et al., 2017). This gap between increasing expectations and inconsistent outcomes suggests that technology integration cannot be understood solely in terms of access or technical skills, but requires a more comprehensive understanding of how technology interacts with pedagogy and subject matter knowledge in specific instructional contexts (Mishra & Koehler, 2006; Voogt et al., 2013).

To address this complexity, the concept of Technological Pedagogical Content Knowledge (TPACK) was proposed to describe the integrated knowledge base required for effective technology-enhanced teaching (Mishra & Koehler, 2006). The TPACK framework emphasises that teachers must understand the dynamic relationships among technological knowledge, pedagogical knowledge, and content knowledge in order to design meaningful learning experiences (Koehler et al., 2013; Tseng et al., 2022). Since its introduction, TPACK has become one of the most influential theoretical models for examining technology integration in teacher education and professional development (Voogt et al., 2013). However, recent systematic reviews indicate that advancing TPACK research requires greater attention to how it is operationalised within professional development designs, rather than focusing solely on the presence of isolated instructional features (Dogan et al., 2025; Li et al., 2025).

In response to persistent challenges in technology integration, teacher professional development (TPD) has been widely recognised as a key mechanism for supporting teachers' development of TPACK and improving instructional practices (Amemasor et al., 2025; Tondeur et al., 2016). Within the broader literature on TPD, substantial attention has been devoted to identifying features of effective professional development. Influential studies have highlighted elements such as content focus, active learning, collaboration, and sustained duration as critical for supporting teacher learning (Desimone, 2009; Darling-Hammond et al., 2017). In the context of technology integration, these features are often operationalised through activities such as collaborative lesson design, classroom implementation, and reflective practice (Yurtseven Avci et al., 2020).

While this body of research provides valuable insights into the components of professional development, it predominantly adopts a component-based perspective in which individual features are treated as discrete variables. This analytical approach presents important conceptual and explanatory limitations. First, it tends to fragment professional development into independent elements, overlooking the interdependent nature of teacher learning processes. Second, it pays limited attention to how learning components are structurally organised, sequenced, and interconnected within coherent instructional designs. Third, by focusing on component inclusion, existing research struggles to explain why similar features often produce inconsistent outcomes across different studies (Philipsen et al., 2019; Fabian et al., 2024). These limitations suggest that current research largely operates at the level of features rather than at the level of learning processes, thereby constraining a deeper understanding of how professional development actually works.

In response to these limitations, recent research has begun to emphasise design-oriented and practice-based approaches to TPD, highlighting the

importance of structured learning processes that integrate design, implementation, and reflection (Godsk & Nielsen, 2024). These approaches conceptualise professional development as a system of interdependent learning activities rather than a collection of isolated features. For example, the DECODE model conceptualises professional development as an iterative cycle of demonstration, co-design or teaching, feedback, and debriefing to support TPACK development (Chang et al., 2025). Similarly, hybrid Community of Practice models emphasise sustained, collaborative, and iterative engagement in authentic teaching contexts (Mahlo & Waghid, 2025). Although these studies highlight the importance of structured processes, they remain fragmented in how such processes are conceptualised and reported, and they provide limited systematic insight into how learning activities are configured into coherent design patterns across different contexts.

To address this gap, this study adopts a configuration-based perspective. In this study, a configuration refers to the structured arrangement of interrelated learning components, including their sequencing, interaction, and iterative enactment within a professional development programme. This perspective enables the analysis of professional development not only in terms of what components are included, but also in terms of how these components are organised into coherent learning processes that shape teacher learning and influence outcomes.

Therefore, the purpose of this study is to conduct a systematic literature review of TPACK-based teacher professional development in order to examine how design approaches are structurally organised and enacted. Drawing on a PRISMA-guided review of empirical studies, this study analyses how learning components are combined into configurations, identifies recurring design patterns across studies, and examines how differences in these configurations contribute to variation in reported outcomes.

Specifically, this study addresses the following

research questions:

RQ1: What key learning components are present in TPACK-based teacher professional development programmes?

RQ2: How are these components structurally configured into recurring design approaches or patterns?

RQ3: How do different configurations help explain variation in the reported effectiveness of TPACK-based professional development?

This study contributes to the literature in three ways. First, it advances a theoretical shift from a component-based perspective to a configuration-based understanding of TPACK-oriented professional development, thereby addressing limitations in existing analytical approaches. Second, it develops an analytical framework for identifying and comparing recurring design patterns across studies, providing a structured basis for cross-study synthesis. Third, it offers an explanatory account of how structural configurations and iterative processes shape variation in professional development outcomes. Through these contributions, the study provides both a theoretically grounded explanation of how TPACK-based professional development operates and practical insights for designing coherent and sustainable professional learning programmes.

2. literature review

2.1 Conceptual Foundations of TPACK in Teacher Professional Development

The Technological Pedagogical Content Knowledge framework, originally proposed by Punya Mishra and Matthew J. Koehler, has become a dominant theoretical lens for understanding teacher knowledge in technology-integrated education. Extending Pedagogical Content Knowledge introduced by Lee Shulman, TPACK conceptualizes teacher knowledge as an interaction among content, pedagogy, and technology, rather than as discrete domains (Mishra & Koehler, 2006).

In the field of teacher learning, teacher professional development (TPD), also referred to as continuing

professional development (CPD), is widely recognized as a key mechanism for enhancing teachers' knowledge and instructional practices in response to evolving educational demands (Desimone & Garet, 2015; Darling-Hammond et al., 2017). Within this context, recent scholarship has increasingly emphasized the dynamic, situated, and context-dependent nature of TPACK, highlighting that teachers' knowledge develops through practice and is shaped by institutional, cultural, and technological environments (Yeh et al., 2022).

This perspective aligns with contemporary theories of TPD that conceptualize teacher learning as socially mediated, practice-based, and embedded in authentic teaching contexts. Accordingly, TPACK is no longer viewed merely as a static knowledge framework but as a lens for understanding how teachers integrate technology meaningfully in real classroom settings (Larsen, 2023).

In TPD contexts, the TPACK framework has been extensively applied to guide the design and evaluation of professional learning interventions. Rather than focusing on isolated technological skills, TPACK-oriented TPD emphasizes the integration of pedagogy and content through purposeful technology use, supporting teachers in developing contextually relevant instructional strategies (Liu & Mutlu, 2025). This shift reflects a broader transformation in TPD toward practice-based, collaborative, and design-oriented approaches that prioritize authentic learning experiences over decontextualized training (Darling-Hammond et al., 2017).

Emerging empirical studies further indicate that TPACK-based TPD can enhance teachers' instructional design competence, technology integration practices, and student engagement, particularly when learning activities are sustained, collaborative, and closely aligned with classroom practice (Kali et al., 2019). However, the reported outcomes vary considerably across studies, suggesting that the effectiveness of TPACK-based TPD is highly dependent on the design approaches and implementation conditions adopted.

Despite its widespread adoption, the TPACK framework has been subject to sustained critique. Concerns have been raised regarding its conceptual ambiguity and overlapping constructs, which complicate both theoretical clarity and empirical measurement (Willermark, 2018; Yeh et al., 2022). In addition, some studies suggest that TPACK-based TPD initiatives remain tool-centric in practice, failing to fully realize the integrative potential of the framework (Choi & Young 2021). Moreover, insufficient attention to contextual factors has limited the transferability of TPACK-informed interventions across diverse educational settings (Gatete, 2026).

These limitations indicate a need to move beyond treating TPACK as a static knowledge framework toward examining how it is enacted through specific design approaches in teacher professional development. In particular, greater attention should be paid to how learning environments, instructional strategies, and collaborative structures are designed to support the development of integrated knowledge. This provides the conceptual foundation for the present systematic literature review, which aims to analyze and compare design approaches in TPACK-based teacher professional development.

2.2 Design Approaches in Teacher Professional Development

Recent research on teacher professional development (TPD) has increasingly shifted from transmission-oriented models toward design-oriented approaches that emphasize how professional learning experiences are structured and enacted. Rather than conceptualizing TPD as a set of isolated activities, contemporary studies highlight the importance of designing coherent learning processes that support teachers' sustained engagement with practice (Darling-Hammond et al., 2017; Harper-Hill et al., 2022). This perspective positions TPD as a structured and iterative system in which multiple learning components are intentionally organized to promote professional

growth.

A central design orientation in TPD is practice-based professional development, which foregrounds the integration of learning activities with authentic classroom practice. In this approach, teachers engage in cycles of lesson planning, classroom implementation, and reflective refinement, allowing them to develop and apply instructional strategies in context (Heitink et al., 2017). Such designs are widely recognized for their effectiveness in bridging the gap between theoretical knowledge and instructional practice, particularly when learning tasks are closely aligned with teachers' everyday teaching responsibilities (Koh et al., 2020). As a result, practice-based structures are increasingly considered a foundational component of effective TPD design.

Closely related to practice-based approaches is the emphasis on reflective and inquiry-oriented design, which supports teachers in critically examining their instructional decisions and student learning processes. Reflection is often embedded within iterative learning cycles through activities such as lesson analysis, peer feedback, and self-evaluation (Cochran-Smith & Lytle, 2009; Postholm, 2012). Inquiry-based elements, including action research and data-informed reflection, further enhance teachers' ability to adapt and refine their practices. These reflective processes are essential for transforming experience into professional knowledge and sustaining long-term learning.

With the increasing integration of digital technologies in education, technology-mediated design has become another important dimension of TPD. Online and blended learning environments provide opportunities for flexible access to resources, asynchronous interaction, and extended learning beyond traditional workshop formats (Trust & Horrocks, 2019; Philipsen et al., 2019; Mulenga & Shilongo, 2025). However, recent studies emphasize that the effectiveness of technology-mediated TPD depends not on the presence of technology itself, but on how learning activities are designed to support interaction,

scaffolding, and meaningful engagement (Dede et al., 2020). This highlights the need to align technological tools with pedagogical purposes and learning goals (Mishra & Koehler, 2006).

In addition to these core design orientations, collaboration is widely recognized as an important supporting feature within TPD design. Rather than functioning as an independent approach, collaboration is most effective when embedded in structured activities such as joint lesson planning, peer discussion, and shared reflection (Voogt et al., 2013; Admiraal et al., 2021; Indriayu, 2025). These collaborative elements can enhance knowledge sharing and reflective dialogue, but their impact depends on how they are integrated into the overall design of professional learning processes.

Across these perspectives, the literature converges on a set of core design features that underpin effective TPD. These include the integration of practice-based activities, opportunities for reflection, the strategic use of technology, and structured forms of collaboration, as well as sustained duration and coherence across learning components (Desimone & Garet, 2015; Darling-Hammond et al., 2017). More recent research further emphasizes the importance of organizing these elements into coherent and iterative learning sequences, suggesting that effective TPD should be conceptualized as a modular and evolving system rather than a collection of discrete interventions (Kohnke 2024; Morgan et al., 2026).

Despite these advances, existing studies reveal considerable variation in how design features are conceptualized and implemented. Similar learning activities are often described using different terminologies, and there is limited consistency in how design elements are combined and evaluated across contexts (Kennedy, 2016; Van Merriënboer et al., 2024). This lack of conceptual clarity makes it difficult to systematically compare TPD models and to identify which configurations of design features are most effective.

Therefore, a more systematic analysis of TPD design is needed, particularly in relation to how

different design features are integrated into coherent learning structures. This need is especially salient in technology-integrated contexts, where teachers are required to develop complex and interconnected forms of knowledge. Accordingly, the following section examines how these design features are specifically enacted within Technological Pedagogical Content Knowledge-based teacher professional development.

2.3 Design Approaches in TPACK-Based Teacher Professional Development

Building on the design-oriented perspectives outlined in the previous section, recent research has increasingly examined how design features are enacted within Technological Pedagogical Content Knowledge-based teacher professional development (TPD). In contrast to general TPD models, TPACK-based approaches place greater emphasis on the integration of technology, pedagogy, and content within structured learning processes. As a result, the design of professional development is not only concerned with how teachers learn, but also with how different knowledge domains are coordinated through specific learning activities (Fathurrochman et al., 2025).

A key characteristic of TPACK-based TPD is the central role of technology-integrated design tasks. Rather than treating technology as an isolated skill, many studies position lesson design as a core learning activity through which teachers develop integrated knowledge (Jiménez Sierra et al., 2023). These design tasks typically require teachers to align technological tools with pedagogical strategies and subject content, thereby operationalizing TPACK in concrete instructional contexts (Koh et al., 2020). This emphasis on design-oriented learning reflects a shift from technology training toward knowledge integration through practice.

In addition to design tasks, practice-based implementation is widely recognized as a critical component of TPACK-based TPD. Effective programs often extend beyond planning activities to

include classroom enactment, allowing teachers to test technology-integrated lessons in real teaching environments (Kali et al., 2019; Agyei et al., 2024). This implementation phase enables teachers to experience the complexities of technology integration and to refine their instructional strategies based on authentic classroom interactions. Closely linked to implementation is the role of structured reflection, which supports the transformation of experience into professional knowledge. Reflection in TPACK-based TPD is typically embedded within iterative cycles and may involve lesson analysis, student feedback, or guided evaluation of teaching practices (De Vries, 2024). Through these reflective processes, teachers are able to critically examine the alignment among technology, pedagogy, and content, thereby deepening their understanding of integrated knowledge.

Another important dimension is the use of technology-mediated learning environments to support professional development. Digital platforms are often employed not only as tools for instruction but also as environments for resource sharing, discussion, and documentation of teaching practices (Trust & Horrocks, 2019; Philipsen et al., 2019). However, consistent with broader TPD research, the effectiveness of these environments depends on how they are integrated into the overall design, particularly in relation to scaffolding, interaction, and continuity of learning activities (Wolfenden, 2022; Nguyen et al., 2026).

While collaboration is frequently incorporated in TPACK-based TPD, it is typically embedded within structured design and reflection activities rather than functioning as a standalone approach. For example, teachers may engage in peer discussion during lesson design or share feedback following classroom implementation (Pieters et al., 2020; Admiraal et al., 2021). In this sense, collaboration serves as a supporting mechanism that enhances reflection and knowledge sharing, rather than as the primary driver of professional learning.

Across these studies, a consistent pattern emerges in which TPACK-based TPD is organized as a sequence of interconnected learning components. These components commonly include (1) technology-oriented input or demonstration, (2) technology-integrated lesson design, (3) classroom implementation, and (4) reflective evaluation. Rather than operating independently, these elements are typically arranged in iterative cycles, allowing teachers to progressively refine their understanding and practice. This structured sequencing suggests that TPACK-based professional development can be conceptualized as a modular and iterative learning system, in which each component contributes to the development of integrated knowledge.

Despite these emerging patterns, existing research remains fragmented in how TPACK-based design approaches are conceptualized and reported. Different studies emphasize different components, and there is limited consistency in how learning sequences are structured or evaluated (Yeh et al., 2022). Moreover, few studies provide a systematic comparison of how different design configurations influence teacher learning outcomes. This lack of coherence highlights the need for a more structured analytical framework to examine TPACK-based TPD design.

Therefore, this study adopts a systematic approach to analyze how design features are combined into coherent learning structures in TPACK-based teacher professional development. In particular, the review focuses on identifying recurring learning components and design patterns, providing the basis for the development of an analytical framework used in the subsequent methodology and results sections.

3. Methodology

This study adopts a systematic literature review approach to examine design approaches in Technological Pedagogical Content Knowledge (TPACK)-based teacher professional development (TPD), guided by the PRISMA (Preferred Rep

orting Items for Systematic Reviews and Meta-Analyses) framework to ensure transparency, rigor, and replicability. In line with the conceptual focus of this study, the review does not aim merely to describe the presence of professional development features, but to analyse how learning components are structured, sequenced, and integrated into coherent design configurations. This configuration-oriented perspective enables the investigation of professional development as a structured learning process rather than a collection of isolated elements.

The literature search was conducted using two major academic databases, Scopus and Web of Science, selected for their comprehensive coverage of high-quality peer-reviewed journals in education and educational technology. The search strategy was developed based on three key conceptual domains, namely TPACK, teacher professional development, and design or structure. Boolean operators were used to construct the search strings, for example (“TPACK” OR “technological pedagogical content knowledge”) AND (“teacher professional development” OR “teacher training”) AND (“design” OR “approach” OR “model”). The search was limited to studies published between 2010 and 2025 in order to capture contemporary developments in technology integration and TPACK-based professional development.

To ensure the relevance and quality of the selected studies, a set of inclusion and exclusion criteria was established. Studies were included if they (1) focused on TPACK in the context of teacher professional development, (2) reported empirical research findings, (3) explicitly described the design or structure of professional development programs, and (4) were published in peer-reviewed journals in English. Studies were excluded if they (1) were purely theoretical or conceptual without empirical data, (2) focused on pre-service teacher education without a professional development component, or (3) lacked sufficient description of program design. After removing duplicates, titles and abstracts were screened, followed by full-text review against the

eligibility criteria. This process resulted in a final sample of 30 studies. Among these, 20 empirical studies provided sufficiently detailed descriptions of professional development activities to support in-depth structural coding, while the remaining 10 studies were retained as supporting and theoretical references to contextualize the findings.

For data analysis, a coding framework was developed through an iterative process, informed by relevant literature on TPACK and teacher professional development, and refined based on patterns emerging from the selected studies. At the first level, the analysis identified recurring learning components in TPACK-based TPD, including technology-related input, technology-integrated lesson design, classroom implementation, reflective activities, and supporting elements such as collaboration and technology-mediated environments. At the second level, the analysis examined how these components were structured and combined within each programme, with particular attention to the sequencing of learning activities, the interaction among components, and the presence of iterative cycles linking design, enactment, and reflection. This two-level analytical approach enables the study to move beyond identifying isolated features and to examine how components form coherent and recurring design configurations across different studies.

The coding process followed a structured and iterative procedure. Categories were refined through constant comparison across studies to ensure conceptual clarity and internal consistency. In addition, pattern identification was conducted by examining structural regularities in how components were combined, rather than relying solely on frequency counts. This involved identifying recurring sequences, relationships, and cycles of learning activities that could be conceptualised as configuration patterns. Such an approach allows for the comparison of design logics across studies and provides a basis for analysing how different configurations relate to variations in reported outcomes.

To enhance analytical rigor, all studies were systematically re-examined throughout the coding process, and discrepancies in interpretation were addressed through repeated comparison with the original texts. This ensured that the identified components and configurations were grounded in the data rather than based on isolated interpretations. Overall, this methodological approach enables a systematic and theoretically grounded examination of TPACK-based teacher professional development, providing a robust foundation for analysing how structured configurations of learning activities shape professional development outcomes.

Section 4 Results

4.1 Study Characteristics

This section presents the overall characteristics of the studies included in the review, providing an empirical foundation for the subsequent coding-based structural analysis. Following a systematic screening procedure guided by the PRISMA framework, a total of thirty studies were retained. The full coding results for all included studies are reported in Appendix A, ensuring transparency and traceability of the analytical process.

Among these studies, a subset of twenty empirical studies (S1–S20) was used for the structural coding and quantitative analysis of learning components. The remaining studies (S21–S30) were retained as supporting and theoretical references to contextualize the findings.

The temporal distribution of the included studies is concentrated between 2020 and 2025, indicating increased research activity in TPACK-based teacher professional development. Earlier studies were included to provide conceptual grounding. Geographically, the studies represent diverse contexts, including Asia, North America, and Europe, suggesting that TPACK-based professional development is widely implemented across educational systems.

Most studies focus on in-service teachers in primary and secondary education, while fewer studies

address pre-service or higher education contexts. Methodologically, the dataset includes qualitative, quantitative, and mixed-methods approaches. Across these studies, professional development activities commonly involve combinations of instructional design, classroom implementation, and reflective processes.

4.2 Learning Components in TPACK-Based Professional Development

4.2.1 Coding Framework and Analytical Strategy

To examine the structural organization of TPACK-based teacher professional development, a coding framework was developed to capture the presence

and co-occurrence of key learning components. Six components were identified: technology-related input, technology-integrated lesson design, classroom implementation, reflective activities, collaboration, and technology-mediated environment.

Each empirical study (S1–S20) was coded at the study level using binary indicators (presence or absence), based on explicit descriptions of professional development activities reported in the original publications. The complete coding results are presented in Appendix A.

Table 1 provides an illustrative excerpt of the coding structure used in this study.

Table 1. Coding Framework for TPACK-Based Teacher Professional Development

Study ID	Tech Input	Lesson Design	Implementation	Reflection	Collaboration	Tech Environment	Pattern
S1	✓	✓	✓	✓	✓	✓	Integrated
S2	✓	✓	✓	✓	✗	✓	Integrated
S3	✓	✓	✓	✗	✗	✓	Practice-based
S4	✓	✓	✗	✗	✓	✓	Design-oriented

The analytical strategy focuses on identifying recurring configurations of components across studies, rather than examining components in isolation. This approach enables the analysis of how learning activities are structurally combined within professional development programs.

4.2.2 Distribution, Co-occurrence, and Structural Roles of Learning Components

The distribution and co-occurrence of learning components across the empirical studies are presented in Table 2.

Table 2. Distribution and Co-occurrence of Learning Components (n = 20)

Component	Frequency	Typical occurrence	Co-Observed Role in Studies
Technology-related input	20	Most components	Reported as initial activity across studies
Technology-integrated lesson design	20	Most components	Present in all studies as a core activity
Classroom implementation	13	Design, Reflection	Reported in studies including enactment phases

Component	Frequency	Typical occurrence	Co-Observed Role in Studies
Reflective activities	12	Design, Implementation	Reported following design or implementation
Collaboration	7	Design	Reported in group-based or co-design activities
Technology-mediated environment	20	Most components	Reported as supporting infrastructure

The results indicate that technology-related input, technology-integrated lesson design, and technology-mediated environments are present in all empirical studies ($n = 20$), suggesting that these components form a common structural foundation in TPACK-based professional development.

In contrast, classroom implementation is reported in 13 studies, reflective activities in 12 studies, and collaboration in 7 studies, indicating variation in how these components are incorporated across different programs.

In terms of co-occurrence, technology-related input and lesson design frequently appear together, indicating that technology training is commonly embedded within structured design activities. Classroom implementation and reflective activities are typically reported in studies that include enactment phases, suggesting that these components are associated with practice-oriented configurations. Collaboration is most often linked to design-oriented activities, particularly in co-design or group-based settings.

Technology-mediated environments are reported across all studies and co-occur with multiple components, indicating their role as enabling infrastructure rather than standalone elements.

From a structural perspective, the components appear to perform different roles within professional development processes. Technology-

related input often functions as an entry point, while lesson design operates as a central integrative activity through which technological, pedagogical, and content knowledge are combined. Classroom implementation represents the contextual enactment of these designs, and reflective activities provide a mechanism for iterative refinement. Collaboration and technology-mediated environments act as supporting conditions that facilitate interaction and access across stages.

Taken together, these findings show that learning components are not implemented independently, but are commonly configured into recurring combinations within individual studies. These recurring configurations provide the empirical basis for identifying design patterns in TPACK-based professional development.

4.3 Design Patterns in TPACK-Based Professional Development

4.3.1 Identification of Design Patterns

Based on the recurring configurations identified in the coding results (Appendix A) and the co-occurrence patterns observed in Table 2, four design patterns were identified. These patterns are defined by the presence and combination of learning components within each study.

Table 3. Design Patterns in TPACK-Based Professional Development

Pattern	Components Included	Number of Studies	Representative Studies	Description
Technology-focused training	Tech, Tech Env	1	S16	Limited configuration centred on technology input
Design-oriented professional development	Tech, Design, (Collab)	7	S4–S7, S11, S17, S19	Design activities as central component
Practice-based professional development	Design, Impl, Reflect	5	S3, S9, S14, S15, S20	Inclusion of enactment and reflection
Integrated modular professional development	Most components	7	S1, S2, S8, S10, S12, S13, S18	Multi-component configurations within the same program

The patterns were derived inductively from the data, reflecting consistent configurations observed across multiple studies rather than predefined categories. Technology-focused training is observed in one study (S16), where professional development is primarily centred on technology-related input with limited integration of other components. Design-oriented professional development is observed in eight studies, where lesson design is the central activity, often accompanied by technology input and, in some cases, collaboration. Practice-based professional development is identified in seven studies, where lesson design, classroom implementation, and reflective activities are reported together. Integrated modular professional development is observed in seven studies, where multiple components co-occur within structured and iterative learning sequences.

4.3.2 Structural Variation Across Design Patterns

The identified patterns differ in terms of both the number of components included and the way these components are combined. These differences can be interpreted as variations in the degree of structural integration within professional development designs.

Technology-focused training represents a limited configuration in which learning is primarily centred on technology-related input. Design-oriented professional development introduces a higher level of integration by positioning lesson design as the central mechanism for connecting technological and pedagogical knowledge. Practice-based professional development extends this configuration by incorporating classroom implementation and reflective activities, thereby strengthening the connection between professional learning and teaching practice. Integrated modular professional development represents the most comprehensive configuration, in which multiple components are systematically aligned and iteratively enacted within the same program. These variations indicate increasing levels of structural integration across patterns, without implying a fixed developmental sequence.

4.4 Structural Synthesis of Learning Activities

The synthesis of evidence from the coding results (Table 1), component distribution (Table 2), design patterns (Table 3), and study-level evidence (Appendix A) indicates recurring sequences and structural relationships among learning activities. Across studies that include multiple components, professional development activities are commonly reported in sequences that begin with technology-

related input, followed by technology-integrated lesson design, and subsequently classroom implementation. Reflective activities are reported in

relation to both design and implementation stages, often forming iterative cycles.

Technology Input → Lesson Design ↔ Reflection → Implementation

Figure 1. Structural Sequence of Learning Activities

In this sequence, technology-related input serves as the entry point into professional learning, while lesson design functions as the central integrative process. Reflection interacts dynamically with both design and implementation, forming a feedback loop that supports iterative refinement of teaching practices. Classroom implementation provides the contextual grounding for this process.

Collaboration and technology-mediated environments are not confined to a single stage but are reported across multiple stages, functioning as enabling conditions that support interaction and access to resources.

Overall, the findings indicate that TPACK-based teacher professional development can be understood as a structurally integrated and iterative configuration of learning activities. Rather than suggesting causal relationships, the results highlight how different components are systematically combined and enacted within coherent sequences across studies. This structural perspective provides a basis for interpreting variation in professional development designs and offers an analytical lens for future research examining how such configurations operate in specific educational contexts.

5. Discussion

This study advances the argument that TPACK-based teacher professional development is more effectively explained as a structurally configured and iteratively enacted system of learning activities, rather than as the accumulation of discrete components. While prior research has predominantly focused on identifying key features of effective professional development, such component-based approaches tend to treat these features as independent variables. This orientation

fragments professional development into isolated elements and limits its capacity to explain the variability and inconsistency observed across empirical studies. The present findings therefore suggest a shift in analytical focus: professional development effectiveness is fundamentally shaped by how learning activities are configured and enacted within coherent instructional sequences.

This perspective establishes a direct dialogue with existing literature. Prior studies have identified features such as content focus, active learning, collaboration, and sustained duration as central to effective professional development (e.g., Desimone, 2009; Philipson et al., 2019; Tondeur et al., 2020). However, these features are typically examined as discrete variables, which constrains their explanatory power in capturing how professional learning unfolds over time. The findings of this study suggest that such features become meaningful primarily when they are structurally aligned within professional development processes. In this sense, the study does not reject component-based perspectives, but repositions them by demonstrating that component inclusion alone is insufficient to explain how professional learning is organised, sustained, and translated into practice.

A central insight emerging from this analysis concerns the differentiated roles of learning components within configurations. At the component level, technology-related input appears consistently across all studies and functions as an entry point into professional learning. However, technology input alone does not constitute the core of professional development. Instead, technology-integrated lesson design operates as the central integrative activity through which technological, pedagogical, and content knowledge are

coordinated. This indicates that TPACK development is driven less by the acquisition of technological knowledge and more by the situated process of designing instruction.

In contrast, classroom implementation and reflective activities are not uniformly present across studies, but tend to co-occur in configurations that emphasise practice-oriented learning. Their inclusion marks a shift toward enactment-based professional development, where teachers engage with authentic classroom contexts. Reflection functions as a linking process between design and implementation, enabling the iterative refinement of instructional practices over time. Collaboration and technology-mediated environments, while frequently highlighted in prior research, operate here as enabling conditions rather than core drivers. Their contribution depends on their structural alignment with core learning activities. When embedded within coherent sequences, they support interaction and access to resources; when introduced as standalone elements, their contribution remains limited.

Building on these component-level configurations, the identification of four design patterns provides a higher-level analytical lens. While configurations describe the co-occurrence and sequencing of components at the micro level, patterns represent recurring configuration logics at the meso level across studies. Technology-focused training reflects a low-integration pattern, where technological knowledge remains weakly connected to pedagogical application. Design-oriented professional development positions lesson design as the central activity and represents the most frequently observed pattern. Practice-based professional development extends this configuration by incorporating classroom implementation and reflection, thereby strengthening the connection between professional learning and teaching practice. Integrated modular professional development represents a high-integration pattern, in which multiple components are systematically aligned and enacted within

sustained cycles. These patterns function not only as descriptive categories, but as an explanatory framework that accounts for variation across studies and clarifies why similar components produce inconsistent outcomes when configured differently. A central mechanism that underpins these configurations is iteration. Across studies, professional development activities are organised in sequences that connect technology input, lesson design, classroom implementation, and reflection. Within these sequences, iteration operates as the mechanism through which components become functionally integrated. First, iteration enables cognitive integration, as repeated engagement in technology-integrated lesson design requires teachers to continuously coordinate technological, pedagogical, and content knowledge. Second, iteration supports contextualised enactment, as classroom implementation situates instructional designs within authentic teaching contexts and allows for adaptation in response to contextual constraints. Third, iteration facilitates feedback-driven refinement, as reflective activities generate evaluative feedback that informs subsequent design decisions. These processes operate as an integrated cycle in which design, enactment, and reflection are recursively linked. Without such iterative cycles, configurations remain structurally present but pedagogically fragmented. Iteration is therefore not merely supportive, but necessary for enabling configurations to function as coherent professional learning systems.

Taken together, these findings support a reframing of TPACK-based professional development. Professional learning is more appropriately understood as a configuration of interdependent learning activities, rather than as a set of independent features to be accumulated. More specifically, the study suggests that professional development effectiveness is shaped by configuration and iteration, rather than by component inclusion alone. This formulation provides a more coherent explanation for the variability observed across studies and addresses a

key limitation in existing component-based accounts.

From a theoretical perspective, this study contributes by shifting the unit of analysis from individual components to the structural relationships among learning activities, and by introducing iteration as a generative mechanism that explains how these structures operate over time. In doing so, it advances a configuration-based and mechanism-oriented framework for understanding TPACK development, offering a more integrated account of how professional learning is organised and sustained.

These insights have implications for both research and practice. For research, the findings highlight the need to move beyond variable-based analyses and adopt approaches that capture the sequencing, interdependence, and dynamics of learning activities. Future studies may examine how different configurations operate across contexts and how iterative mechanisms support sustained teacher development. For practice, the findings indicate that effective professional development requires the orchestration of coherent learning sequences, in which technology input, lesson design, implementation, and reflection are systematically connected. Enabling conditions such as collaboration and technology-mediated environments should be strategically aligned with these sequences to support, rather than substitute for, structural coherence.

At the same time, several boundary conditions should be acknowledged. The analysis is based on reported descriptions of professional development in published studies and therefore reflects how programmes are documented rather than how they are enacted in practice. In addition, the coding framework captures the presence of components but does not account for differences in quality, intensity, or contextual implementation. These factors may influence how configurations operate in specific settings. Furthermore, while the study identifies recurring configurations and patterns, it does not establish causal relationships between

these configurations and teacher outcomes. Further empirical research is needed to examine how different configurations influence learning outcomes and how contextual factors shape their implementation.

6. Conclusion, Implications, and Limitations

This study set out to systematically examine design approaches in TPACK-based teacher professional development through a structured synthesis of empirical literature. By moving beyond descriptive accounts of individual components, the study provides a theoretically informed understanding of how professional development is organized and enacted.

The findings demonstrate that TPACK-based professional development is more appropriately conceptualized as a structurally integrated and iteratively enacted system, rather than as a collection of discrete instructional elements. In particular, the study highlights the centrality of iterative cycles linking lesson design, classroom implementation, and reflective practice, through which integrated teacher knowledge is progressively developed. Furthermore, the identification of distinct design patterns underscores that the effectiveness of professional development is closely associated with the degree of structural coherence and integration achieved within program design. This suggests that the effectiveness of professional development is not determined by component inclusion alone, but by how these components are systematically configured and enacted over time.

From a theoretical perspective, this study contributes to the literature by advancing a structural-processual conceptualization of TPACK development. Rather than treating professional development as the accumulation of independent features, this study reframes it as a configuration of interdependent learning activities. This perspective extends existing interpretations of the TPACK framework by emphasizing not only the integration of knowledge domains but also the mechanisms through which such integration is realized in practice. In particular, iteration is identified as a key

mechanism that enables the integration of learning components; without iterative cycles linking design, enactment, and reflection, the configuration of components is unlikely to function as a coherent professional learning system. In doing so, the study addresses a critical gap in prior research, where the lack of structural theorization has limited the explanatory depth of professional development models.

From a practical perspective, the findings provide important implications for the design of TPACK-based professional development programs. Specifically, effective programs should prioritize:

- □ the systematic integration of multiple learning components rather than isolated training activities;
- □ the incorporation of iterative learning cycles that enable continuous refinement of teaching practice;
- □ the alignment of professional development activities with authentic classroom contexts to support meaningful enactment.

In addition, collaboration and technology-mediated environments should be strategically aligned with these learning sequences to support interaction and access, rather than treated as standalone features. These principles offer a foundation for the development of structured and scalable professional development modules, particularly in the context of continuing professional development for in-service teachers.

Despite these contributions, several limitations

should be acknowledged. First, the study is based on a selected corpus of empirical studies, and while efforts were made to ensure diversity and relevance, the sample may not fully capture the breadth of global research on TPACK-based professional development. Second, the analysis relies on interpretive coding of published studies, which is inherently subject to researcher interpretation, despite efforts to maintain analytical consistency. Third, the focus on design approaches means that the study does not directly evaluate the effectiveness of specific interventions in terms of measurable learning outcomes. In addition, the analysis is based on reported descriptions of professional development, and therefore may not fully capture how these configurations are enacted in practice or how variations in quality and intensity influence their operation.

Future research should extend this work by conducting empirical investigations that examine how configuration and iteration operate within specific educational contexts. In particular, there is a need for design-based research that examines how iterative and modular professional development models can be implemented and adapted in practice. Such research would further strengthen the connection between theoretical conceptualization and practical application in the field of TPACK-based teacher professional development.

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