



Discipline-Based Disparities and Measurement Validity in TPACK: A Meta-Synthesis of Teacher Professional Development Evidence in Indonesia (2015–2025)

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Abstract: This study synthesizes empirical evidence on Technological Pedagogical Content Knowledge (TPACK) in Indonesia through a Systematic Literature Review using the PRISMA 2020 protocol and thematic meta-synthesis. Articles were retrieved from Scopus, Web of Science, ERIC, and Google Scholar, yielding 22 peer-reviewed studies published between 2015 and 2025. The review identifies three consistent patterns. First, TPACK profiles differ across disciplines: language teachers generally show high technological confidence but limited pedagogical integration, whereas science and elementary teachers demonstrate stronger content-pedagogical foundations yet weaker technological integration. Second, most early studies rely on self-report instruments, which tend to inflate perceived competence; more recent studies using Rasch modeling and confirmatory factor analysis provide stronger measurement validity. Third, collaborative, practice-based professional development models, such as lesson study, project-based learning, and reflective practicum, are more effective than short-term ICT workshops. Overall, the evidence highlights the need for discipline-sensitive training, valid assessment, and sustainable teacher development policies across Indonesian education systems and institutions.

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Abstrak: Penelitian ini menyintesis bukti empiris tentang Technological Pedagogical Content Knowledge (TPACK) di Indonesia melalui Systematic Literature Review dengan protokol PRISMA 2020 dan thematic meta-synthesis. Artikel dikumpulkan dari Scopus, Web of Science, ERIC, dan Google Scholar, menghasilkan 22 artikel peer-reviewed yang diterbitkan pada 2015–2025. Hasil sintesis menunjukkan tiga pola utama. Pertama, profil TPACK berbeda antar disiplin; guru bahasa umumnya memiliki kepercayaan teknologi yang tinggi tetapi integrasi pedagogis yang masih terbatas, sedangkan guru sains dan sekolah dasar menunjukkan fondasi konten-pedagogik yang lebih kuat namun integrasi teknologi lebih lemah. Kedua, sebagian besar studi awal menggunakan instrumen self-report yang cenderung melebihkan kompetensi, sementara studi terbaru dengan Rasch modeling dan confirmatory factor analysis menunjukkan validitas pengukuran yang lebih baik. Ketiga, model pengembangan profesional yang kolaboratif dan berbasis praktik, seperti lesson study, project-based learning, dan reflective practicum, lebih efektif daripada pelatihan ICT jangka pendek. Temuan ini menegaskan pentingnya pelatihan sensitif disiplin, asesmen valid, dan kebijakan pengembangan guru yang berkelanjutan di berbagai satuan pendidikan.

A. Introduction

Digital transformation has fundamentally reshaped the competencies expected of teachers in the twenty-first century. Teachers are no longer required only to master subject matter and conventional pedagogy; they are also expected to integrate technology in ways that improve instructional quality, deepen learning, and support students' higher-order thinking skills (Gallardo-Echenique et al., 2023; Voogt & McKenney, 2017). Yet, across educational systems, a persistent gap remains between the functional use of digital tools and their meaningful pedagogical integration. In many classrooms, technology is still used primarily for presentation, communication, or administration rather than as a medium for inquiry, collaboration, problem solving, and conceptual development (Díaz-Morales et al., 2022). This gap shows that digital access alone does not guarantee instructional transformation, and that teacher competence remains central to the quality of technology-enhanced learning.

This problem becomes more visible when teachers face increasing demands to design learning experiences that are contextually relevant and cognitively demanding. In practice, many teachers are familiar with digital applications but still struggle to connect content knowledge, pedagogical strategy, and technological tools within a coherent instructional framework. Limited experience, the lack of contextual technology-based learning models, and insufficient professional support contribute to this problem (Mahdum, 2015). The challenge is especially significant in subjects that require visualization, simulation, data interpretation, and authentic inquiry, such as science literacy, climate change education, and project-based learning (Canbazoglu Bilici et al., 2016). In such contexts, technology should function not as an accessory but as an epistemic tool that helps students understand complex concepts more deeply.

In Indonesia, this issue is equally urgent. A national survey showed that although most teachers feel confident using digital devices, the actual integration of technology in learning remains limited and has not yet reached an integrative or transformative level (Ibrohim et al., 2022). This indicates that technical confidence does not automatically translate into pedagogical competence (Ertmer & Ottenbreit-Leftwich, 2010). Teachers may be able to operate applications and digital platforms but still fail to use them to support meaningful knowledge construction. The Indonesian context therefore reflects a broader structural issue aligned with global trends identified by UNESCO (2017), technology integration is not only a matter of infrastructure or access, but also of teacher readiness, instructional design, and pedagogical transformation.

Within this broader discussion, Technological Pedagogical Content Knowledge (TPACK) has become one of the most widely used frameworks for explaining teacher readiness in technology-enhanced learning. TPACK, originally rooted in Shulman (1987) concept of pedagogical content knowledge, emphasizes that effective teaching with technology emerges from the interaction of technological knowledge, pedagogical knowledge, and content knowledge, rather than from any single component alone (Koehler & Mishra, 2009). Studies in Indonesia show that this integration does not develop uniformly

across disciplines. Language teachers often report high technological self-efficacy, yet their technology use remains mostly instrumental and communication-oriented (Ma'mun et al., 2021; Aisyah et al., 2021). By contrast, science and elementary school teachers generally show stronger pedagogical content foundations, but face greater difficulties in TK, TCK, and TPK, particularly when technology is needed to represent scientific phenomena or support conceptual exploration (Irwanto et al., 2022; Fakhriyah et al., 2022). These differences suggest that TPACK is deeply shaped by disciplinary demands and cannot be developed through one-size-fits-all approaches (Lie et al., 2023).

At the same time, the literature shows that TPACK measurement itself is still methodologically uneven. Many early studies in Indonesia relied on self-report instruments, which are vulnerable to perception bias and often produce scores that are higher than what is observed in actual classroom practice (Irwanto, 2021; Prasojo et al., 2020). This gap between perceived competence and enacted competence raises concerns about the validity of teacher competency mapping. If the measurement tool is weak, then the resulting profile may mislead policy decisions and professional development planning. In response to this limitation, recent studies have increasingly used Rasch modeling and confirmatory factor analysis (CFA) to improve construct validity, detect item misfit, and distinguish actual ability from self-confidence bias. Nevertheless, these methodological improvements have not yet been systematically synthesized to show how measurement validity has evolved across the last decade.

Another key issue concerns the effectiveness of teacher professional development. Short-term ICT workshops and one-way training programs have repeatedly shown limited impact on strengthening teachers' integrative competence (Habibi et al., 2020). Such programs may improve basic operational skills, but they rarely lead to sustained pedagogical change. In contrast, practice-based and collaborative models appear far more effective. Lesson study, project-based learning, reflective practicum, and other models that provide repeated cycles of planning, implementation, reflection, and feedback tend to produce stronger gains in TPACK integration because teachers learn within authentic classroom situations. These findings suggest that effective teacher development must go beyond technical training and move toward professional learning that is embedded in practice and guided by reflection.

Although many studies have examined TPACK profiles, measurement quality, and professional development outcomes separately, very few have integrated these dimensions into one coherent analysis. This is a significant gap because disciplinary differences, measurement validity, and intervention effectiveness are closely related and should not be treated as isolated issues. Without an integrated synthesis, the literature remains fragmented: some studies map teacher competence, others validate instruments, and others test interventions, but few connect these strands to explain the broader development of TPACK as a pedagogical ecosystem. As a result, there is still limited understanding of how teacher competence, assessment quality, and professional learning interact across disciplines and over time in the Indonesian context.

To address this gap, the present study offers a distinctive contribution by integrating three analytical dimensions into one thematic meta-synthesis: discipline-based TPACK differences, the development of measurement validity, and the effectiveness of professional development interventions. This novelty is important because previous studies typically focused on a single dimension without linking it to the wider pedagogical and methodological context. Theoretically, the study enriches understanding of TPACK as a dynamic, contextual, and discipline-sensitive construct. Practically, the findings are expected to inform teacher education institutions, schools, and policymakers in designing more valid assessment systems and more sustainable professional development programs that are better aligned with disciplinary needs.

Accordingly, this study aims to synthesize empirical evidence on TPACK in Indonesia during the 2015–2025 period through a Systematic Literature Review and thematic meta-synthesis. Specifically, this study addresses three research questions: (1) How do TPACK profiles differ across disciplinary contexts among Indonesian teachers? (2) How has the validity of TPACK measurement evolved over the past decade? (3) Which professional development models are most effective in strengthening integrated TPACK competencies? Through these questions, the study does not only to present empirical patterns, but also to provide conceptual and practical directions for developing competencies that are more responsive to contemporary educational demands, more robust methodologically, and more sensitive to disciplinary characteristics.

B. Method

This study employed a Systematic Literature Review (SLR) integrated with thematic meta-synthesis to examine the development of Technological Pedagogical Content Knowledge (TPACK), the evolution of measurement validity, and the effectiveness of teacher professional development models in Indonesia during the 2015–2025 period. The SLR approach was selected because it provides a systematic, transparent, and replicable procedure for identifying, selecting, and synthesizing empirical evidence from previous studies. To strengthen methodological rigor and reporting transparency, the review process followed the PRISMA 2020 framework, which guided the stages of identification, screening, eligibility assessment, and final inclusion of studies. Through this approach, the study aimed not only to summarize previous findings but also to interpret broader patterns and relationships among disciplinary contexts, methodological approaches, and intervention effectiveness within the Indonesian TPACK literature.

The literature search was conducted using four academic databases, namely Scopus, Web of Science, ERIC, and Google Scholar. These databases were selected because they provide broad coverage of educational and teacher development research at both international and national levels. The search process used combinations of keywords and Boolean operators, including “TPACK,” “teacher professional development,” “technology integration,” “measurement validity,” and “Indonesia.” The search was limited to articles published between 2015 and 2025 in order to capture the most relevant decade of TPACK

development in the Indonesian educational context. Only peer-reviewed empirical studies were considered eligible because the study focused on synthesizing evidence-based findings rather than conceptual arguments. Articles were included if they discussed teacher or pre-service teacher TPACK, TPACK measurement instruments, or professional development interventions related to technology integration in Indonesia. Meanwhile, conceptual papers, non-empirical studies, conference abstracts without full reports, and studies conducted outside Indonesia were excluded from the review process.

The initial database search yielded 187 records. After removing 43 duplicate articles, the remaining studies underwent title and abstract screening to determine their relevance to the focus of the review. At this stage, 89 records were excluded because they did not meet the inclusion criteria or lacked sufficient empirical relevance. The full texts of the remaining 55 articles were then carefully examined to assess methodological appropriateness, contextual relevance, and completeness of findings. Following the eligibility assessment, 22 studies were retained for final synthesis. This multi-stage selection process ensured that the articles included represented studies with sufficient methodological clarity and direct relevance to the three analytical dimensions examined in this review. The review procedure is summarized in Figure 1, which illustrates the flow of article identification, screening, eligibility assessment, and thematic synthesis.

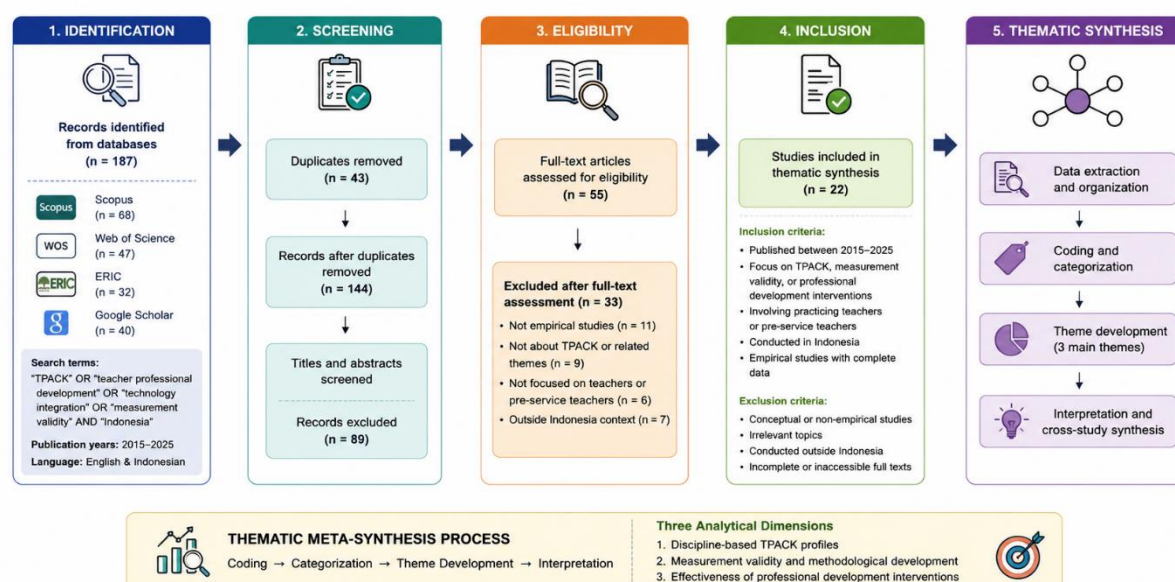


Figure 1. Flow of Article Identification, Screening, Eligibility Assessment, and Thematic Synthesis

To organize the review systematically, data from each article was extracted using a structured matrix that included the author, publication year, research context, participant characteristics, disciplinary focus, methodological approach, instruments used, and principal findings. The extracted findings were repeatedly reviewed and coded to identify recurring concepts and patterns across studies. To enhance analytical credibility, the categorization process was conducted through iterative comparison and discussion until conceptual

consistency was achieved. Although this study did not employ a formal quantitative appraisal tool, all included studies were screened based on relevance, empirical contribution, methodological transparency, and alignment with the objectives of the review.

The analysis employed thematic meta-synthesis as the primary interpretive strategy. This approach enabled the integration of findings from diverse methodologies, including quantitative, qualitative, and mixed-method studies, into broader conceptual themes (Braun & Clarke, 2006; Xu & Zammit, 2020). The coding process generated three dominant thematic categories: disciplinary differences in TPACK profiles, the development of measurement validity and psychometric approaches, and the effectiveness of professional development interventions. Through iterative interpretation, the synthesis moved beyond descriptive reporting to construct a more integrated understanding of TPACK as a dynamic and discipline-sensitive pedagogical construct within Indonesian education. The resulting themes were then interpreted comparatively to explain how technological integration, assessment quality, and professional learning models interact in shaping teachers' TPACK development across different educational contexts.

C. Result

The synthesis of 22 empirical studies revealed three dominant thematic patterns related to disciplinary disparities in TPACK profiles, the evolution of measurement validity, and the effectiveness of professional development interventions in Indonesia. The reviewed studies were published between 2015 and 2025 and involved diverse educational contexts, including elementary, secondary, vocational, and teacher education institutions. Most studies employed quantitative survey methods and self-report instruments, although more recent research has increasingly adopted psychometric approaches such as Rasch modeling and confirmatory factor analysis (CFA). Overall, the findings indicate that TPACK development in Indonesia is shaped not only by teachers' technological competence, but also by disciplinary characteristics, methodological quality, and the nature of professional learning interventions.

Overview of Reviewed Studies

The descriptive mapping of the reviewed literature demonstrates several important trends. Of the 22 studies included in the synthesis, language, science, and elementary education constituted the most dominant disciplinary contexts. Quantitative survey methods remained the most frequently used research design, while only a limited number of studies incorporated classroom observation, mixed methods, or psychometric validation approaches. In terms of publication trends, studies published after 2020 increasingly focused on measurement validity and effectiveness intervention, reflecting a growing concern with methodological rigor and sustainable teacher development.

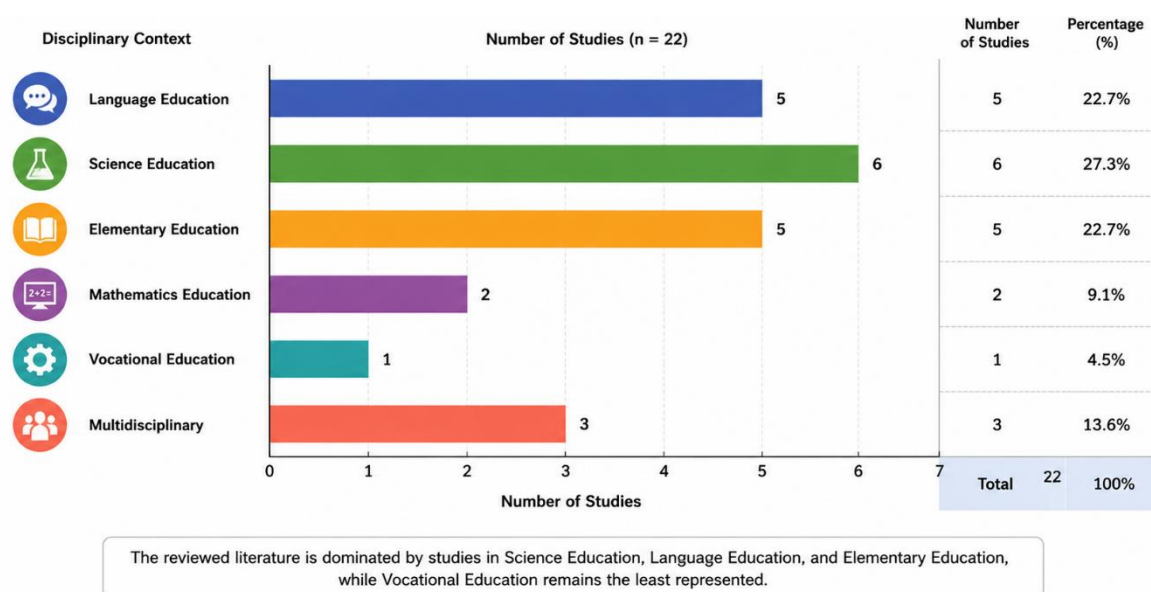


Figure 2. Distribution of Reviewed Studies by Discipline (2015–2025)

Figure 2 presents the distribution of reviewed studies across disciplinary contexts, while Table 1 summarizes the characteristics of the selected articles, including discipline, methodological approach, and principal findings.

Table 1. Summary of Articles Reviewed in TPACK Systematic Review (2015–2025)

No	Author & Year	Subject/Discipline	Method & Instrument	Main Findings
1	Mahdum (2015)	Language Teachers (EFL)	Self-report survey	High technological efficacy, but integration remains instrumental
2	Aisyah et al (2021)	Language Teachers	TPACK survey	Strong TK and TPK, dominance of digital applications
3	Ma'mun et al (2021)	Arabic Language Teachers	Survey and interviews	Increased use of digital platforms, low pedagogical integration
4	Prasojo et al (2020)	Elementary Teachers	Survey	Self-report produces high positive bias
5	Irwanto (2021)	Science Teachers	TPACK survey and observation	Gap between perceived and actual TCK performance
6	Irwanto et al (2022)	Science Teachers	Mixed methods	Strong PCK, weak TCK
7	Fakhriyah et al (2022)	Elementary Teachers	Survey and FGD	Challenges in integrating technology for scientific concepts
8	Sudrajat et al (2024)	Science Teachers	Classroom observation	Digital visualization is not optimally utilized
9	Rahmadi et al (2020)	Civic Education Teachers	Rasch modeling	TPACK instrument becomes valid after item modification

No	Author & Year	Subject/Discipline	Method & Instrument	Main Findings
10	Fadzil et al (2022)	Mathematics Teachers	Rasch analysis	Misfit items identified; more accurate competency diagnosis
11	Ibrohim et al (2022)	Vocational Teachers	CFA and Rasch	Improved construct validity, reduced self-report bias
12	Habibi et al (2020)	Senior High School Teachers	Post-training survey	Short-term workshops are ineffective
13	Rochintaniawati et al (2019)	Science Teachers	Lesson Study	Significant improvement in TPK and TCK
14	Purwianingsih et al (2022)	Elementary/Science Teachers	ESD-TPACK intervention	Increased TPACK integration across three domains
15	Canbazoglu Blici et al (2016)	Senior High School Teachers	Reflective practicum	Improved TPACK integration and pedagogical reflection
16	Fakhriyah et al (2022)	Elementary Teachers	Project-based learning	TK and TPK improved through project activities
17	Habibi et al (2020)	Language Teachers	Post-training survey	Integration skills did not improve significantly
18	Prasojo et al (2020)	Multidisciplinary Teachers	Mixed methods	TPACK improved through learning communities
19	Restiana et al (2019)	Mathematics Teachers	Survey	Low TK as the main barrier
20	Irwanto (2021)	Science Teachers	Observation	Main obstacle in integrating simulation applications
21	Mahdum (2015)	Language Teachers	Survey	Use of digital applications tends to be repetitive
22	Purwianingsih et al (2022)	Elementary Teachers	Survey and observation	TPK improved after long-term mentoring

Table 1 demonstrates that TPACK development in Indonesia remains uneven across disciplines and methodological approaches. The dominance of survey-based studies indicates that teacher competency mapping still relies heavily on perception-based measurement, whereas observation-based and psychometric studies remain relatively limited. In addition, intervention-oriented studies consistently report stronger outcomes when professional learning is collaborative, practice-based, and sustained over time.

Discipline-Based Differences in TPACK Profiles

To answer the first research question regarding disciplinary differences in TPACK profiles, the synthesis identified a consistent divergence between language-oriented disciplines and science-oriented disciplines. Language teachers generally demonstrated high technological confidence and frequent use of digital applications; however, technology integration tended to remain instrumental and communication-oriented rather than

transformative. Technology was commonly used for presentation, audiovisual support, and online interaction, but less frequently employed to facilitate critical literacy, discourse analysis, or inquiry-based learning.

In contrast, science and elementary school teachers demonstrated relatively stronger pedagogical and content knowledge foundations but experienced substantial limitations in the technological integration domains, particularly TK, TCK, and TPK. Difficulties were most visible in competencies involving simulation tools, scientific visualization, digital representation of phenomena, and data-driven inquiry activities. These findings indicate that TPACK integration is strongly influenced by the epistemic characteristics of each discipline and therefore cannot be strengthened through generic training approaches alone.

Table 2. Cross-Disciplinary Characteristics of TPACK Profiles

Discipline	Dominant Strength	Main Weakness	Recurring Pattern
Language Education	Technological Knowledge (TK)	Pedagogical integration	Instrumental technology use
Science Education	Pedagogical Content Knowledge (PCK)	TCK and TPK	Limited scientific visualization
Elementary Education	Pedagogical Knowledge (PK)	Technology integration	Low conceptual digital representation
Mathematics Education	Content Knowledge (CK)	Technological adaptation	Limited use of interactive tools
Vocational Education	Practical content orientation	Measurement consistency	Need for validated assessment

The findings collectively show that TPACK profiles are discipline-sensitive and shaped by the cognitive and pedagogical demands of different subject areas.

Evolution of Measurement Validity

The second research question examined how TPACK measurement validity evolved during the 2015–2025 period. The review found that early studies were dominated by self-report surveys, which frequently produced inflated competency scores and inconsistencies between perceived and observed classroom practices. Most of the reviewed studies relied primarily on perception-based instruments, particularly self-report surveys, while only a limited number employed psychometric validation approaches.

Following 2020, however, a methodological shift became increasingly visible. Studies began adopting Rasch modeling, CFA, and observation-based validation approaches to improve construct validity and reduce self-report bias. These approaches enabled more accurate item calibration, detection of measurement inconsistencies, and identification of weak competency domains. As a result, more recent studies produced competency profiles that were diagnostically stronger and methodologically more rigorous than earlier survey-dominated studies.

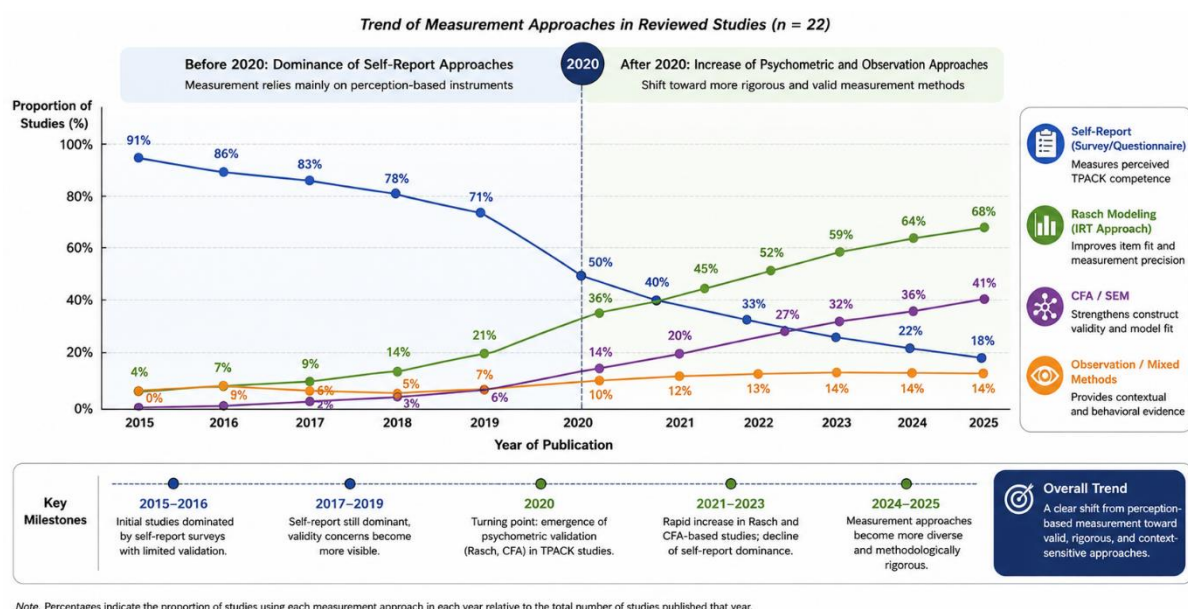


Figure 3. Evolution of TPACK Measurement Approaches (2015–2025)

Figure 3 demonstrates a clear methodological transition in Indonesian TPACK research during the 2015–2025 period. Prior to 2020, most studies relied heavily on self-report surveys that emphasized perceived technological competence. However, studies published after 2020 increasingly adopted psychometric and observation-based approaches, particularly Rasch modeling and confirmatory factor analysis (CFA), to improve construct validity and reduce perception bias. This trend indicates growing awareness among researchers regarding the importance of more rigorous and diagnostically accurate assessment procedures in measuring integrated TPACK competencies. To further clarify the methodological distinctions identified in the reviewed studies, Table 3 compares the major TPACK measurement approaches, including their principal strengths, limitations, and implications for teacher competency assessment.

Table 3. Comparison of TPACK Measurement Approaches

Measurement Approach	Strength	Limitation	Implication
Self-report Survey	Easy administration	Perception bias	Inflated competency scores
Classroom Observation	Contextual evidence	Time intensive	More authentic competency mapping
Rasch Modeling	Item calibration and fit analysis	Requires statistical expertise	More objective diagnosis
Confirmatory Factor Analysis (CFA)	Strong construct validation	Requires larger samples	Improved measurement validity

These findings demonstrate that methodological quality has become an increasingly important concern in Indonesian TPACK research, particularly in relation to the accuracy of teacher competency assessment.

Effectiveness of Professional Development Interventions

The third research question focused on identifying the most effective professional development models for strengthening integrated TPACK competencies. The synthesis consistently showed that collaborative and practice-based interventions produced substantially stronger outcomes than short-term ICT workshops or one-way training programs. Lesson study, project-based learning, reflective practicum, and ESD-integrated interventions were repeatedly associated with improvements across multiple TPACK domains because they provided authentic teaching contexts, repeated reflection cycles, and collaborative problem solving.

By contrast, short-duration technology workshops generally improved only surface-level operational skills without producing meaningful pedagogical transformation. Several studies reported that teachers participating in workshop-only models remained unable to integrate technology into inquiry-based or conceptually rich instructional practices. These findings suggest that sustainable professional learning requires long-term engagement, classroom-based implementation, and reflective collaboration.

Table 4. Effectiveness of Professional Development Models

Intervention Model	Main Characteristics	Impact on TPACK
Lesson Study	Collaborative reflection cycles	Strong improvement in TPK and TCK
Project-Based Learning	Authentic project activities	Improved TK and pedagogical integration
Reflective Practicum	Classroom-based reflection	Sustainable TPACK development
Learning Communities	Peer collaboration	Increased integrative competence
Short-term ICT Workshop	Technical training only	Minimal pedagogical impact

Overall, the synthesis confirms that TPACK development in Indonesia is influenced by the interaction among disciplinary characteristics, methodological quality, and the practice-based nature of teacher professional development. These patterns position TPACK not as a static competency construct, but as a dynamic pedagogical ecosystem that requires discipline-sensitive assessment and sustainable professional learning models.

D. Discussion

The findings of this review demonstrate that TPACK development in Indonesia is not a uniform process, but rather a dynamic and discipline-sensitive phenomenon shaped by differences in pedagogical orientation, technological integration, and methodological approaches to competency assessment. Across the reviewed studies, three major patterns emerged consistently: unequal TPACK profiles across disciplines, the gradual transition toward more valid measurement approaches, and the superior effectiveness of collaborative and practice-based professional development models. These findings collectively position

TPACK not merely as an individual competency framework, but as a broader pedagogical ecosystem influenced by contextual, methodological, and institutional factors.

Regarding the first research question, the synthesis confirms that TPACK profiles differ substantially across disciplinary contexts. Language teachers generally demonstrate high technological confidence and frequent use of digital applications, yet the integration of technology often remains instrumental and communication-oriented. Studies by [Mahdum \(2015\)](#), [Ma'mun et al \(2021\)](#), and [Aisyah et al \(2021\)](#) consistently show that technology is commonly used for audiovisual support, online interaction, and digital communication rather than for deeper pedagogical transformation or critical literacy development. This finding suggests that technological familiarity alone does not necessarily produce integrative TPACK competence. As argued by [Chai et al \(2019\)](#), technology adoption in language education frequently emphasizes operational fluency while lacking sufficient metacognitive and pedagogical scaffolding to support transformative learning. In this context, technology functions more as a delivery tool than as a cognitive instrument for inquiry, reflection, and discourse construction.

In contrast, science and elementary school teachers demonstrate relatively stronger pedagogical content knowledge but continue to experience substantial limitations in technological integration, particularly within the TK, TCK, and TPK domains. Studies by [Irwanto et al \(2022\)](#), [Fakhriyah et al \(2022\)](#), and [Sudrajat et al \(2024\)](#) indicate that many teachers struggle to utilize digital simulations, scientific visualization tools, and data-based inquiry platforms effectively. These findings support the argument of [Angeli & Valanides \(2015\)](#), who emphasize that science educators often encounter difficulties when translating conceptual understanding into technology-mediated representational forms. The present synthesis therefore reinforces the discipline-specific nature of TPACK development. Effective integration of technology depends not only on technological access or confidence, but also on how disciplinary epistemology shapes teachers' pedagogical decisions. As suggested by [Voogt & McKenney \(2017\)](#), generic technology training programs are insufficient because each discipline requires distinct forms of technological representation and pedagogical adaptation.

The second research question examined the evolution of TPACK measurement validity during the 2015–2025 period. The findings reveal a clear methodological shift from perception-based assessment toward psychometrically validated approaches. Earlier studies were dominated by self-report surveys, which frequently generated inflated competency profiles and inconsistencies between perceived competence and observable classroom practice. [Prasojo et al \(2020\)](#) and [Irwanto \(2021\)](#) both demonstrate that teachers often report high confidence in technological integration despite limited enactment of integrative practices in actual teaching contexts. This discrepancy confirms the broader critique proposed by [Schmid et al \(2020\)](#), who argue that self-assessment instruments tend to overestimate TPACK competence because they measure perception rather than performance. Such overestimation has important implications for educational policy because inaccurate competency mapping

may lead to ineffective professional development planning and misallocation of institutional resources.

More recent studies have increasingly adopted Rasch modeling, confirmatory factor analysis (CFA), and observation-based validation procedures to strengthen construct validity and reduce perception bias. [Rahmadi et al \(2020\)](#), [Fadzil et al \(2022\)](#), and [Irwanto et al \(2022\)](#) demonstrate that psychometric approaches provide more objective calibration, identify item misfit, and produce diagnostically stronger competency profiles. These developments align with the methodological recommendations of [Bond & Fox \(2015\)](#), who emphasize the importance of probabilistic measurement models in educational assessment because they distinguish actual ability from measurement error more effectively than conventional survey approaches. The increasing use of Rasch and CFA therefore represents not only a technical improvement, but also a broader methodological maturation within Indonesian TPACK research. Nevertheless, the findings also indicate that perception-based surveys continue to dominate many practical research settings, suggesting that methodological rigor has not yet become fully standardized across studies.

The third research question focused on identifying the most effective professional development models for strengthening integrated TPACK competencies. The synthesis consistently demonstrates that collaborative and practice-based interventions produce substantially stronger outcomes than short-term ICT workshops or one-way training programs. Lesson study ([Rochintaniawati et al., 2019](#)), project-based learning ([Fakhriyah et al., 2022](#)), reflective practicum ([Rochintaniawati, 2019](#)), and ESD-integrated TPACK interventions ([Purwianingsih et al., 2022](#)) all resulted in measurable improvements across multiple TPACK domains. These interventions were effective because they engaged teachers in authentic classroom contexts, iterative reflection cycles, collaborative problem solving, and continuous peer feedback. Such characteristics are closely aligned with the framework proposed by [Darling-Hammond et al \(2017\)](#), who identify active learning, sustained duration, contextual coherence, and collaboration as core features of effective professional development.

Conversely, studies by [Habibi et al \(2020\)](#) reveal that short-term technology workshops generally fail to produce meaningful pedagogical transformation. Teachers participating in these programs may improve basic operational skills, but they often remain unable to integrate technology into inquiry-based, conceptually rich, or student-centered instructional practices. This finding supports the argument of [Opfer & Pedder \(2011\)](#), who criticize episodic and decontextualized teacher training models for their inability to generate sustainable professional learning. In the Indonesian context, these results indicate that professional development should move beyond technical orientation and focus more strongly on reflective pedagogy, classroom experimentation, and collaborative learning communities ([Cochran-Smith & Lytle, 1999](#)).

Taken together, the findings of this review position TPACK as a dynamic pedagogical construct shaped by disciplinary context, methodological quality, and professional learning processes. The unequal distribution of TPACK competencies across disciplines demonstrates

that technology integration cannot be approached through universal training models. Similarly, the shift toward psychometric validation highlights the growing importance of accurate competency assessment in supporting evidence-based policy decisions. At the same time, the effectiveness of collaborative interventions reinforces the argument that meaningful pedagogical transformation requires sustained, practice-oriented professional learning rather than isolated technical instruction. Consequently, this study suggests that future teacher development policies in Indonesia should integrate discipline-sensitive training models, psychometrically rigorous assessment systems, and long-term collaborative learning structures in order to strengthen teachers' capacity for meaningful technology integration in contemporary education.

E. Implication

The findings of this study provide important theoretical, practical, and policy implications for the development of teacher competencies in technology-enhanced learning. Theoretically, the study reinforces the view that TPACK is a dynamic and discipline-sensitive construct, indicating that technological integration cannot be separated from the epistemic characteristics of each subject area. Practically, the findings highlight the necessity of shifting teacher professional development from short-term technical training toward collaborative, reflective, and practice-based learning models such as lesson study, project-based learning, and reflective practicum. The study also emphasizes the importance of adopting psychometrically validated and performance-based assessment approaches, including Rasch modeling and CFA, to produce more accurate teacher competency mapping and reduce perception bias associated with self-report instruments. At the policy level, the findings suggest that teacher education institutions and educational authorities should design sustainable professional development systems that integrate discipline-responsive training, valid competency assessment frameworks, and continuous pedagogical mentoring to support meaningful and contextually relevant technology integration in Indonesian education.

F. Limitations and Suggestions for Further Research

Despite the important contributions of this study, several limitations should be acknowledged. First, the review was limited to studies indexed in Scopus, Web of Science, ERIC, and Google Scholar, which may have excluded relevant findings published in non-indexed national journals, institutional repositories, or other forms of grey literature. Second, the reviewed studies demonstrated substantial methodological heterogeneity in terms of research design, participant characteristics, intervention models, and measurement instruments, thereby limiting direct comparability across findings. In addition, most studies relied on cross-sectional and self-report approaches, which may not fully represent teachers' actual classroom practices or the long-term development of integrated TPACK competencies. The limited representation of certain disciplines, such as social studies, arts education, and

physical education, also indicates that the current body of Indonesian TPACK literature remains unevenly distributed across subject areas.

Building upon the implications of this review, future research should adopt more rigorous and comprehensive methodological approaches to strengthen the evidence base of TPACK development in Indonesia. Longitudinal and experimental studies are needed to examine how teachers' competencies evolve through sustained professional learning and how specific interventions influence pedagogical transformation over time. Future studies should also prioritize the development of psychometrically validated and performance-based assessment instruments in order to reduce perception bias and generate more accurate competency mapping. Furthermore, comparative cross-disciplinary investigations involving underrepresented subject areas are necessary to provide a more comprehensive understanding of how contextual, pedagogical, and technological factors interact in shaping teachers' TPACK integration across diverse educational settings.

G. Conclusion

This study concludes that the development of Technological Pedagogical Content Knowledge (TPACK) in Indonesia during the 2015–2025 period reflects a complex and discipline-sensitive pedagogical ecosystem shaped by differences in disciplinary characteristics, methodological approaches, and professional learning models. The synthesis demonstrates that language teachers generally exhibit strong technological confidence but limited transformative pedagogical integration, whereas science and elementary school teachers possess relatively stronger pedagogical-content foundations yet continue to experience difficulties in technological integration domains such as TK, TCK, and TPK. These findings confirm that TPACK development cannot be approached through uniform training models because each discipline requires distinct forms of technological representation and pedagogical adaptation.

The review also reveals a substantial methodological transition in Indonesian TPACK research, particularly from the dominance of self-report instruments toward more psychometrically rigorous approaches such as Rasch modeling and confirmatory factor analysis (CFA). This shift indicates growing awareness of the importance of constructing validity and accurate competency assessment in teacher education research. In addition, the synthesis consistently demonstrates that collaborative and practice-based professional development models, including lesson study, project-based learning, reflective practicum, and learning communities, are significantly more effective than short-term ICT workshops in strengthening integrated TPACK competencies. Collectively, these findings position TPACK not as a static competency construct, but as a dynamic and contextually embedded framework that requires discipline-responsive assessment systems, sustainable professional learning structures, and pedagogically oriented technology integration policies. Consequently, this study provides an integrated evidentiary foundation for teacher education institutions, schools, and policymakers to design more valid, reflective, and sustainable teacher

development systems capable of responding to the evolving demands of contemporary education.

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