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Revisiting TPACK research through measurement, context, and affective dimensions: A thematic synthesis of empirical studies (2015–2024)

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Abstract

This study presents a systematic thematic synthesis of empirical research on Technological Pedagogical Content Knowledge (TPACK) published between 2015 and 2024. Following PRISMA 2020 guidelines, 94 peer-reviewed studies indexed in Scopus and Web of Science were analyzed to examine how program design features, contextual conditions, measurement approaches, and affective variables shape teachers' enactment of TPACK. Using qualitative thematic synthesis, findings were organized into four analytical dimensions: professional development and teacher education design, contextual enablers and constraints, measurement regimes, and affective factors such as beliefs, attitudes, and self-efficacy. The results indicate that TPACK development is a dynamic and context-sensitive process rather than a static body of knowledge. Importantly, frequently reported TPACK gains are often contingent on the measurement regime employed and the contextual affordances within which teachers operate, rather than serving as direct indicators of enacted classroom transformation. Systematic discrepancies between self-reported and performance-based measures reveal critical methodological challenges in interpreting TPACK outcomes and help explain persistent contradictions in the literature. By integrating measurement, context, and affective dimensions within a single analytical framework, this synthesis provides an explanatory evidence map that clarifies divergent findings and offers actionable implications for future teacher education research and practice.

Introduction

Digital technologies have become an integral component of curricula and teacher education policies in many countries around the world. International policy documents emphasize teachers' ability to use technology in pedagogically meaningful ways in their classrooms as a fundamental requirement and have developed various frameworks to support this goal accordingly. For instance, UNESCO's ICT Competency Framework for Teachers (ICT-CFT) sets out a range of standards for technology-enhanced teaching within teacher education programs; similarly, teacher education standards in many countries expect graduating teachers to demonstrate specific competencies related to technology integration (Martin et al., 2024; Tondeur et al., 2020). These requirements indicate that teacher education programs need to restructure their curricula to incorporate technology use and develop approaches that systematically support technology integration. In this context, the present systematic review synthesizes primary empirical studies published between 2015 and 2024 to examine measurement approaches in TPACK research and the role of contextual conditions.

The theoretical foundation of this transformation lies in the concept of Technological Pedagogical Content Knowledge (TPACK), which was proposed by Mishra and Koehler (2006) through an extension of Shulman's (1987) pedagogical content knowledge (PCK) framework. TPACK is a framework that explains the integrated use of content knowledge, pedagogy, and technology in instructional design, emphasizing its context-sensitive and interactive nature. By highlighting the interconnected and interdependent consideration of content, pedagogy, and technology, the framework seeks to articulate the comprehensive knowledge base that teachers require for effective technology integration. Numerous empirical studies conducted across different countries and contexts have positioned TPACK as

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a central reference point in both pre-service and in-service teacher education research (Backfisch et al., 2025; Schmid et al., 2024).

Nevertheless, TPACK has not only been conceptualized in the literature as a "success model" but has also become the focus of substantial debate. Abbitt (2011) and Graham (2011) argue that the boundaries between the knowledge domains within the framework are conceptually blurred and difficult to distinguish clearly among the components. Angeli and Valanides (2009), Brantley-Dias and Ertmer (2013), and Schmid et al. (2020) further criticize TPACK as being overly complex and impractical for research and implementation. Moreover, a considerable body of empirical evidence indicates that the mere inclusion of digital technologies in teaching does not automatically lead to improvements in instructional quality; rather, the anticipated shift toward student-centered pedagogy often remains limited (Chen et al., 2023; Koh, 2019; von Kotzebue, 2022). These findings suggest that teachers experience difficulties in changing their established pedagogical beliefs and practices and underscore that technology is not merely a technical tool but a complex element that must be addressed in conjunction with pedagogical transformation (Koh, 2019; Wu et al., 2022).

TPACK Research and Existing Reviews

In parallel with the growing interest in TPACK, research focusing on this framework has increased rapidly since the mid-2000s, resulting in a substantial body of studies conducted across different disciplines, educational levels, and contexts. To make sense of this initial period of "expansion," comprehensive reviews examining studies published between 2005 and 2011 have provided an important framework for understanding the theoretical foundations and practical uses of TPACK (Tondeur et al., 2020; Voogt et al., 2013). These reviews highlighted key issues such as the diversity in how TPACK is defined, how technological knowledge is conceptualized, and how these differences are reflected in measurement approaches.

Following 2010, the increasing volume of TPACK-related studies was also reflected in subsequent systematic reviews, bibliometric analyses, and meta-analyses. Some of these reviews focused on specific contexts, such as pre-service teacher education, while others concentrated on the development of TPACK measurement instruments and the examination of their psychometric properties (Backfisch et al., 2025; Schmid et al., 2024). Other studies limited their scope to publications within specific time periods, focused exclusively on quantitative research, or examined particular components of TPACK (Tseng et al., 2022).

For example, in a systematic review of 184 articles indexed in Scopus between 2010 and 2020, Dewi et al. (2021) reported that a substantial proportion of studies addressed TPACK components (TK, PK, CK, and their intersections) in a predominantly descriptive manner, while themes related to "development" and "integration" received comparatively limited attention, and publications in the context of science education were relatively scarce. In a more recent review focusing on science education, Jamaludin et al. (2024) examined the media and contexts used within the TPACK framework between 2014 and 2023 and reported that the distribution of contexts was heavily concentrated on classroom/learning environments, whereas studies at the school or institutional level remained limited. In addition, many studies focused on specific digital media or technologies and tended to address them in isolated or small-scale contexts. Backfisch et al. (2025), in a meta-analytic examination of validity evidence for TPACK self-report scales, reported that the majority of studies relied on self-report measures and demonstrated considerable heterogeneity in findings across studies.

More recent second-level reviews have made recurring theoretical and methodological issues in the TPACK literature more visible, particularly emphasizing the need to address the complex, situational, and dynamic nature of TPACK in an integrated manner (Backfisch et al., 2025; Schmid et al., 2024). By their very nature, such reviews often reduce key dynamics of primary research to a summary level, which makes it difficult to compare studies in terms of the conditions under which findings are produced.

Rationale and Research Gap

Although the TPACK literature appears to have been partially mapped through systematic reviews and bibliometric studies, particularly after 2010, an examination of their focal dimensions reveals significant gaps. The selection of the 2015–2024 period enables the development of an up-to-date evidence map, given both the diversification of measurement instruments and the increasing prevalence of designs that more explicitly report classroom and school contexts. First, there is a substantial body of intervention studies in teacher education and professional development that center on TPACK. These studies indicate that short-term seminars and instructional designs employing emerging

media such as augmented reality, mobile games, social networks, and interactive whiteboards often report increases in teachers' or pre-service teachers' self-efficacy and attitudes toward technology (Açıkgül & Aslaner, 2020; Lee & Kim, 2014; Tondeur et al., 2016). However, such interventions are typically implemented in isolated contexts; …the pedagogical strategies used, contextual conditions, and program design features are rarely compared systematically, and findings are seldom synthesized holistically in terms of how they translate into teachers' long-term classroom technology integration (Hsu & Lin, 2020; Tondeur et al., 2020).

Second, teachers' attitudes, beliefs, and self-efficacy related to technology are frequently highlighted in the literature as key determinants of technology integration (Abbitt, 2011a; Ertmer & Ottenbreit-Leftwich, 2010; Tondeur et al., 2020; Veal, 2004; Yeh et al., 2017). Although studies conducted between 2015 and 2024 have linked teachers' attitudes, pedagogical beliefs, and self-efficacy perceptions to technology integration, research that examines these affective variables alongside the transformation of TPACK into classroom practice (i.e., performance and actual use indicators) remains limited. Existing findings often rely solely on perception-based measures or treat contextual conditions (classroom and school levels) as secondary background variables. Consequently, there is a need for integrative syntheses that combine affective factors, measurement approaches, and context within a single analytical framework.

Third, the measurement and assessment of TPACK constitute another major area of debate. The literature indicates that self-report scales are most commonly used to determine TPACK levels; however, recent studies suggest that such self-assessments do not always reflect teachers' actual performance and knowledge levels (Backfisch et al., 2025; Schmid et al., 2020; Soler-Costa et al., 2021). Studies reporting weak relationships between self-report scales and performance-based indicators, such as lesson plan quality or classroom practices (von Kotzebue, 2022), suggest that survey-based measures alone may be insufficient to capture an integrated construct such as TPACK. In contrast, performance-based assessments, rubrics, lesson plan analyses, and discipline-specific TPACK scales offer alternative approaches for context-sensitive evaluation (Kopcha et al., 2014). Nevertheless, the types of measurement instruments used, the validity and reliability evidence supporting them, and the relationships between the resulting TPACK indicators and teachers' actual technology integration remain fragmented and dispersed in the literature (Fabian et al., 2024; Schmid et al., 2020).

This fragmentation not only results in an incomplete evidence map but also obscures the practical implications of the TPACK framework for educational research and practice. When teacher education interventions, classroom practices, measurement approaches, and affective variables are examined in isolation, several fundamental questions remain unanswered. For example, why do some programs lead to substantial improvements in TPACK and technology integration while others with seemingly similar designs produce limited effects? Do reported differences in TPACK levels reflect genuine changes in teacher knowledge, or are they primarily artifacts of the measurement instruments used? Why do teachers' beliefs and attitudes sometimes fail to translate into classroom practice despite strong TPACK profiles? In other words, examining program design, classroom strategies, measurement, and affective dimensions separately makes it difficult to explain why TPACK has yet to become a universally practical guide or why empirical findings sometimes appear contradictory. Without addressing the disconnects among theoretical debates, methodological choices, and practical applications, questions regarding how TPACK can be transformed into a more functional framework for teacher education remain unresolved.

Building on this diagnosis of "circular progress," the present study advances the field by systematically restructuring primary empirical findings from the 2015–2024 period at the study level and directly targeting two major blind spots. First, it examines the methodological artifacts produced by different measurement regimes, particularly how the choice of measurement instruments shapes the nature of reported TPACK levels. Second, it investigates the enabling or constraining role of contextual conditions in the process by which teachers translate their TPACK knowledge into classroom practice. Within this framework, the study systematically elucidates the extent to which reported "TPACK gains" reflect genuine competency transformation versus the inherent characteristics of the measurement approach. At the same time, it identifies the classroom- and school-level contextual conditions under which strong TPACK profiles are translated into pedagogical technology integration, as well as the conditions under which such knowledge remains unactivated, through a thematic evidence map. Rather than merely updating the literature, the study offers a critical synthesis that jointly examines the measurement and contextual mechanisms shaping TPACK research outcomes. By reclassifying reported "development" findings according to the type of measurement regime (self-report vs. performance-based) and the enabling or constraining conditions of context (classroom/school level), the study provides an explanatory framework for commonly observed contradictions, such as "TPACK increased, but classroom transformation remained limited." In doing so, it makes visible which findings are

more indicative of genuine competency development and which are more sensitive to reporting or measurement choices, thereby offering a critical reading of the TPACK literature. From this perspective, a holistic and thematically deepened synthesis that brings together TPACK research conducted with pre-service teachers and in-service teachers along the following dimensions is necessary not only to address what has not yet been done but also to clarify contradictory findings and the limited practical guidance in the field:

- the design features and outcomes of TPACK-focused teacher education and professional development programs
- pedagogical strategies and contextual diversity in classroom technology integration
- the types of instruments used to measure TPACK and their validity and reliability evidence, and
- the relationships among TPACK, teachers' attitudes, beliefs, self-efficacy perceptions, and actual technology use

By integrating findings accumulated across fragmented subfields, the present study aims to provide a more explanatory account of when, how, and under what conditions TPACK serves as a functional framework for teacher education.

The Present Study and Research Questions

This study presents a critical systematic review that not only thematically categorizes empirical TPACK studies conducted between 2015 and 2024 but also employs measurement approaches and contextual conditions as analytical lenses to explain inconsistencies across findings. The review includes empirical TPACK studies published in peer-reviewed journals and indexed in the Web of Science and Scopus databases. The analyzed studies were examined across four main dimensions: the design and reported outcomes of TPACK-focused teacher education and professional development programs; pedagogical strategies and contextual characteristics of classroom technology integration; the characteristics and psychometric evidence of instruments used to assess TPACK components; and the relationships between TPACK and teachers' attitudes, beliefs, self-efficacy, and actual technology use. In line with these overarching aims, the study seeks to address the following research questions:

1. How do the design features of TPACK-focused professional development programs (duration, content, and pedagogical approach) shape teachers' TPACK development outcomes?
2. In what ways do different contextual conditions, such as classroom and school levels, constrain or support teachers' processes of translating their theoretical TPACK knowledge into classroom pedagogical practices?
3. To what extent do the measurement approaches used in TPACK research (self-report scales versus performance-based assessments) affect the validity and interpretability of reported TPACK findings?
4. What relational patterns exist between teachers' attitudes, beliefs, and self-efficacy related to technology and TPACK, and their enacted TPACK performance and actual technology use?

By presenting the recent development of the TPACK literature within a comprehensive framework structured around these four core dimensions, this systematic and thematic review aims to contribute both to clarifying limitations in theoretical debates and to elucidating the conditions under which TPACK serves as a functional guide for the design of teacher education programs and future research.

Method

Research Design

This study was designed as a systematic literature review to synthesize research trends, findings, and debates in the field of Technological Pedagogical Content Knowledge (TPACK) within a holistic framework. To integrate the findings of the included studies, a qualitative approach namely, thematic synthesis was adopted. The entire reporting process was conducted in accordance with the PRISMA 2020 statement (Page et al., 2021), and the study selection process is illustrated in Figure 1.

Search Strategy

To identify relevant publications, systematic searches were conducted in the Scopus and Web of Science (WoS) databases, which are widely recognized as authoritative sources for peer-reviewed educational research. The search was limited to empirical journal articles published between 2015 and 2024, written in English, and directly related to

TPACK. This time frame was selected to capture the diversification of measurement approaches and contextual reporting characteristic of what is commonly described as the second wave of TPACK research.

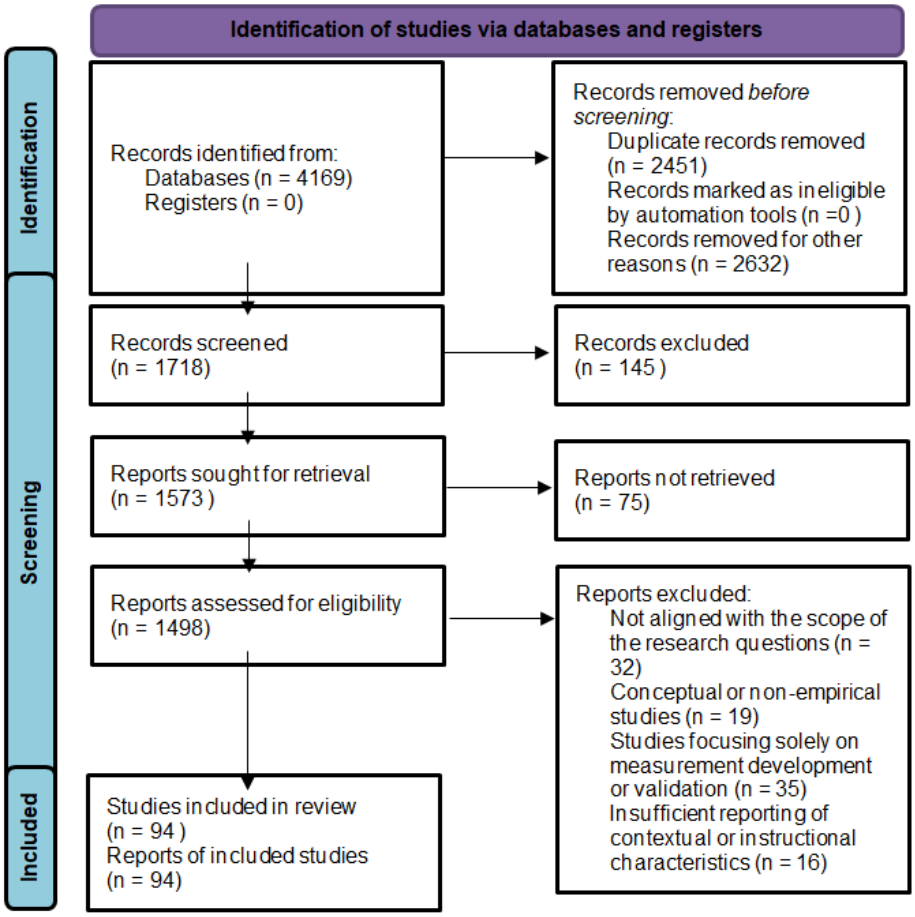

Fig. 1. PRISMA flow diagram: screening, selection, and inclusion process.

Two primary search strings were used in both databases: “TPACK” and “technological AND pedagogical AND content AND knowledge.” In Scopus, searches were conducted within the fields “Article Title, Abstract, Keywords,” while in WoS the fields “Title, Abstract, Author Keywords” were used. More restrictive combinations including contextual terms (e.g., teacher education, classroom, professional development) were initially tested but excluded in order to maximize sensitivity and avoid omitting conceptually relevant studies that did not explicitly reference TPACK in titles or abstracts.

Inclusion and Exclusion Criteria

To determine the studies to be included in the synthesis, explicit and auditable inclusion and exclusion criteria consistent with systematic review standards were applied (Page et al., 2021). In order to ensure transparency in the research process and to minimize potential selection bias, these criteria were predefined and documented in a review protocol prior to the screening process (Shamseer et al., 2015). Moreover, the use of clearly articulated criteria allows the review to be audited and replicated by other researchers (Xiao & Watson, 2019). The inclusion criteria were defined as follows:

- The study must be indexed in at least one of the Scopus or Web of Science databases, with full-text access available
- The study must be an empirical research article published in a peer-reviewed journal

- The terms “TPACK” or “technological pedagogical content knowledge” must be explicitly stated in the title, abstract, or keywords
- The study must have been published within the specified time frame (January 1, 2015, to December 31, 2024)
- The study must have been conducted within an educational context and must report original empirical data directly related to TPACK (i.e., studies involving pre-service teachers, in-service teachers, or educators directly engaged in the instructional process)

The exclusion criteria were defined as follows:

- Studies that include only theoretical or conceptual discussions without reporting empirical data
- Secondary studies such as systematic reviews, meta-analyses, or comprehensive review articles
- Conference proceedings, book chapters, theses, and other forms of grey literature
- Studies conducted in non-educational contexts or those that establish only an indirect relationship with TPACK
- Studies for which the full text is not accessible or that were published outside the specified time frame

These criteria were established to focus the review on empirical evidence concerning the use of TPACK within educational contexts (Chai et al., 2013) and to maintain the scope of the review at a manageable level given the density of the existing literature (Booth et al., 2016). Throughout all stages of the screening and selection process, the same inclusion and exclusion criteria were applied consistently, with the aim of reducing selection bias and enhancing the reliability of the synthesis findings (Page et al., 2019).

Screening and Selection Process

The screening process was structured in accordance with the flow diagram recommended by the PRISMA 2020 statement and encompassed the stages of identification, screening, eligibility assessment, and inclusion. First, a comprehensive literature search was conducted in the Scopus and Web of Science databases using the predefined keywords, yielding a total of 6,801 records. These records were imported into a reference management software; duplicates within each database were removed using both automated and manual procedures, after which records appearing in both databases were deduplicated.

In the subsequent stage, the titles and abstracts of the remaining records were independently reviewed by two researchers in accordance with the predefined inclusion and exclusion criteria. Records involving disagreements were resolved through discussion by revisiting the criteria. This initial screening was first piloted on a randomly selected small subsample to test the applicability of the criteria; based on this pilot experience, criteria that were insufficiently explicit were further clarified.

For records deemed potentially eligible based on the title–abstract screening, full texts were retrieved and subjected to detailed full-text assessment. For studies excluded at the full-text stage, the primary reason for exclusion (e.g., indirect relationship to the TPACK framework, purely theoretical discussion, samples not involving teachers or pre-service teachers, lack of empirical data) was documented under standardized categories. This procedure enabled transparent reporting, within the PRISMA flow diagram, of how many studies were excluded at each stage and for what reasons.

As a result, 94 studies meeting the eligibility criteria and deemed methodologically adequate (listed in Appendix 1) were included in the synthesis. At each stage of the process, the number of excluded studies and the corresponding reasons were recorded, and the entire selection process was documented to ensure traceability. In this way, the reproducibility and transparency of the review were ensured.

Quality Assessment of Included Studies

In this study, the methodological quality of the primary research included in the synthesis was systematically assessed in order to enhance the reliability of the synthesis findings (Higgins et al., 2019; McKenzie et al., 2019). As is common in systematic thematic reviews in the field of education, a structured quality appraisal form was used for each article. This form was adapted based on the Mixed Methods Appraisal Tool (MMAT) developed for the evaluation of mixed-methods research (Hong et al., 2018), as well as prior quality frameworks in educational research, and was organized to accommodate different methodological designs.

The appraisal form included criteria such as clarity of the research purpose, appropriateness of the research design and sampling strategy, validity and reliability evidence for data collection instruments, alignment of data analysis techniques with the research questions, consistency between data and findings, and adequacy of ethical reporting. A three-level rating scale ("inadequate," "partially adequate," and "highly adequate") was used for each criterion, and these ratings were used to construct an overall methodological quality profile for each study.

Quality assessments were conducted independently by two researchers, disagreements were resolved through discussion, and, when necessary, the opinion of a third expert was sought (Boutron et al., 2019). Studies were not excluded from the meta-synthesis solely on the basis of methodological quality; instead, an "evidence weight" approach was adopted during interpretation (Gough, 2007), whereby findings from studies with higher methodological quality were given greater analytical weight (Petticrew & Roberts, 2006a, 2006b).

Data Analysis

Data analysis was conducted at two levels. First, a descriptive analysis summarized study characteristics such as publication year, sample type, research design, and focus areas using frequencies and percentages to identify general trends. Second, a thematic and relational synthesis was performed. Findings from each study were decomposed into meaning units and coded in alignment with the research questions.

Codes captured both content themes and relational patterns. For example, program design features were linked to reported cognitive, affective, and behavioral outcomes, while pedagogical strategies were examined in relation to contextual levels and degrees of transformation in TPACK use. Measurement instrument types were coded as distinct categories and analyzed in relation to reported TPACK levels and technology integration outcomes. Relationships between TPACK and attitudes, beliefs, self-efficacy, and use were also examined across contexts and teacher experience levels. Constant comparison was used to identify similarities and differences across studies.

Coding

During the coding process, each study included in the systematic review was analyzed in detail using a structured coding form. This form included descriptive fields such as publication year, country or region, educational level, characteristics of the study group, research design, data collection instruments, the specific TPACK components addressed, and key findings, as well as analytical fields aligned with the research questions. For example, program design features, reported TPACK and technology integration outcomes, type of measurement instrument used, findings related to TPACK–attitude/belief/self-efficacy relationships, and contextual conditions were coded as separate fields. As a result, each study was coded as a single-row record, and a structured database suitable for comparative and relational analyses across all studies was constructed.

Coding was conducted independently by at least two researchers, and inter-coder agreement was calculated by comparing code lists. Using the formula proposed by Miles and Huberman (1994), the percentage agreement coefficient (Agreement / [Agreement + Disagreement]) was calculated and found to be 92.21%. Codes with discrepancies were discussed until consensus was reached, and code definitions were revised when necessary. Throughout the process, the codebook was dynamically updated; codes with overlapping meanings were merged, while overly broad codes were subdivided into subcodes to enhance analytical differentiation.

This systematic and replicable coding process ensured the consistency and traceability of both the categories used in descriptive analyses and the higher-order themes constructed in the thematic and relational synthesis. Accordingly, the coding approach adopted in this study aligns with the principles of transparency and reliability emphasized in systematic thematic reviews.

Theme Development

Themes were developed through an iterative process combining a priori theoretical categories with inductive patterns emerging from the data. Provisional themes were initially guided by core debates in the TPACK literature and subsequently refined through comparison and abstraction. Thematic analysis followed a cyclical process of familiarization, coding, comparison, refinement, and synthesis. Higher-order themes were constructed to capture not only dominant practices and tools but also the conditions under which particular outcomes and relationships emerged. This process enabled the consolidation of fragmented findings into coherent, theoretically grounded themes reflecting program design, context, measurement, and affective dimensions.

Self-Efficacy Scale for Children: The original version of the scale was developed by Muris (2001) with 330 participants aged 14-17. It is a Likert-type scale, scored between 1 - Not at all and 5 - Very good. The original form consists of 21 items, with 7 items measuring social self-efficacy, 7 items measuring academic self-efficacy, and 7 items measuring emotional self-efficacy. Additionally, the total score obtained from the scale indicates the general self-efficacy level. The Cronbach's alpha coefficient for the original version was .88 for general self-efficacy, .88 for academic self-efficacy, and .88 for emotional self-efficacy. The Turkish validity and reliability studies were conducted by Telef and Karaca (2012) with 933 students in elementary and high school. It was reported that the scale preserved its original 21-item and 3 sub-dimensional structure, with the total score range being between 21 and 105, item loadings ranging from .305 to .612, and the general Cronbach's alpha value being .86. The Cronbach's alpha for the subdimensions was .84 for academic self-efficacy, .64 for social self-efficacy, and .78 for emotional self-efficacy.

Personal Information Form: The Personal Information Form was developed by the researchers to determine the participants' socio-demographic characteristics. It aims to collect information about variables such as gender, grade level, parents' educational level, and number of siblings.

Data Analysis

After selecting the measurement tools, permission for use was obtained from the authors who conducted the validity and reliability studies of the scales via email. Subsequently, the necessary applications were made to the relevant units of the Ministry of National Education, and approval was obtained. After receiving permission, participants were contacted and invited to complete the forms after consent was obtained from both the participants and their parents. The socio-demographic variables were determined through descriptive statistics from the data obtained via the aforementioned measurement tools. Hakem 1: Additionally, several statistical tests were conducted. Levene's test was used to assess the homogeneity of variances, Shapiro-Wilk test was applied to check the normality of the data, Durbin-Watson test was performed to evaluate autocorrelation in the residuals. The skewness, kurtosis, tolerance, and VIF (Variance Inflation Factor) values were also analyzed to assess the assumptions of normality and multicollinearity. The results indicated that there were no issues with multicollinearity, and the data distribution was normal.

Results

This study presents a synthesis of 94 empirical studies ([A1]–[A94]) published between 2015 and 2024 and included in the systematic review (see Appendix 2). The extracted data were thematically organized around the four research questions (RQs) outlined in the Introduction. The synthesis integrates fragmented findings in the TPACK literature and constructs an evidence map addressing teachers' technology integration competencies, contextual determinants, measurement-related challenges, and interactions with affective variables.

The geographical distribution, diversity of educational levels, and methodological approaches represented in the reviewed studies indicate that TPACK research has reached a relatively mature global distribution, while still exhibiting substantial contextual variation. Overall, the findings confirm that TPACK is not a static body of knowledge but a dynamic and situational construct shaped by program design, school culture, and teachers' belief systems. The following sections present these dynamics through subthemes and cross-study comparisons.

Design Features and Outcomes of TPACK-Focused Professional Development and Teacher Education Programs

The first research question examined how the design features of TPACK-focused intervention and training programs-specifically duration, content focus, and pedagogical approach—are associated with development outcomes. The reviewed studies (k = 32) indicate that effective TPACK development is grounded in deliberate design principles, including continuity over time, active engagement in design processes, content specificity, and opportunities for collective participation.

Process Orientation and Distributed Structuring Over Time

A consistent finding across the literature is that short-term, one-shot workshops rarely lead to sustained changes in teachers' technology integration practices. In contrast, programs that are long-term, distributed over time, and organized around iterative cycles tend to produce more durable increases in TPACK levels. Longitudinal and multi-semester designs emphasize the importance of extended "incubation" periods that allow teachers to internalize technology integration within their own instructional contexts. While intensive short-term courses may raise

awareness of specific TPACK components, several studies note that the translation of such gains into classroom practice typically requires longer-term support through practicum-based or field experiences.

Learning by Design (LbD)

Across studies published between 2015 and 2024, the most prevalent pedagogical strategy involves engaging teachers in the design of technology-enhanced instructional materials rather than focusing on passive technology training. Learning by Design (LbD) emerges as a key mechanism through which TPACK is operationalized, enabling teachers to explore how specific technologies can address pedagogical challenges within particular content areas. Design-oriented experiences position teachers as active decision-makers who critically evaluate technological affordances in relation to instructional goals, thereby supporting more integrated and transferable TPACK development.

Content- and Discipline-Specific Focus

A recurring finding is that discipline-specific technology education is more effective for TPACK development than generic technology training. Studies conducted in science, mathematics, and language education contexts consistently report that effective technology integration depends on alignment with discipline-specific practices and epistemologies. Rather than emphasizing general technological skills, successful programs focus on how particular tools support subject-specific reasoning, representation, and communication processes.

Collective Participation and Collaborative Learning

Another prominent theme is that TPACK development is inherently social. Community-based and collaborative approaches; such as peer interaction, mentoring, and professional learning networks; are associated with stronger and more sustained outcomes than isolated training initiatives. Collaborative environments support the sharing of experiences, collective reflection on practice, and the development of shared understandings of technology integration, thereby contributing to what several studies describe as collective TPACK.

Table 1

Summarizes the Key Program Design Features Identified Across Studies as Supporting TPACK Development.

Design Feature	Impact Mechanism	Related Studies
Continuity and Iteration	Provides teachers with opportunities for experimentation, trial and error, and reflection; reduces anxiety and enhances sustainability.	[A1], [A54], [A63]
Design Orientation (Learning by Design – LbD)	Positions teachers as active producers; transforms theoretical connections among Technology, Pedagogy, and Content into concrete instructional materials.	[A13], [A25], [A67], [A79]
Content Specificity	Transforms technology from a generic tool into a discipline-specific cognitive instrument (e.g., mathematical modeling, scientific inquiry).	[A38], [A49], [A93], [A12]
Collective Participation	Supports social learning; fosters “collective TPACK” by compensating for individual limitations and enhancing motivation.	[A8], [A54], [A75]

The Role of Contextual Conditions in TPACK Integration: Enablers and Barriers

The second research question examined how contextual factors at the school, classroom, and student levels influence teachers’ processes of translating TPACK into classroom practice. Across the reviewed studies ([A28], [A33], [A48], [A50], [A57], [A83], among others), context emerges not as an external variable but as a filtering mechanism that directly shapes the enactment of TPACK.

Infrastructure and Access to Technology: First-Order Barriers

Studies conducted in developing or rural contexts [A28, A56, A57, A89] consistently indicate that inadequate technological infrastructure constitutes a primary barrier to TPACK integration, regardless of teachers' knowledge levels. Even when teachers possess strong pedagogical understandings of technology use, unstable access to devices, unreliable internet connectivity, or frequent technical disruptions often compel them to revert to traditional instructional practices. Beyond basic access, technical reliability plays a crucial role, as uncertainty about whether technologies will function as intended reduces teachers' willingness to take pedagogical risks and undermines sustained technology-based lesson planning. Notably, studies rated as having higher methodological quality tended to provide more detailed and context-sensitive evidence regarding infrastructural constraints and institutional support conditions, whereas lower-quality studies often reported these factors in more general or descriptive terms.

School Leadership and Institutional Culture

School leadership and institutional culture are repeatedly identified as critical enablers of TPACK enactment. Studies show that supportive leadership characterized by encouragement of innovation, provision of resources, and tolerance for experimentation can be more influential than individual teacher beliefs in predicting technology use. Conversely, unsupportive school environments may erode even strong initial TPACK competencies, particularly among novice teachers, highlighting that institutional support is essential for sustaining technology integration over time.

Curriculum Pressure and Time Management

Several studies [A31, A57, A83] report that dense curricula and examination pressures lead teachers to perceive technology integration as a time-intensive add-on. Under such constraints, technology use is often limited to superficial applications, despite high levels of motivation. However, evidence also suggests that when teachers are able to align curricular objectives with technology use and receive autonomy support from school leadership, contextual pressures can be mitigated. In these cases, teachers' pedagogical design capacity enables deeper and more meaningful integration of technology.

Macro-Context and Cultural Factors

At the macro level, cultural and systemic factors further shape how TPACK is enacted. Studies conducted in East Asian contexts [A51, A66] indicate that pedagogical traditions emphasizing teacher-centered instruction influence the ways technology is used, often positioning it as a tool for information transmission rather than student-centered learning. These findings demonstrate that TPACK is not culturally neutral; instead, local educational norms mediate how technological, pedagogical, and content knowledge intersect in practice.

The third research question examined how the type of measurement instruments used in TPACK research—self-report scales, performance-based assessments, and mixed-methods designs—shapes reported findings. Across the reviewed studies, a consistent discrepancy emerges between teachers' perceived competencies and their demonstrated performance, indicating that the choice of measurement approach directly influences reported TPACK levels.

Dominance and Limitations of Self-Report Scales

The majority of the reviewed studies [A2, A3, A4, A19, A21, A38, A40, A46, A49, A61, A64, A66, A70, A72, A82, A85, A89] relied primarily on self-report surveys, often reporting TPACK levels as "high" or "adequate." However, studies adopting more critical methodological perspectives [A19, A64, A84] highlight important validity limitations. Factor analytic findings indicate that respondents frequently struggle to differentiate among TPACK subcomponents—particularly TCK and TPK—and that responses are influenced by general technology self-efficacy perceptions or social desirability effects. Comparisons between self-report scores and performance-based measures further reveal only moderate to weak associations, suggesting that surveys tend to capture perceived rather than enacted knowledge.

In addition, scale development and cross-cultural adaptation studies [A21, A38, A40, A60] report variability in factor structures, with adapted instruments sometimes yielding fewer or differently organized dimensions. This variability complicates cross-study comparisons and challenges the establishment of a universal measurement standard for TPACK.

Table 2

Summarizes the Effects of Contextual Factors on TPACK Integration Identified Across Studies.

Context Level	Factors	Type of Effect	Related Studies
Physical / Infrastructure	Lack of hardware, limited internet access, insufficient technical support.	Constraining: Prevents enactment even among teachers with strong TPACK.	[A28/A57], [A50], [A89]
Institutional / School	Leadership support, vision, culture of collaboration, departmental pressure.	Regulatory: Shapes teachers' motivation for technology use and its perceived legitimacy.	[A48], [A39], [A44]
Curriculum / Policy	Examination pressure, dense content, rigid curricula.	Directive: May lead to the use of technology for "rapid content delivery" rather than for deep learning.	[A31], [A83], [A54]
Socio-Cultural	Teacher–student roles, pedagogical traditions.	Shaping: Influences the pedagogical philosophy (e.g., constructivist vs. traditional) through which technology is enacted.	[A51], [A66]

The Rise of Performance-Based and Objective Measures

In response to these limitations, a growing number of studies [A13, A53, A59, A67, A84] employ performance-based instruments such as lesson plan analyses, observation rubrics, classroom observations, and scenario-based assessments. These approaches typically yield lower but more realistic TPACK profiles, as they make visible the gap between claimed competencies and actual instructional practice.

Performance-based measures conceptualize TPACK as an observable quality of teaching rather than a static self-assessment score, emphasizing how technology is used to support subject-specific understanding and address students' learning needs. Such instruments frequently reveal that teachers may demonstrate high technical proficiency (TK) while encountering difficulties integrating technology pedagogically and content-specifically, distinctions that are often obscured in survey-based measures.

Depth Offered by Mixed-Methods Approaches

The most robust and interpretable findings are reported in mixed-methods studies that triangulate self-report data with performance-based evidence [A1, A10, A39, A63]. These studies indicate that surveys primarily capture intentions and self-confidence, whereas qualitative and observational data reflect enacted practice. When improvements in self-report scores are corroborated by observable changes in instructional artifacts or classroom practice, the resulting evidence for TPACK development is substantially strengthened.

Relational Patterns Between TPACK and Affective Variables

The fourth research question examined the relationships between teachers' attitudes, beliefs, and self-efficacy perceptions and both TPACK and technology integration. Across the reviewed studies, the findings consistently indicate that TPACK alone is insufficient for effective integration; affective variables play a critical role in activating knowledge in practice [A20, A33, A41, A42, A68].

Table 3

Presents a Comparative Overview of Measurement Approaches Used in the Reviewed TPACK Studies.

Measurement Approach	Typical Instruments	General Findings	Advantages / Limitations
Self-Report	Likert-type surveys (e.g., adaptations of Schmidt et al.).	Typically high TPACK scores; strong correlations among subdimensions (limited discriminant validity).	(+) Easy to administer; suitable for large samples; captures beliefs and confidence. (–) Subjective; ceiling effects; social desirability bias; may not reflect actual performance.
Performance-Based	Lesson plan rubrics, observation protocols, scenario-based tests.	Lower and more variable scores; clearly reveal pedagogical shortcomings.	(+) Objective; action-oriented; diagnostically informative. (–) Time-consuming; requires scorer reliability; often limited to small samples.
Mixed Methods	Surveys combined with observations/interviews/ artifact analysis.	Explain alignment or discrepancies between reported scores and enacted practice.	(+) High validity; provides in-depth insights. (–) Analytical complexity.

The Determinative Role of Self-Efficacy

Self-efficacy is the most frequently examined affective variable in TPACK research. Studies employing self-efficacy instruments consistently report strong positive associations between teachers' self-efficacy for technology integration and their TPACK levels [A20, A41, A53]. Structural equation modeling studies further demonstrate that while TPACK directly influences technology integration, this relationship is significantly strengthened by self-efficacy and related social-cognitive factors. Teachers who perceive themselves as competent are more willing to enact TPACK in classroom practice, whereas low self-efficacy often linked to technology anxiety or fear of failure can inhibit technology use despite adequate knowledge levels [A50, A91].

Pedagogical Beliefs and Modes of Technology Use

Teachers' pedagogical beliefs function as a key filter shaping how TPACK is enacted. Studies indicate that constructivist beliefs are associated with deeper and more student-centered forms of technology use, while more traditional beliefs tend to constrain technology to superficial or instrumental roles. Evidence from game-based learning and early childhood education contexts demonstrates that teachers' beliefs influence not only whether technology is used, but also how it is pedagogically positioned within instruction.

Attitudes and Technology Acceptance

General attitudes toward technology and technology acceptance variables such as perceived usefulness and ease of use also play a mediating role in the relationship between TPACK and technology integration. Findings suggest that TPACK predicts teachers' intentions to use technology primarily through positive attitudes and perceived instructional value. In emerging technology domains, such as artificial intelligence, affective factors including attitudes and anxiety appear to be particularly salient, often outweighing knowledge-related barriers.

Section Conclusion

The synthesis of 94 empirical studies conducted between 2015 and 2024 indicates that TPACK research has increasingly shifted from definitional concerns toward questions of development, measurement, and enactment. Overall, the findings demonstrate that TPACK yields the most effective outcomes when it is supported by long-term, design-oriented interventions; aligned with contextual conditions such as school culture and infrastructure; assessed through performance-based or triangulated measurement approaches; and reinforced by teachers' self-efficacy and pedagogical belief systems.

A critical implication emerging from this review is the methodological divergence between optimistic findings derived from self-report measures and more conservative results produced by performance-based assessments. This divergence highlights the need for future research and teacher education programs to move beyond an exclusive focus on technology skills toward approaches that integrate measurement rigor, contextual sensitivity, and the transformation of teacher beliefs.

Discussion

This systematic thematic synthesis revisited empirical TPACK research published between 2015 and 2024 through three interpretive lenses (measurement, context, and affective dimensions) while retaining program design as the central developmental mechanism. The integrated evidence map developed in this review indicates that much of the apparent inconsistency in the TPACK literature is not merely theoretical disagreement, but an artifact of how TPACK is designed for, enabled or constrained in practice, and operationalized through measurement. Across the corpus, TPACK functions less as a stable "possession" and more as a situated design capacity whose enactment depends on iterative learning opportunities, organizational conditions, and motivational–belief systems.

Program Design Features Shaping TPACK Development Outcomes

The first research question examined how program design characteristics influence TPACK development. A central implication of the synthesis is that TPACK growth is most plausibly interpreted as a trajectory rather than an immediate outcome. When professional development and teacher education are structured as distributed, iterative, and design-oriented experiences, teachers have opportunities to test ideas, recover from failure, and refine pedagogical decisions over time. In contrast, "one-shot" formats frequently appear to produce attitudinal boosts and perceived readiness without consistently supporting sustained instructional transformation. A key contribution of the RQ1 synthesis is clarifying why design-oriented approaches are repeatedly associated with stronger outcomes: Learning by Design functions as a mechanism that forces integration work to happen at the level where TPACK is most meaningful—lesson goals, representations of content, and pedagogical reasoning. In that sense, the primary value of design-oriented interventions is not increased exposure to technology, but the creation of structured conditions under which teachers must coordinate content, pedagogy, and technology in decision-making. The implication is that effective programs should be evaluated less by the novelty of tools and more by whether the design tasks require teachers to reason about pedagogical trade-offs and student learning.

Contextual Conditions Shaping Enactment of TPACK in Practice

The second research question addressed how contextual factors constrain or support enactment. The synthesis indicates that context operates as a filter: it determines whether TPACK remains latent or becomes actionable practice. Infrastructure and technical reliability are not merely logistical issues; they set the boundaries of what is pedagogically "thinkable" in real time. When devices, connectivity, or technical support are unreliable, teachers rationally reduce risk, narrow instructional ambitions, and revert to practices that protect lesson continuity. Under such conditions, TPACK capacity can exist cognitively while remaining behaviorally suppressed.

At the institutional level, leadership and school culture shape technology integration by conferring legitimacy, time, and psychological safety. The review suggests that teachers are more likely to translate knowledge into practice when leadership provides not only resources but also permission to experiment especially when early attempts may fail. Similarly, curriculum density and assessment pressure tend to steer technology toward efficiency-driven usage (e.g., presentation and delivery) rather than transformational use aligned with deep learning. The broader implication is that TPACK development initiatives cannot be evaluated or scaled as if they were context-neutral. Instead, program effects must be interpreted in relation to the organizational and policy environments that define teachers' discretionary space for pedagogical redesign.

Measurement Approaches and the Interpretability of Reported TPACK Findings

The third research question examined how measurement regimes shape reported findings. The most consequential implication of the synthesis is that the TPACK evidence base is partially bifurcated because self-report and performance-based indicators frequently capture different facets of competence. Self-report instruments tend to index confidence, perceived readiness, and generalized technological self-efficacy; performance-based tools more directly reflect enacted integration quality and pedagogical reasoning. Therefore, consistently "high TPACK" scores observed in survey-dominant studies should not be interpreted as direct evidence of strong enactment capacity.

This review clarifies that measurement is not a neutral technical choice but an interpretive lens that can inflate or attenuate conclusions about "development." The divergence between self-reported and observed performance is methodologically meaningful: it signals that TPACK outcomes may be overestimated when the construct is operationalized primarily through perception-based instruments. Conversely, performance-based assessments may yield lower levels but provide more instructionally actionable diagnostics by locating where integration breaks down (e.g., at the level of representations, misconceptions, or pedagogical moves). The implication is not that self-report measures are unusable, but that claims about growth and effectiveness require alignment between the measurement regime and the intended construct (confidence vs. enacted competence), and ideally triangulation when the research question concerns practice.

Relational Patterns among Affective Variables, TPACK, and Enacted Practice

The fourth research question explored relationships between affective variables and TPACK enactment. The synthesis suggests that affective variables function as mobilizers—or inhibitors—of knowledge. Self-efficacy, attitudes, and pedagogical beliefs appear to shape whether teachers convert integration knowledge into classroom action, particularly under uncertainty and risk. In practice, teachers rarely implement technology integration in "ideal conditions"; they do so under time pressure, technical unpredictability, and accountability demands. In such contexts, confidence and beliefs about learning plausibly determine whether teachers persist with technology-mediated pedagogy or retreat to familiar routines. Importantly, affective factors also appear to influence how technology is used. Pedagogical beliefs can steer technology toward student-centered inquiry and exploration or toward teacher-centered delivery and control. This finding strengthens the argument that TPACK should not be treated as a purely cognitive framework. Rather, enactment is better understood as an interaction among knowledge, beliefs, and perceived capability within a given context. For emerging technologies (e.g., AI-related applications), the synthesis further suggests that affective barriers such as anxiety and perceived usefulness may be especially salient, meaning that capacity-building efforts that ignore beliefs and risk perceptions may yield superficial uptake.

Integrated interpretation

Taken together, the four research questions converge on a single explanatory account: TPACK-related outcomes in the literature are best interpreted as the product of (a) developmental design conditions, (b) contextual affordances and constraints, (c) measurement choices, and (d) affective mobilization mechanisms. This integrated view helps explain a recurring empirical pattern documented across studies: "TPACK increased" while "classroom transformation remained limited." In many cases, the synthesis suggests that such divergence can be explained by the joint effects of survey-based measurement, constrained school conditions, and insufficient attention to belief/efficacy mechanisms, rather than by an absence of learning.

Implications for Emerging Technologies, Particularly Artificial Intelligence (AI)

The findings of this synthesis suggest that successful AI integration in teacher education depends not only on teachers' technological and pedagogical knowledge but also on affective readiness. Evidence across the reviewed studies indicates that self-efficacy, beliefs, and technology-related anxiety function as critical filters shaping whether new technologies are enacted in practice. Accordingly, teacher education programs aiming to support AI integration should prioritize the reduction of anxiety and the strengthening of perceived instructional control before or alongside technical training. Design-oriented activities that allow teachers to experiment with AI tools in low-stakes, discipline-specific contexts, coupled with reflective discussions addressing pedagogical beliefs and ethical concerns, may foster more sustainable and meaningful adoption. Framing AI not as an autonomous instructional solution but as a pedagogical support aligned with teachers' existing instructional goals appears particularly important for translating AI-related competencies into classroom practice.

Limitations

This study has several limitations. First, the review was restricted to peer-reviewed journal articles indexed in Scopus and Web of Science and published in English between 2015 and 2024; therefore, relevant evidence from other databases, non-English publications, and grey literature (e.g., theses, reports, conference proceedings) may not be represented. Second, although the synthesis applied explicit inclusion/exclusion criteria and a structured quality appraisal, the thematic interpretation necessarily involves analytic judgment, and some study-level nuances may have been condensed during cross-study coding. Third, the review did not compute effect sizes; consequently, the conclusions describe thematic and relational patterns rather than estimating the magnitude of program impacts. Finally, the heterogeneity of contexts, disciplines, and measurement instruments across the included studies limits direct comparability and may contribute to variability in reported TPACK outcomes.

Suggestions

Future research should prioritize mixed-method and triangulated designs that combine self-report measures with performance-based indicators (e.g., lesson artifacts, observations, scenario-based tasks) when the research aim is to explain enacted TPACK and classroom practice

Researchers should report contextual variables with greater precision (e.g., infrastructure reliability, technical support, leadership practices, curriculum/exam pressure) to enable clearer interpretation of when strong TPACK translates into enactment

Teacher education and professional development programs should be designed as sustained, iterative, and design-oriented experiences (plan–implement–reflect–revise) rather than relying on one-shot workshops or tool-focused training

Interventions should explicitly address affective mechanisms (especially self-efficacy and pedagogical beliefs) by incorporating structured reflection, peer collaboration, and supported risk-taking in authentic classroom tasks

Measurement studies should strengthen validity arguments by clarifying the target construct (perceived readiness vs. enacted competence), reporting psychometric evidence transparently, and examining measurement invariance across cultures/disciplines where applicable

For emerging technologies (e.g., AI-supported tools), future studies should examine how attitudes, anxiety, and perceived usefulness interact with TPACK to shape adoption and instructional transformation under real-world constraints

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Ethical Approval

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Consent for Publication

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Authors' Contributions

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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Appendix 1.

List of Studies Included in the Thematic Synthesis (2015–2024).

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