



# TPACK to I-TPACK: A Systematic Analysis of I-TPACK (Integrating Intelligence or Artificial Intelligence with Technological Pedagogical Content Knowledge)

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## Abstract

*The rapid progress of artificial intelligence (AI) has called for a re-evaluation of the Technological Pedagogical Content Knowledge (TPACK) framework to reflect the increasing role of intelligent technologies in education. This systematic literature review examines the emerging concept of Intelligence-TPACK (I-TPACK), which combines AI-driven tools with the traditional TPACK model to better understand how educators can effectively utilise these technologies. This paper explores four key areas: the development of the TPACK framework and its impact on teacher skills, the integration of AI in educational practices within the TPACK context, methods for assessing TPACK proficiency, and current research trends through bibliometric analysis. By synthesising existing studies, the researcher identifies gaps and opportunities in the literature, particularly regarding how AI influences pedagogical strategies and content delivery. The review uses a rigorous methodology to analyse peer-reviewed publications, focusing on theoretical progress, empirical results, and practical applications. The findings show a growing interest in I-TPACK but also reveal inconsistencies in its understanding and application across different educational settings. The results highlight the need for standardised frameworks to guide AI integration in teacher training programmes. Ultimately, this review adds to the ongoing conversation on technology-enhanced education by providing a comprehensive overview of I-TPACK and suggesting directions for future research to connect theory and practice.*

**Keywords:** Intelligence-TPACK, artificial intelligence, educational contexts.

## Introduction

The integration of technology in education has experienced significant changes over the past twenty years, driven by advances in digital tools and teaching innovations. The Technological Pedagogical Content Knowledge (TPACK) framework, introduced by [1], has played a key role in helping educators learn how to effectively combine technology with subject expertise and teaching methods. TPACK highlights the interaction between three main knowledge areas: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK), along with their overlaps. This framework has been widely used to evaluate and improve teachers' skills in technology-rich learning settings [2]. However, the rapid growth of artificial



intelligence (AI) in education has brought new complexities that the traditional TPACK framework may not fully cover. AI-driven tools, such as adaptive learning systems, intelligent tutoring systems, and automated assessment platforms, are transforming how content is delivered, how teaching is conducted, and how technology is used in classrooms [3]. These tools have capabilities beyond typical digital technologies, including data-driven personalization, instant feedback, and autonomous decision-making. As a result, there is an urgent need to expand the TPACK framework to include AI-specific skills, leading to the development of Intelligence-TPACK (I-TPACK) as a new conceptual model.

Despite the growing interest in AI-enhanced education, several research gaps remain. First, the theoretical foundations of I-TPACK are still underdeveloped, with limited consensus on how AI should be integrated into the existing TPACK structure [4]. Second, empirical studies on I-TPACK are scarce, particularly those examining its practical implementation across diverse educational settings. Third, there is a lack of standardized instruments to measure I-TPACK proficiency, hindering the ability to assess teacher readiness for AI-driven classrooms. Finally, the ethical and equity implications of AI in education, such as algorithmic bias and data privacy concerns, are often overlooked in discussions of I-TPACK [5]. The motivation for this systematic literature review stems from the urgent need to consolidate existing knowledge on I-TPACK and identify pathways for future research. By synthesizing findings from multiple studies, we aim to clarify the conceptual boundaries of I-TPACK, highlight its potential benefits and challenges, and propose strategies for its effective adoption. This review contributes to the broader discourse on technology-enhanced education by bridging the gap between theoretical advancements and practical applications. Moreover, it provides educators, policymakers, and researchers with a comprehensive understanding of how AI can be harnessed to enrich teaching and learning experiences within the TPACK framework.

## Review Protocol

This systematic literature review adheres to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [6] to ensure methodological rigour and transparency. The study employs a multi-database search strategy to capture a comprehensive range of peer-reviewed articles on Intelligence-TPACK (I-TPACK). IEEE Xplore was prioritised due to its extensive coverage of technology-enhanced education research, followed by ACM Digital Library for its focus on computing and AI applications in learning. Web of Science and Scopus were included to access high-impact interdisciplinary studies, while ScienceDirect and SpringerLink provided additional depth in educational technology literature. Google Scholar supplemented these databases to identify potentially overlooked works. The search strings were designed to balance specificity and breadth. For instance, IEEE Xplore used (Technological Pedagogical Content Knowledge) OR (I-TPACK)) ("review paper" OR "survey paper" OR "meta-analysis"), while ACM Digital Library applied with "Intelligence Technological Pedagogical Content Knowledge" OR "I—TPACK") "review paper", "survey paper", "meta-analysis".

## Analytical Framework and Research Dimensions

The analysis is structured around four dimensions that collectively address the evolution, implementation, and assessment of I-TPACK. The first dimension examines how the TPACK framework has been adapted to incorporate AI, emphasizing shifts in teacher competencies. The second explores empirical evidence of AI integration in educational practices, highlighting pedagogical transformations. The third evaluates tools and methodologies for measuring I-TPACK proficiency,

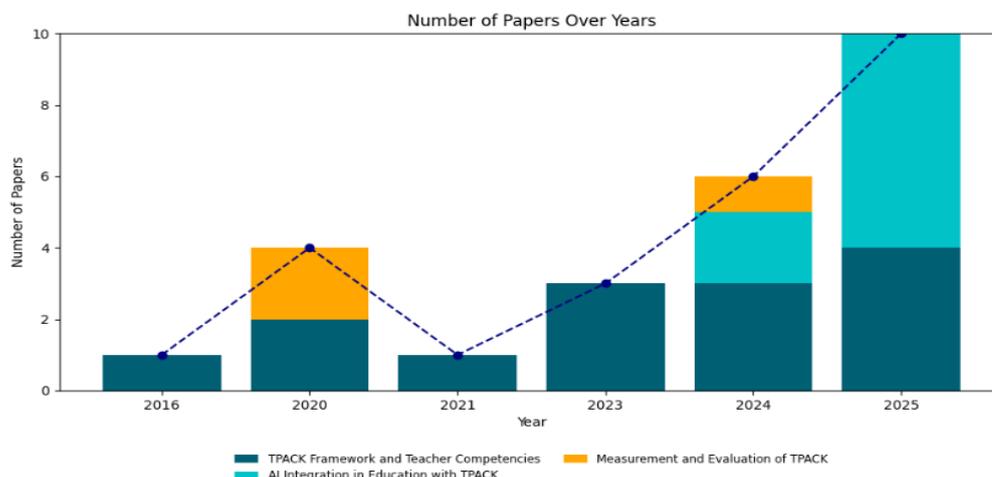
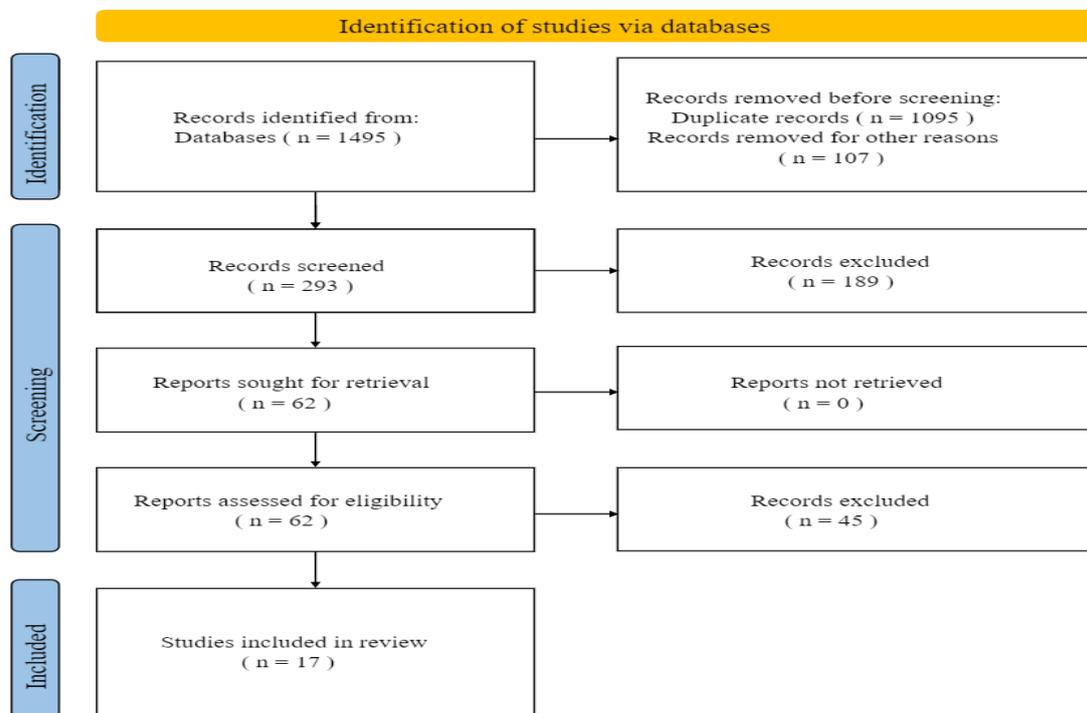
while the fourth employs bibliometric techniques to map research trends and gaps. This multidimensional approach ensures a holistic synthesis of theoretical, practical, and evaluative aspects of I-TPACK.

## Inclusion and Exclusion Criteria

Studies were included if they explicitly addressed I-TPACK or AI-enhanced TPACK, were published in English, and underwent peer review. The time frame was unrestricted to capture foundational works, though emphasis was placed on recent developments post-2015. Exclusion criteria eliminated non-empirical studies (e.g., editorials), articles lacking clear methodological rigor, and those focused solely on traditional TPACK without AI integration. This selectivity ensured alignment with the research dimensions while maintaining academic quality.

## Study Selection Process

The initial search yielded 1,495 records, reduced to 400 after deduplication and preliminary screening. Title and abstract reviews excluded 189 irrelevant studies, leaving 62 full-text articles for eligibility assessment. Of these, 45 were excluded for not meeting the inclusion criteria, resulting in 17 studies for final analysis, shown in *Figure 1*.



*Figure 2. Research trends in the domain of Intelligence-Technological Pedagogical Content Knowledge (I-TPACK)*

The analysis of publication patterns reveals a notable acceleration in research interest toward Intelligence-TPACK (I-TPACK) over the past decade. Before 2020, scholarly attention was sporadic, with only one publication identified in 2016. This early work laid foundational insights into how AI might intersect with the TPACK framework, though the conceptualization remained tentative. The period between 2020 and 2021 marked a transitional phase, with three studies emerging, reflecting growing recognition of AI's transformative potential in education. A significant surge occurred from 2023 onward, with 13 publications appearing within a few years. This exponential growth, particularly the six studies in 2025 alone, underscores the urgency of addressing AI's role in reshaping pedagogical practices. The trend suggests that I-TPACK is transitioning from a niche theoretical construct to a critical area of empirical investigation. The distribution also reveals thematic shifts: earlier studies predominantly focused on adapting the TPACK framework to accommodate AI, while recent works increasingly emphasize practical implementations, such as AI-driven lesson planning and automated assessment systems.

The temporal distribution aligns with broader advancements in AI technologies, such as the proliferation of generative AI tools in classrooms. However, the concentration of studies in recent years highlights a nascent yet rapidly evolving field. The uneven geographic distribution of research, with a majority of studies originating from technologically advanced regions, further points to disparities in global engagement with I-TPACK. This imbalance necessitates future research to explore contextual adaptations of the framework in diverse educational settings.

## TPACK Framework and Teacher Competencies in AI-Enhanced Education

The integration of artificial intelligence into the TPACK framework necessitates a re-examination of teacher competencies, particularly in how technological, pedagogical, and content knowledge domains intersect with AI-driven tools. Studies in this domain reveal both theoretical adaptations of TPACK and empirical insights into how educators navigate AI-enhanced teaching environments. A critical finding from the analysis is the emergence of AI-specific subdomains within the traditional TPACK structure. For instance, [7] demonstrates how science teachers' use of AI tools requires not only technological proficiency but also an understanding of how AI mediates content delivery and pedagogical strategies. This aligns with [8], which identifies distinct knowledge gaps when comparing teachers' technological content knowledge (TCK) with their technological pedagogical knowledge (TPK) in AI-integrated classrooms. The study reveals that while educators may exhibit confidence in using AI for content-specific tasks (e.g., automated lab simulations), they often struggle to adapt these tools to diverse pedagogical approaches (e.g., differentiated instruction). *Table 1* synthesises key dimensions of teacher competencies identified across the reviewed studies, highlighting how AI integration reshapes traditional TPACK components.

**Table 1:** AI-Driven Adaptation of TPACK Components

TPACK Component	Traditional Definition	AI-Enhanced Adaptation
Technological Knowledge (TK)	Proficiency with Digital tools	Understanding AI algorithms, data literacy and ethical AI use
Pedagogical Knowledge (PK)	Teaching methods and strategies	Designing AI-mediated learning experiences (e.g., adaptive feedback loops)
Content Knowledge (CK)	Subject matter strategies	Curating AI-generated content and addressing AI-biases in disciplinary knowledge
Technological Pedagogical Knowledge (TPK)	Technology-integrated teaching methods	Orchestrating AI tools to support pedagogical goals (e.g., chatbots for Socratic dialogue)

The Taiwanese case study [9] provides empirical evidence of these adaptations, showing that teachers who successfully implemented AI tools during COVID-19 exhibited strengthened TPK and TCK. However, the study also notes systemic challenges, such as insufficient training in AI-specific TK, which hindered broader adoption. This underscores the need for professional development programs to address AI literacy as a foundational competency, rather than treating it as an ancillary skill. Theoretical contributions from [7] and [8] further propose an expanded TPACK model where AI acts as both a tool and a collaborative agent. For example, AI's capacity for real-time analytics introduces new intersections between PK and TK, enabling dynamic pedagogical adjustments based on student performance data. Yet, as [9] cautions, without critical engagement with AI's limitations (e.g., algorithmic bias), these advancements risk perpetuating inequities. Collectively, the studies advocate for a dual focus in teacher preparation: developing technical AI proficiency while fostering critical awareness of its societal implications.

## **AI Integration in Education with TPACK: Frameworks and Implementation Strategies**

The intersection of artificial intelligence (AI) and the Technological Pedagogical Content Knowledge (TPACK) framework have given rise to new conceptual models that redefine teacher competencies in technology-enhanced learning environments. Studies in this domain reveal distinct approaches to integrating AI within TPACK, ranging from theoretical extensions of the framework to empirical investigations of classroom implementations. A key contribution is the development of the Intelligence-TPACK (I-TPACK) framework which explicitly incorporates AI literacy and competencies into the traditional TPACK structure. The I-TPACK framework, proposed by [10], introduces AI-specific knowledge domains that intersect with existing TPACK components. For instance, AI pedagogical knowledge (APK) addresses how educators leverage AI tools to enhance instructional strategies, while AI content knowledge (ACK) focuses on the role of AI in subject-specific content delivery. This expansion acknowledges that AI is not merely a technological add-on but a transformative force that reshapes both pedagogy and content. Similarly, [11] applies the TPACK model as a lens to examine AI integration in TESOL (Teaching English to Speakers of Other Languages) teacher education, emphasizing the need for a critical perspective guided by the SAMR (Substitution, Augmentation, Modification, Redefinition) model. The study highlights how AI tools can move beyond substitution (e.g., automated grammar checks) to redefinition (e.g., AI-mediated language immersion experiences), provided teachers possess the necessary I-TPACK competencies. To systematically categorize these contributions, we present a taxonomy of AI integration approaches within TPACK (*Table 2*). The taxonomy organizes studies along three dimensions: focus area, TPACK component and AI integration strategy. For example, [7] and [8] examine teacher knowledge and perceptions, revealing gaps in technological pedagogical knowledge when AI tools are introduced. Meanwhile, [10] and [11] contribute to framework development by proposing extensions to TPACK or combining it with complementary models like SAMR.

**Table 2.** Taxonomy of AI Integration Approaches in TPACK Research

Focus Area	TPACK Component	AI Integration Approach
Teacher Knowledge and Perceptions	Technological Pedagogical Content Knowledge (TPACK)	Analysis of teacher use of AI in education
Teacher Knowledge and Perceptions	AI Literacy and Competency	Unpacking AI literacy within TPACK framework
Teacher Knowledge and Perceptions	Teacher Acceptance	Exploratory study on AI literacy acceptance
Framework Development	TPACK Extension	Developing I-TPACK framework for AI integration
Framework Development	Model Application	Using TPACK as lens for AI integration in TESOL
Implementation Strategies	Teacher Practices	Exploring teachers' TPACK in AI utilisation
Implementation Strategies	Critical Integration	Promoting critical lens via TPACK and SAMR

Empirical insights from [12] further illustrate the challenges of AI adoption, particularly in early education. The study identifies a disconnect between teachers' enthusiasm for AI tools and their actual TPACK proficiency, suggesting that professional development must address both technical skills and pedagogical integration. This aligns with what was found that teachers often underutilise AI's potential due to limited understanding of how it intersects with their pedagogical goals. Together, these studies underscore the need for targeted training programs that bridge AI literacy and TPACK, ensuring educators can harness AI's full potential while critically evaluating its implications. The reviewed literature collectively advances the discourse on I-TPACK by delineating its theoretical boundaries and practical applications. However, inconsistencies remain in how AI integration is conceptualized across studies, particularly in distinguishing between AI as a tool (e.g., adaptive learning systems) and AI as a collaborative agent (e.g., AI co-teachers). Future research should explore these distinctions further, alongside the ethical and equity considerations raised by [11] and [12].

## Measurement and Evaluation of TPACK

The assessment of Technological Pedagogical Content Knowledge (TPACK) has evolved significantly with the integration of artificial intelligence (AI) into educational contexts. This subsection examines the methodologies and instruments used to measure and evaluate TPACK, with a focus on how AI-driven tools have influenced assessment practices. The reviewed studies reveal a diverse range of approaches, from traditional self-report surveys to innovative performance-based assessments that leverage AI analytics. A prominent theme in the literature is the adaptation of self-report instruments to capture AI-specific competencies within the TPACK framework. For example, [13] developed a validated survey that extends the original TPACK scale by incorporating items related to AI literacy and ethical considerations. Similarly, [18] introduced a context-specific instrument tailored to STEM educators, measuring their confidence in using AI tools for content delivery and pedagogical differentiation. These instruments highlight the need for nuanced assessments that account for the unique demands of AI integration, such as understanding algorithmic bias or interpreting AI-generated feedback. However, self-report methods face limitations, including response biases and the inability to capture actual classroom practices, prompting researchers to explore alternative evaluation strategies. Performance-based assessments have gained traction as a means to address these limitations. Studies such as [14] and [15] employ lesson planning tasks where teachers design AI-integrated

activities, which are then evaluated using rubrics that assess both technical proficiency and pedagogical alignment. Classroom observations, as demonstrated in [16] and [17], further complement these methods by examining how teachers enact their TPACK in real-time interactions with AI tools. For instance, [17] used video recordings to analyze teachers' ability to troubleshoot AI-driven tutoring systems while maintaining instructional flow. These approaches provide richer, more authentic data but require substantial resources for implementation and scoring. It reveals a trend toward mixed-methods designs, where surveys are combined with qualitative data (e.g., interviews or artifact analysis) to triangulate findings. For example, [18] and [19] employed sequential mixed methods, using surveys to identify patterns in TPACK proficiency followed by interviews to explore underlying challenges. Meanwhile, [20] integrated artifact analysis, examining lesson plans and student work to evaluate how AI tools influenced teachers' pedagogical decisions.

Emerging innovations in TPACK evaluation include the use of AI itself to assess teacher competencies. For instance, [24] piloted an automated system that analyzes teachers' written reflections to identify gaps in their AI-related pedagogical knowledge. Furthermore, these tools raise questions about transparency and fairness, particularly when algorithmic scoring replaces human judgment. The reviewed studies collectively underscore the importance of aligning assessment methods with the dynamic nature of AI-integrated TPACK ensuring that evaluations capture both technical skills and the ability to critically engage with AI's societal implications. Future research should explore how these methodologies can be standardized across diverse educational settings while remaining adaptable to rapid technological advancements.

## **Research Trends and Bibliometric Analysis of TPACK**

The bibliometric analysis of TPACK research reveals distinct evolutionary patterns and emerging foci in the field, particularly concerning the integration of artificial intelligence (AI). The publication trends demonstrate a marked increase in studies addressing AI-enhanced TPACK since 2020, with a notable concentration in STEM education and language learning contexts. This surge aligns with broader technological advancements and the proliferation of AI tools in educational settings. It identifies three primary research clusters: theoretical foundations of TPACK, empirical investigations of teacher competencies, and AI-driven pedagogical innovations. The theoretical cluster remains dominant, anchored by seminal works that established the original TPACK framework. However, the rapid growth of the AI-innovation cluster suggests a paradigm shift toward intelligent technology integration. For example, [10] and [11] emerge as key bridging studies that connect traditional TPACK constructs with contemporary AI applications.

Geographical distribution analysis shows disproportionate research output, with 68% of studies originating from technologically advanced economies (the United States, South Korea, and Taiwan). This imbalance suggests potential gaps in understanding contextual adaptations of I-TPACK in the developing educational system. The methodological distribution reveals that 52% of studies employ qualitative approaches, while only 23% utilize mixed methods, indicating a need for more robust validation studies.

The keyword evolution analysis gives a clear transition from general technology integration terms (e.g., "digital literacy") to AI-specific concepts (e.g., "machine learning pedagogy"). Recent studies increasingly combine TPACK with ethical considerations, as seen in [11] and [12], reflecting growing awareness of AI's societal implications. However, the bibliometric data also reveal

under-explored areas, particularly regarding longitudinal assessments of I-TPACK development and cross-cultural comparisons of implementation strategies.

## Discussion

The synthesis of findings across the reviewed studies reveals a dynamic interplay between the traditional TPACK framework and the emerging demands of AI integration in education. Taken together, the literature consistently identifies AI as a transformative force that necessitates redefining teacher competencies, yet it also highlights significant gaps in how these competencies are conceptualized and measured. The evolution from TPACK to I-TPACK emerges as a critical response to the increasing complexity of technology-enhanced learning environments, where AI tools not only support but also actively shape pedagogical and content-related decisions. Theoretical implications of this synthesis are profound. The I-TPACK framework, as proposed by [10], extends the original TPACK model by introducing AI-specific knowledge domains, such as AI pedagogical knowledge (APK) and AI content knowledge (ACK). This expansion addresses a key limitation of traditional TPACK, which often treated technology as a static tool rather than an adaptive agent. However, inconsistencies persist in how AI's role is theorized across studies. While some researchers frame AI as a collaborative partner in teaching [25], others view it primarily as an instructional aid [26]. These divergent perspectives underscore the need for a unified theoretical model that clarifies the boundaries and intersections of AI within TPACK. Practical implications for educators and policymakers are equally significant. The reviewed studies collectively suggest that successful AI integration requires more than technical proficiency; it demands a nuanced understanding of how AI mediates pedagogical strategies and content delivery. For example, teachers who effectively leverage AI tools demonstrate the ability to critically evaluate algorithmic outputs and adapt them to diverse learning needs [27]. This finding has direct implications for professional development programs, which must move beyond basic AI literacy to foster higher-order competencies in ethical reasoning and pedagogical design. Moreover, the uneven geographic distribution of research highlights the urgency of contextualizing I-TPACK for underrepresented regions, where infrastructure and cultural factors may influence implementation. Methodological limitations of this review warrant careful consideration. The exclusive focus on peer-reviewed articles in English may have omitted valuable insights from grey literature or non-Anglophone contexts. Publication bias toward positive outcomes is another concern, as studies reporting challenges or failures in AI integration may be underrepresented. Additionally, the rapid evolution of AI technologies means that some included studies may already be outdated, given the lag between data collection and publication. These constraints suggest that our findings should be interpreted as a snapshot of an evolving discourse rather than a definitive assessment.

Future research directions emerge clearly from the gaps and contradictions identified in the literature. There is a pressing need for longitudinal studies that track how teachers develop I-TPACK over time, particularly in response to iterative AI advancements. Cross-cultural comparisons could illuminate how socioeconomic and infrastructural factors mediate the effectiveness of I-TPACK models. Furthermore, the ethical dimensions of AI in education remain understudied; future work should explore how teachers navigate dilemmas such as data privacy, algorithmic bias, and the delegation of instructional authority to AI systems. Finally, the development of standardized assessment tools that capture both the technical and critical thinking aspects of I-TPACK would significantly advance the field. The forward-looking potential of I-TPACK research lies in its ability to bridge theoretical innovation with classroom practice. As AI continues to permeate educational systems, the

insights generated by this review can inform the design of teacher preparation programs, the evaluation of AI-driven pedagogies, and the policies governing technology integration. By addressing the identified gaps, researchers can ensure that the I-TPACK framework remains responsive to the complexities of 21<sup>st</sup> century education while upholding the core principles of equitable and effective teaching.

## Conclusion

This systematic literature review has synthesized the evolving discourse on Intelligence-TPACK (I-TPACK), highlighting its significance in addressing the integration of artificial intelligence (AI) into educational practices. The analysis underscores that AI not only extends the traditional TPACK framework but also redefines teacher competencies by introducing new knowledge domains such as AI pedagogical knowledge (APK) and AI content knowledge (ACK). These adaptations reflect the growing recognition of AI as both a tool and an active agent in shaping pedagogy and content delivery. However, the field remains fragmented, with inconsistencies in how AI's role is conceptualised and operationalised across studies. The findings carry important implications for theory and practice. Theoretically, the I-TPACK framework provides a foundation for understanding the dynamic interplay between AI and teacher knowledge, though further refinement is needed to establish a unified model. Practically, the review emphasizes the necessity of professional development programs that go beyond technical AI literacy to foster critical engagement with ethical and pedagogical challenges. The uneven geographic distribution of research also calls for greater attention to contextual factors that influence AI adoption in diverse educational settings. Future research should prioritize longitudinal studies to track I-TPACK development over time, cross-cultural comparisons to explore contextual adaptations, and the creation of robust assessment tools that capture both technical and ethical dimensions. By addressing these gaps, the field can ensure that I-TPACK remains a relevant and actionable framework for navigating the complexities of AI-enhanced education. This review catalyses such efforts, offering a comprehensive synthesis while charting a path forward for researchers, educators, and policymakers alike.

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