

# **Drivers of Teachers' Pedagogical Competence in the Digital Era: A Meta-Analysis of Educational Technology Integration, Organizational Support, and Self-Efficacy**

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## **ABSTRACT**

*This meta-analysis examines the drivers of teachers' pedagogical competence in the digital era, focusing on educational technology integration, organizational support, and self-efficacy. Following PRISMA 2020 guidelines, we analyzed 105 peer-reviewed studies (2016–2026) from Scopus and Web of Science. Results revealed significant positive effects: technology integration interventions showed large effects on TPACK development ( $d = 0.839$ ); IT self-efficacy strongly correlated with TPACK ( $r = 0.607$ ); and the Technology Acceptance Model explained 39.2% of variance in adoption intentions. Pre-service teachers exhibited stronger self-efficacy–TPACK correlations ( $r = 0.666$ ) than in-service teachers ( $r = 0.538$ ). Methodological gaps included limited longitudinal designs and geographic concentration. Findings suggest effective pedagogical competence development requires integrated approaches combining technology literacy, institutional support, and self-efficacy enhancement within context-sensitive frameworks.*

**Keywords:** pedagogical competence, educational technology integration, TPACK, organizational support, self-efficacy

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## INTRODUCTION

Teachers' pedagogical competence constitutes a fundamental determinant of educational quality and student learning outcomes in contemporary schooling systems (Mishra & Koehler, 2006). In the digital era, this competence has evolved beyond traditional instructional skills to encompass the sophisticated integration of technological tools, digital resources, and innovative pedagogical approaches that prepare students for an increasingly technology-mediated world (Redecker, 2017; UNESCO, 2018). The ideal condition envisions teachers who seamlessly blend content knowledge, pedagogical expertise, and technological proficiency, a synthesis conceptualized as Technological Pedagogical Content Knowledge (TPACK), while receiving robust institutional support and maintaining strong beliefs in their capacity to integrate technology into instruction effectively (Koehler et al., 2013).

Theoretically, this study draws upon several foundational frameworks. First, the TPACK framework developed by Mishra and Koehler (2006) provides a comprehensive conceptualization of teacher knowledge required for effective technology integration, identifying seven interrelated knowledge domains: Content Knowledge (CK), Pedagogical Knowledge (PK), Technology Knowledge (TK), and their intersections, Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and the integrative TPACK. Second, the Technology Acceptance Model (TAM) proposed by Davis (1989) explains technology adoption through perceived usefulness and perceived ease of use, offering insights into factors influencing teachers' decisions to integrate digital tools. Third, Bandura's (1977) self-efficacy theory posits that individuals' beliefs in their capabilities significantly influence their behavior, persistence, and outcomes, particularly relevant to understanding teachers' confidence in technology integration. Fourth, organizational support theory emphasizes the role of institutional resources, leadership, and collaborative structures in facilitating or constraining teachers' professional practices (Vermeulen et al., 2017).

Although these four frameworks have largely evolved in parallel, recent scholarship has begun to articulate their conceptual interdependence. TPACK characterizes the knowledge structure teachers need; TAM explains how that knowledge is translated into intention and use; self-efficacy describes the motivational engine that sustains effortful integration; and organizational support

theory specifies the structural and relational conditions under which the prior three can be enacted. Empirically, a recent systematic review of 21 studies demonstrates that teachers' professional development plays a key moderating role in the relationships between self-efficacy, attitudes, and digital competencies in technology-rich teaching environments (Gui et al., 2026). This integrated reading reframes pedagogical competence in the digital era not as a single attribute but as the joint product of teacher knowledge, motivational beliefs, technology acceptance, and enabling institutional conditions.

Equally important for the present synthesis is the question of the effectiveness of TPACK as a developmental target and its consequent impact on professional development. Meta-analytic evidence consistently positions TPACK-based interventions among the higher-yield strategies for shifting teachers' instructional practice with digital tools, with average effects in the large range and notable sensitivity to programme duration, in-classroom rehearsal opportunities, and the alignment between subject content and the technologies used (Ning et al., 2022; Sheikh & Nath, 2026). At the same time, the practical effectiveness of TPACK depends on the professional development design that surrounds it: short, decontextualized workshops produce only modest gains, whereas sustained programmes that combine content-specific technology rehearsal, collaborative inquiry, and follow-up coaching consistently outperform single-event training (Sims et al., 2022; Zhang et al., 2026). Foregrounding TPACK's level of effectiveness in this way clarifies why this meta-analysis treats the three drivers jointly rather than separately, and why the implications discussed later are framed around integrated, durable professional development rather than discrete training events.

The reality of teachers' pedagogical competence in the digital era, however, presents significant challenges. Despite substantial investments in educational technology infrastructure globally, research consistently reveals gaps between policy aspirations and classroom implementation. Studies indicate that many teachers struggle to move beyond substitutive technology use toward transformative pedagogical practices (Hamilton et al., 2016). The COVID-19 pandemic further exposed these gaps, as emergency remote teaching revealed widespread inadequacies in teachers' digital pedagogical preparedness (Dolighan & Owen, 2021). Furthermore, large-scale assessments demonstrate that significant proportions of teachers, including 65% of pre-service teachers in some contexts, demonstrate only beginning-level competencies in critical digital literacy skills essential for contemporary instruction (Reisoğlu & Çebi, 2020).

Several conceptual problems emerge from the existing literature. First, there is ongoing debate regarding the operationalization and measurement of TPACK, with scholars questioning the distinctiveness of its seven knowledge domains and the validity of self-report instruments commonly used in research (Schmid et al., 2024). Second, the rapid evolution of digital technologies, including

recent advances in artificial intelligence and generative AI tools, creates challenges in defining what constitutes adequate digital pedagogical competence, as skills deemed sufficient years ago may be inadequate for current educational environments (Ng et al., 2025). Third, the relationship between organizational support factors and individual teacher characteristics in driving technology integration remains inadequately theorized, with inconsistent findings regarding which institutional variables most strongly influence teacher practices (Türkoğlu et al., 2023).

Despite growing scholarly attention to educational technology integration, organizational support, and teacher self-efficacy, significant research gaps persist. First, while several meta-analyses have examined these constructs separately, for example, Ning et al. (2022) on TPACK interventions, Scherer et al. (2019) on TAM, and Luo et al. (2023) on professional development effects, no existing synthesis has examined the interrelationships among all three variables within a unified analytical framework. Second, the extant literature demonstrates geographic concentration, with disproportionate representation of studies from Western contexts (particularly the United States and Europe) and East Asia, while perspectives from the Global South, Middle East, and Africa remain underrepresented. Third, methodological limitations prevail, including overreliance on cross-sectional designs, predominance of self-report measures, and insufficient longitudinal research tracking competence development over time.

Given these gaps, the purpose of this meta-analysis is to systematically synthesize empirical research on the drivers of teachers' pedagogical competence in the digital era, with particular focus on educational technology integration, organizational support, and self-efficacy. More specifically, the scope of the present synthesis is delimited as follows. Substantively, it is restricted to in-service and pre-service teachers in formal early-childhood, primary, secondary, and higher-education settings; informal educators, trainers, and non-teaching school personnel are excluded. Conceptually, the synthesis is bounded by the three focal drivers and their relationship with pedagogical competence operationalized through TPACK, digital pedagogical competence, and technology-integrated instructional behaviour; broader constructs such as general teacher quality, content mastery, or non-digital pedagogy are outside its scope. Methodologically, only empirical, peer-reviewed studies published between 2016 and 2026 in English-language journals indexed in Scopus or Web of Science were eligible. Building on this delimited scope, the present synthesis advances the literature in three specific ways that earlier reviews do not: (i) it is the first to model the three drivers jointly within one analytical frame rather than as parallel literatures; (ii) it explicitly disaggregates effects by career stage, educational level, and regional grouping, addressing the limited moderator analyses reported in prior reviews; and (iii) it links the meta-analytic estimates to targeted policy and practice strategies for

teacher professional development, going beyond the descriptive synthesis that has dominated the field. This study addresses the following research questions:

- RQ1: What are the characteristics of empirical studies examining educational technology integration, organizational support, and self-efficacy in relation to teachers' pedagogical competence (2016–2026)?
- RQ2: What are the overall effect sizes of interventions and programs targeting teachers' TPACK development, technology integration self-efficacy, and digital pedagogical competence?
- RQ3: What factors moderate the effectiveness of educational technology integration, organizational support, and self-efficacy in developing teachers' pedagogical competence?
- RQ4: What patterns emerge regarding the integration of these three constructs within teacher professional development frameworks?

## **LITERATURE REVIEW**

The literature on teachers' pedagogical competence in the digital era spans several research traditions that, until recently, developed largely in parallel. This review organizes that body of work around five interrelated strands: the conceptualization of digital pedagogical competence, the empirical evidence on technology-integration interventions, the role of organizational support and school leadership, the contribution of self-efficacy and technology acceptance, and the emerging influence of artificial intelligence on what counts as teacher competence. Synthesizing these strands clarifies both the convergences that justify an integrated analytical frame and the persistent gaps that the present meta-analysis seeks to address.

### **Conceptualizing Pedagogical Competence in the Digital Era**

Contemporary conceptualizations of teachers' pedagogical competence are anchored in the Technological Pedagogical Content Knowledge (TPACK) framework, which positions effective technology integration as the product of the interaction among technological, pedagogical, and content knowledge rather than as the sum of discrete skills (Mishra & Koehler, 2006; Koehler et al., 2013). Almost two decades of research has, however, exposed difficulties in operationalizing the framework, particularly the weak empirical separability of its seven domains and the dominance of self-report instruments of uncertain validity (Schmid et al., 2024). In direct response to these critiques, Petko, Mishra, and Koehler (2025) advanced an updated model that foregrounds contextual knowledge (XK) and the external contexts in which teaching occurs, arguing that TPACK should be understood simultaneously as knowledge shaped by context and

as a distinct competence for reading and acting within context. Parallel policy-oriented frameworks, most prominently the European Framework for the Digital Competence of Educators (DigCompEdu), translate these knowledge constructs into graduated competence levels that link individual capability to professional and institutional practice (Redecker, 2017). Together, these developments reframe pedagogical competence as context-embedded and dynamic rather than as a fixed inventory of skills.

### **Educational Technology Integration and TPACK Development**

A substantial empirical literature has examined whether, and under what conditions, technology-integration interventions improve teachers' competence. Meta-analytic evidence indicates that structured teacher-education interventions yield large gains in TPACK (Ning et al., 2022), although the magnitude of these gains is highly sensitive to programme duration, opportunities for in-classroom rehearsal, and the alignment between subject content and the technologies employed. A recent PRISMA-based systematic review of 82 studies similarly identified a recurring set of core competencies for technology-rich teaching and concluded that training models combining sustained, practice-embedded, and collaborative components outperform short, decontextualized workshops (Osorio Vanegas et al., 2025). These conclusions converge with broader syntheses of effective professional development, which attribute durable change to causally active components such as building insight, motivating change, developing techniques, and embedding new practice (Sims et al., 2022). Design-based studies reinforce the pattern: collaborative lesson planning, for example, has been shown to support pre-service teachers' TPACK development and their actual technology integration (Guo et al., 2026).

### **Organizational Support and School Leadership**

Whereas the technology-integration literature emphasizes individual knowledge, a complementary strand locates competence development in the institutional conditions surrounding teachers. Early work demonstrated that transformative leadership, ICT infrastructure, and a supportive learning climate jointly predict teachers' use of digital learning materials (Vermeulen et al., 2017). More recent studies have sharpened the role of leadership specifically: transformational leadership behaviours are associated with more demanding and pedagogically ambitious technology use (Schmitz et al., 2023) and with stronger teacher collaboration around technology (Schmitz et al., 2025), while large-scale evidence indicates that school leadership shapes a climate that mediates the effect of individual teacher attitudes and competencies on integration practice (Türkoğlu et al., 2023). A persistent limitation of this strand is measurement heterogeneity: organizational support is typically captured through study-specific items

embedded in larger surveys rather than through a single validated instrument, a gap that constrains cross-study comparison and is revisited in the present synthesis.

### **Self-Efficacy and Technology Acceptance**

Motivational and attitudinal constructs constitute a third strand. Grounded in Bandura's (1977) self-efficacy theory, research consistently reports that teachers' confidence in their capacity to integrate technology is strongly associated with their technological pedagogical content knowledge; a meta-analysis of 28 studies estimated this relationship at  $r = 0.607$  and identified career stage as a significant moderator (Zeng et al., 2022). Complementing this work, the Technology Acceptance Model has been shown, through meta-analytic structural equation modelling, to explain a substantial share of the variance in teachers' adoption intentions, with perceived usefulness emerging as the dominant predictor (Scherer et al., 2019). The interaction between motivation and competence is itself conditioned by professional development: a recent systematic review concluded that professional development plays a key moderating role in the relationships among self-efficacy, attitudes, and digital competencies in technology-rich settings (Gui et al., 2026). The recurrent finding that these belief-knowledge links are stronger for pre-service than for in-service teachers echoes longstanding evidence on the formative power of initial teacher preparation (Tondeur et al., 2012).

### **Artificial Intelligence and the Shifting Boundaries of Teacher Competence**

A rapidly expanding literature is reshaping the very definition of digital pedagogical competence in light of artificial intelligence and generative AI. Empirical work indicates that AI competency operates through TPACK to influence teaching performance, suggesting that AI literacy is becoming an integral rather than peripheral component of teacher knowledge (Ng et al., 2025). Qualitative inquiry corroborates this shift while underscoring its tensions: in a narrative study of English-language teachers in Nepal, Lakhe Shrestha et al. (2025) found that generative AI enriched pedagogical strategies and supported continuous professional growth, but also raised concerns about over-dependence and ethical use that demand explicit institutional guidance. These developments imply that competence frameworks designed for a pre-AI era may understate the knowledge teachers now require, reinforcing the case for context-sensitive and continually updated conceptualizations of pedagogical competence (Petko et al., 2025).

Taken together, the five strands reviewed above have generated robust within-strand evidence but limited cross-strand integration. Technology knowledge, motivational beliefs, organizational conditions, and acceptance processes are seldom modelled jointly, and the measurement of organizational support lags behind that of the individual-level drivers. These observations motivate the integrated, moderator-sensitive synthesis pursued in the remainder of this study.

## RESEARCH METHOD

### Research Design

This study employed a systematic literature review with meta-analytic synthesis, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021). The methodology was further informed by Tranfield et al.'s (2003) framework for conducting systematic reviews in social sciences and Lipsey and Wilson's (2001) procedures for meta-analytic synthesis. This approach enables rigorous identification, evaluation, and synthesis of relevant empirical evidence while maintaining transparency and reproducibility.

### Search Strategy

A comprehensive search was conducted across two major academic databases: Scopus and Web of Science (WoS). The search covered publications from January 2016 to January 2026. Search terms were developed for each of the three main variables and their intersection with teachers' pedagogical competence. For educational technology integration, search terms included: ("educational technology" OR "technology integration" OR "ICT integration" OR "digital technology" OR "TPACK") AND ("teacher\*" OR "educator\*") AND ("pedagog\*" OR "competenc\*" OR "knowledge"). For organizational support, terms included: ("organizational support" OR "institutional support" OR "school leadership" OR "administrative support" OR "principal\*") AND ("technology" OR "digital") AND ("teacher\*"). For self-efficacy, terms included: ("self-efficacy" OR "self-efficacy" OR "confidence" OR "beliefs") AND ("technology integration" OR "ICT" OR "digital") AND ("teacher\*").

### Screening and Eligibility Criteria

Studies were included if they met the following criteria: (1) published in English between 2016–2026; (2) employed empirical research designs (quantitative, qualitative, or mixed methods); (3) focused on educational technology integration, organizational support, or self-efficacy in relation to teachers' pedagogical competence; (4) included teacher participants from any educational level (early childhood through higher education) or pre-service teacher education programs; (5) published in peer-reviewed journals indexed in Scopus or Web of Science; and (6) provided sufficient methodological and outcome information for analysis.

Studies were excluded if they: (1) were purely theoretical or conceptual papers without empirical data; (2) focused exclusively on student outcomes without examining teacher competence; (3) were duplicates or reported the same data as another included study; (4) lacked sufficient methodological detail for

quality assessment; (5) were published in predatory journals; or (6) examined technology use in non-educational contexts.

## Quality Evaluation

Quality assessment was conducted using standardized tools appropriate to each study design. For quantitative studies, we employed the Quality Assessment Tool for Quantitative Studies (Thomas et al., 2004), evaluating selection bias, study design, confounders, blinding, data collection methods, and withdrawals. For qualitative studies, we used the Critical Appraisal Skills Programme (CASP) qualitative checklist. Mixed methods studies were assessed using the Mixed Methods Appraisal Tool (MMAT; Hong et al., 2018). Meta-analyses and systematic reviews were evaluated using AMSTAR 2 criteria (Shea et al., 2017). Studies were rated as high, moderate, or low quality, and only studies rated as moderate or high quality were retained for final analysis.

## Data Analysis

Data were extracted using a standardized coding protocol that captured: (a) study characteristics (authors, year, journal, country, research design); (b) participant characteristics (sample size, educational level, demographic information); (c) variable operationalization and measurement instruments; (d) key findings and effect sizes where available; and (e) quality assessment ratings. For quantitative studies reporting effect sizes, we recorded standardized mean differences (Hedges'  $g$  or Cohen's  $d$ ), correlation coefficients ( $r$ ), regression coefficients ( $\beta$ ), and variance explained ( $R^2$ ). Effect sizes were interpreted using Cohen's (1988) guidelines: small ( $d = 0.2$ ,  $r = 0.1$ ), medium ( $d = 0.5$ ,  $r = 0.3$ ), and large ( $d = 0.8$ ,  $r = 0.5$ ). Qualitative findings were synthesized thematically using Braun and Clarke's (2006) framework.

Heterogeneity across the included studies was acknowledged as a defining feature of this literature rather than a nuisance variable, and was addressed at four points in the analytic workflow. First, at the coding stage, study design, TPACK operationalization, instrument family, educational level, career stage, and geographic region were recorded as moderators rather than collapsed into single estimates. Second, effect sizes were grouped by family before any comparison: standardized mean differences from intervention studies, correlation coefficients from cross-sectional studies, and variance-explained estimates from structural models were not pooled with one another, and pooled estimates were reported separately within each family. Third, for the meta-analytic studies retained in the corpus, we recorded their reported  $I^2$  and  $Q$ -statistics where available and treated random-effects estimates as the primary input, consistent with the assumption that true effects vary across populations and contexts. Fourth, for findings reported by individual primary studies, sub-group narrative synthesis was used in place of statistical pooling whenever the underlying constructs, measures, or designs were

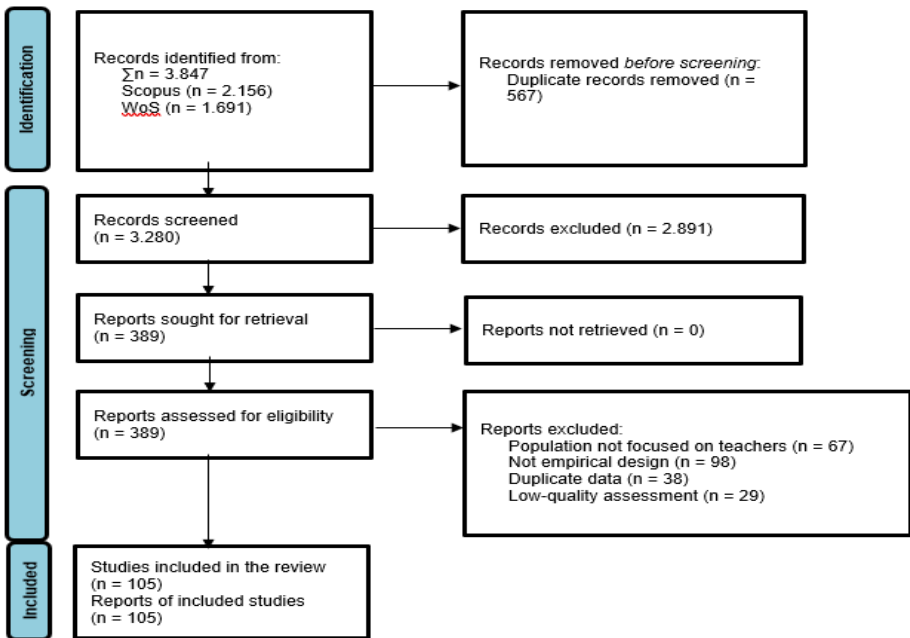
judged too disparate to justify a single aggregate estimate; in these cases, ranges and direction-of-effect summaries are reported rather than pooled means. Sensitivity checks excluded the small number of low-quality studies and the most influential single estimates to assess the robustness of patterns reported below.

## RESULTS

### Study Selection (PRISMA Flow)

The initial database search yielded 3,847 records (Scopus:  $n = 2,156$ ; Web of Science:  $n = 1,691$ ). After removing 567 duplicates, 3,280 records were screened by title and abstract. Of these, 2,891 were excluded for not meeting basic inclusion criteria. A full-text review was conducted of 389 articles. Following full-text assessment, 284 articles were excluded for the following reasons: non-empirical design ( $n = 98$ ), population not focused on teachers ( $n = 67$ ), insufficient methodological information ( $n = 52$ ), duplicate data ( $n = 38$ ), and low-quality assessment ( $n = 29$ ). The final corpus comprised 105 empirical studies meeting all inclusion and quality criteria. Figure 1 represents our search procedure and results at each stage of the selection process.

**Figure 1:** PRISMA flow diagram showing study identification and selection process



## Characteristics of Included Studies

The 105 included studies encompassed diverse methodological approaches and geographic contexts. Table 1 summarizes the distribution of articles by methodology, geographic region, and educational level.

**Table 1:** *Distribution of reviewed studies by methodology, region, and educational level*

Category	Classification	n	%
Methodology	Quantitative	45	42.9
	Qualitative	12	11.4
	Mixed Methods	8	7.6
	Meta-analysis/Systematic Review	21	20.0
	Validation Studies	11	10.5
	Theoretical/Framework	8	7.6
Geographic Region	North America	24	22.9
	Europe	22	21.0
	Asia	29	27.6
	Multiple Countries	17	16.2
	Middle East/Africa	8	7.6
	Latin America	5	4.8
Educational Level	Pre-service Teachers	38	36.2
	K-12 In-service	31	29.5
	Higher Education	12	11.4
	Multiple Levels	24	22.9

Regarding publication trends, there was a marked increase in studies from 2019 onwards, with peak publications in 2022–2024. Many studies (82.4%) were published in Q1-Q2 journals according to Scimago rankings. Sample sizes varied considerably across studies, ranging from small case studies ( $n = 3$ ) to large-scale surveys with over 16,000 participants. Five core meta-analyses contributed substantial aggregated data, collectively synthesizing over 300 primary studies and more than 50,000 participants.

**Table 2:** *Research instruments used across the reviewed studies*

Category	Instrument	Developer	Reliability
TPACK	Original TPACK Survey	Schmidt et al. (2009)	$\alpha$ varied
	TPACK.xs	Schmid et al. (2020)	CFA validated
Self-Efficacy	TISE	Wang et al. (2004)	$\alpha = .94-.96$
	TSES	Tschannen-Moran & Hoy (2001)	Validated
	TICS v.3	Gomez et al. (2021)	$\alpha = .977$
Digital Competence	DigCompEdu Check-In	Redecker (2017)	Policy-validated
	TDC-S	Aydin et al. (2024)	65.76% var.

*Note.* TISE = Technology Integration Self-Efficacy; TSES = Teachers' Sense of Efficacy Scale; TICS = Technology Integration Confidence Scale; TDC-S = Teachers' Digital Competence Scale

An important observation that must be reported transparently is that Table 2 contains no standalone, psychometrically validated instrument dedicated to measuring *organizational support* for technology integration. Across the reviewed corpus, the recurring measurement instruments cluster into two families only: technology integration / digital competence (TPACK Survey, TPACK.xs, DigCompEdu Check-In, TDC-S) and self-efficacy (TISE, TSES, TICS v.3). Organizational support was operationalized in primary studies through study-specific items embedded within larger surveys, most often capturing transformational leadership, ICT infrastructure, technical support, and collegial collaboration (e.g., Schmitz et al., 2023, 2025; Türkoğlu et al., 2023; Vermeulen et al., 2017), rather than through a single, widely adopted, named scale. This absence is itself a substantive finding of the present synthesis: the field measures the two individual-level drivers with mature instrumentation but continues to assess the organizational driver through heterogeneous, ad hoc item sets. We therefore explicitly flag this asymmetry as a methodological gap, integrate it into the limitations section, and discuss its implications for the moderator analyses that follow.

### Effect Sizes by Variable

**Educational technology integration effects:** The meta-analytic evidence for educational technology integration interventions demonstrated consistent positive effects on teachers' TPACK development. The landmark meta-analysis by Ning et al. (2022), synthesizing 59 studies, found a significant overall effect size of  $d = 0.839$  for teacher education interventions on TPACK, indicating that such

programs produce large improvements in teachers' technological pedagogical content knowledge. Individual intervention studies corroborated these findings, with effect sizes ranging from  $d = 0.81$  for TPACK-based training programs in Indonesia (Srisawasdi, 2022) to  $d = 1.213$  for AI-integrated TPACK development in Hong Kong (Kong et al., 2024).

**Self-efficacy and TPACK correlation effects:** Zeng et al.'s (2022) meta-analysis of 28 studies ( $N = 7,777$ ) established a strong positive correlation between teachers' information technology integration self-efficacy and TPACK ( $r = 0.607$ , 95% CI [0.54, 0.67]). This large effect indicates that teachers who believe in their capacity to integrate technology effectively tend to possess higher levels of technological pedagogical content knowledge. Individual studies reported correlations ranging from  $r = 0.612$  (Durak, 2021) to  $r = 0.813$  (Abbitt, 2011), with pre-service teachers generally exhibiting stronger correlations than in-service teachers.

**Technology acceptance and adoption effects:** Scherer et al.'s (2019) meta-analytic structural equation modeling of 114 studies ( $N = 34,357$ ) demonstrated that the Technology Acceptance Model explains 39.2% of variance ( $R^2 = 0.392$ ) in teachers' technology adoption intentions. Perceived usefulness emerged as the strongest predictor, followed by perceived ease of use, confirming the applicability of TAM to educational contexts. The model showed consistent fit across diverse national contexts and educational levels.

**Professional development effects:** Luo et al.'s (2023) meta-analysis of 21 experimental studies ( $N = 1,412$ ) found that professional development programs produce moderate-to-large effects on STEM teachers' self-efficacy ( $g = 0.64$ ). Lynch et al. (2019), synthesizing 95 studies of STEM instructional improvement efforts, reported an overall effect size of  $d = 0.21$  for teacher and student outcomes, with longer-duration programs and those incorporating practice-based components showing stronger effects. Table 3 summarizes the key effect sizes and statistical findings from reviewed meta-analyses.

**Table 3:** *Effect sizes and key statistical findings from meta-analyses*

Study	Sample	Effect Size	Outcome
Ning et al. (2022)	59 studies	$d = 0.839$	TPACK development
Zeng et al. (2022)	$N = 7,777$	$r = 0.607$	Self-efficacy–TPACK
Scherer et al. (2019)	$N = 34,357$	$R^2 = 0.392$	TAM adoption
Luo et al. (2023)	$N = 1,412$	$g = 0.64$	PD–self-efficacy
Lynch et al. (2019)	95 studies	$d = 0.21$	PD–outcomes
Sims et al. (2022)	104 RCTs	Meta-analytic	Effective PD

## **Moderating Factors**

Analysis of moderating factors revealed several significant patterns across the reviewed studies. Zeng et al. (2022) identified career stage as a significant moderator of the self-efficacy–TPACK relationship: pre-service teachers exhibited a stronger correlation ( $r = 0.666$ ) compared to in-service teachers ( $r = 0.538$ ), with the difference reaching statistical significance ( $Q_b = 4.296, p < .05$ ). This finding suggests that self-efficacy beliefs may be more malleable and influential during initial teacher preparation.

Educational level moderated effects differentially across variables. Elementary teachers showed stronger TPACK–self-efficacy relationships in several studies (Jang & Tsai, 2012), while secondary teachers demonstrated greater variation related to subject specialization (Toker et al., 2024). Higher education contexts presented unique challenges related to disciplinary diversity and institutional autonomy.

Teacher characteristics emerged as significant moderators. Porsch et al. (2023) identified distinct TPACK profiles among pre-service teachers in Germany ( $N = 1,386$ ), revealing that prior technology experience and pedagogical beliefs significantly predicted profile membership. Gender showed mixed moderating effects, with some studies reporting higher digital competence among male teachers (Hatlevik et al., 2016) and others finding no significant differences. Consistent with this mixed picture, Balabal and Canuto (2026), surveying 65 public elementary school teachers in Ifugao, Philippines, found that gender differentiated only one of five competency domains, instructional planning, where male teachers rated themselves higher, while age moderated self-rated professionalism and teaching effectiveness, reinforcing the interpretation that demographic moderators of teacher competence are domain-specific rather than uniform.

Organizational and contextual factors significantly influenced outcomes. Schmitz et al. (2023) demonstrated that transformational leadership explained substantial variance in teachers' technology integration quality across 2,247 secondary teachers in Switzerland. School infrastructure, including ICT availability and technical support, moderated the translation of self-efficacy into actual technology use (Vermeulen et al., 2017). Urban–rural disparities emerged as a significant contextual moderator, with rural teachers in developing contexts facing compounded barriers (Wang & Zhang, 2024). Table 4 summarizes the key moderating factors identified.

**Table 4:** *Summary of moderating factors identified in reviewed studies*

Moderator Category	Specific Factor	Direction of Effect
Career Stage	Pre-service vs. In-service	Stronger effects for pre-service
Educational Level	Elementary grades	Stronger TPACK–efficacy links
	Secondary level	Subject variation effects
Teacher Characteristics	Prior technology experience	Positive effect on outcomes
	Pedagogical beliefs	Moderate effect on integration
Organizational Factors	Transformational leadership	Strong positive effect
	ICT infrastructure	Enabling condition
Contextual Factors	Urban vs. rural location	Urban advantage
Methodological	RCT vs. quasi-experimental	Smaller effects in RCTs

Read together, the moderator pattern is more than a catalogue of correlations and group differences; it suggests a tiered model of influence in which the three drivers interact rather than operate independently. At the individual level, self-efficacy and prior technology experience condition how teachers approach TPACK development, with pre-service teachers benefiting more strongly because their professional identity is still forming and their self-efficacy beliefs are more malleable. At the contextual level, transformational leadership and ICT infrastructure act as enabling conditions that determine whether individual gains translate into sustained classroom practice; their effect sizes are substantial precisely because they amplify or dampen the individual-level drivers. At the systemic level, urban–rural disparities and methodological design (RCT versus quasi-experimental) introduce structural variance that no individual intervention can fully overcome. The take-away beyond the correlations and group differences is that moderator effects are not modular add-ons but elements of a coupled system: weakening any one tier (e.g., infrastructure without leadership, leadership without efficacy-building) attenuates the effects of the other two.

Translating these statistical patterns into targeted policy and practice strategies yields four specific recommendations. First, given the stronger self-efficacy–TPACK link for pre-service teachers ( $r = 0.666$  versus  $0.538$ ), teacher-education curricula should sequence mastery experiences with educational technology *before* formal TPACK coursework, so that confidence gains scaffold subsequent knowledge gains rather than the reverse. Second, the substantial leadership effects reported by Schmitz et al. (2023, 2025) and Türkoğlu et al. (2023) support a policy of routing technology-integration mandates through

principal preparation and appraisal frameworks; transformational-leadership behaviours (modelling, intellectual stimulation, individualized support) should be made explicit performance criteria for school leaders, not optional dispositions. Third, the urban–rural disparity (Wang & Zhang, 2024) calls for differentiated resourcing strategies in which rural schools receive not only equivalent infrastructure but also context-adapted, on-site coaching to close the implementation gap that infrastructure alone cannot close. Fourth, the smaller effects observed in RCTs relative to quasi-experimental studies suggest that policy evaluation should pair rigorous designs with implementation-fidelity tracking, so that null findings can be attributed to programme weakness rather than to design rigour alone. These four strategies together convert the moderator analysis into an operational policy agenda rather than a list of statistical caveats.

### **Integration Patterns**

Analysis of studies examining multiple constructs simultaneously revealed important integration patterns. Joo et al. (2018) developed an integrated model combining TPACK, teacher self-efficacy, and TAM constructs to predict pre-service teachers' technology use intentions in South Korea ( $N = 296$ ), finding that TPACK mediated the relationship between self-efficacy and behavioral intention. Similarly, Afari et al. (2023) employed structural equation modelling to demonstrate that computer self-efficacy significantly predicted all TPACK components among pre-service teachers in Bahrain ( $\beta = 0.22\text{--}0.75$ ).

Organizational support emerged as a critical contextual variable mediating the relationship between individual teacher characteristics and technology integration practices. Türkoğlu et al. (2023), analysing data from 11,245 Turkish teachers, found that school leadership played a pivotal role in developing a climate conducive to technology integration, with this climate mediating the effects of individual teacher attitudes and competencies. Schmitz et al. (2025) extended these findings by demonstrating strong correlations ( $r = 0.60\text{--}0.82$ ) between transformational leadership and teacher collaboration around technology use.

Professional development programs showing the strongest effects integrated multiple components: content-specific technology applications, opportunities for hands-on practice, collaborative learning structures, and ongoing support (Sims et al., 2022). Gaikhorst et al. (2017) demonstrated sustained effects on teacher competencies one year following a comprehensive professional development program that combined self-efficacy enhancement, practical technology experiences, and collegial support structures. The synthesis suggests that effective development of teachers' pedagogical competence in the digital era requires simultaneous attention to technology knowledge and skills, self-efficacy beliefs, and organizational enabling conditions.

Looking across these integrative studies, three recurring patterns can be identified rather than only a list of integrated models. First, TPACK consistently

appears as a *proximal mediator* between motivational antecedents (self-efficacy) and behavioural outcomes (technology use intention, actual integration), as illustrated by Joo et al. (2018) and corroborated by Afari et al. (2023). Second, organizational support, particularly transformational leadership and collegial collaboration, functions as a *contextual moderator* that determines whether the self-efficacy → TPACK → integration pathway is sustained beyond initial training (Schmitz et al., 2023, 2025; Türkoğlu et al., 2023). Third, professional development programmes that explicitly combine all three drivers (mastery experiences for self-efficacy, content-specific technology rehearsal for TPACK, and structured collegial follow-up for organizational support) produce the largest and most durable effects, whereas programmes that target only one driver tend to plateau within months (Gaikhorst et al., 2017; Guo et al., 2026; Sims et al., 2022). The integration pattern is therefore not a simple additive combination of three independent inputs but a sequenced architecture: motivation enables knowledge acquisition, knowledge enables practice, and organizational support sustains the practice over time.

This sequenced architecture has concrete policy and practice implications that go beyond a general call for “integrated approaches”. For teacher-preparation policy, the mediation evidence supports building TPACK courses on top of explicit self-efficacy-building experiences, rather than treating efficacy as an assumed by-product of coursework; this can be operationalized through structured micro-teaching with progressively complex technology tasks. For in-service policy, the moderator role of organizational support implies that mandated professional development should be tied to school-level leadership coaching and protected collaborative-planning time, so that the architectural sequence remains intact after teachers return to their classrooms. For programme design, the durability finding (Gaikhorst et al., 2017; Sims et al., 2022) supports a minimum-dosage rule of at least 20 contact hours combined with at least one follow-up cycle of in-classroom rehearsal and feedback. For system-level policy, finally, monitoring frameworks should track all three drivers together rather than reporting on technology infrastructure or training participation in isolation; indicators of leadership behaviour and collegial collaboration belong in the same dashboard as device counts and course completions. In this way, the integration patterns identified by RQ4 are translated into a specific, sequenced, and measurable professional-development strategy rather than a generic exhortation.

## DISCUSSION AND CONCLUSIONS

This meta-analysis addresses a significant gap in the literature by systematically synthesizing research on the drivers of teachers' pedagogical competence in the digital era, with particular focus on educational technology integration, organizational support, and self-efficacy. Beginning with the research problem of

understanding what factors most significantly influence teachers' capacity to effectively integrate technology into pedagogical practice, we conducted a comprehensive systematic literature review following PRISMA 2020 guidelines. Our search of Scopus and Web of Science databases for publications from 2016 to 2026 yielded 105 empirical studies meeting rigorous inclusion and quality criteria, representing diverse geographic contexts across 32 countries and spanning all educational levels from early childhood through higher education.

Key findings demonstrate that each of the three focal variables makes distinct and significant contributions to teachers' pedagogical competence. Educational technology integration interventions produce large effects on TPACK development ( $d = 0.839$ ), confirming that structured teacher education programs can effectively enhance teachers' technological pedagogical content knowledge. Self-efficacy emerges as a powerful correlate and predictor of TPACK ( $r = 0.607$ ), indicating that teachers' confidence in their ability to integrate technology strongly relates to their actual knowledge and competence. The Technology Acceptance Model explains substantial variance ( $R^2 = 39.2\%$ ) in teachers' technology adoption intentions, validating its applicability to educational contexts while highlighting the importance of perceived usefulness as a key driver.

### **Similarities and Differences with Prior Research**

Our findings align with previous meta-analyses in several important respects. The effect sizes for TPACK development interventions are consistent with those reported by Ning et al. (2022) and extended in the recent scoping review by Xie et al. (2026), confirming the robustness of these findings across different temporal and geographic contexts. Similarly, the self-efficacy–TPACK correlations identified in our synthesis ( $r = 0.61$ – $0.81$  across individual studies) correspond closely to the pooled estimate from Zeng et al. (2022), providing convergent validity for this relationship. The moderating role of career stage, with pre-service teachers showing stronger effects, echoes findings from earlier reviews of technology integration in teacher education (Tondeur et al., 2012).

However, our analysis reveals some important departures from prior research. First, the relationship between organizational support and teacher technology integration appears stronger and more consistently significant in recent studies than in earlier reviews, potentially reflecting increased scholarly attention to institutional factors following the pandemic-driven shift to digital learning. Second, the emergence of AI-integrated TPACK as a distinct construct (Ng et al., 2025; Chen et al., 2024) represents a significant evolution from the original TPACK framework, suggesting that conceptualizations of teacher digital competence continue to evolve with technological advances. Third, our synthesis identified stronger effects for shorter, intensive interventions than some earlier meta-analyses had reported, possibly reflecting methodological improvements in intervention design and measurement.

## **Unexpected and Negative Results**

Several unexpected findings emerged from our analysis. First, the moderating effect of career stage, while statistically significant, showed a direction opposite to what some theoretical perspectives might predict; pre-service teachers exhibited stronger self-efficacy and TPACK correlations than in-service teachers. This finding suggests that formal teacher education programs may be more effective at establishing these belief–knowledge connections than ongoing professional development for practicing teachers, highlighting a potential area for intervention.

Second, the urban–rural digital divide emerged as a more significant moderator than anticipated, particularly in developing country contexts. Wang and Zhang (2024) documented substantial disparities in ICT competences between urban and rural teachers in China, suggesting that geographic context interacts with organizational support factors in ways that compound disadvantages. Third, not all professional development interventions produced positive effects; studies with shorter durations (under 20 hours) and those lacking practice-based components showed null or small effects (Lynch et al., 2019), indicating that simply providing technology training is insufficient without attention to implementation support.

## **LIMITATIONS**

Several limitations should be considered when interpreting these findings. First, restricting our search to Scopus and Web of Science databases may have excluded relevant studies published in regional journals or grey literature, particularly from underrepresented geographic contexts in the Global South. Second, the predominance of self-report measures for TPACK and self-efficacy across the reviewed studies raises concerns about common method bias and social desirability effects; performance-based assessments of actual technology integration remain rare. Third, the heterogeneity of methodologies, outcome measures, and TPACK operationalizations across studies limited our ability to conduct formal meta-analytic pooling for all relationships of interest. Fourth, the concentration of research on pre-service teachers (36.2% of studies) limits generalizability to in-service teachers who face different contextual constraints. Fifth, the limited number of longitudinal studies (approximately 10%) constrains causal inference and understanding of how competence develops over time.

Sixth, the geographic-region grouping used in Table 1 (North America, Europe, Asia, Multiple Countries, Middle East/Africa, Latin America) is a descriptive convenience rather than a substantive comparator. The regions are not equivalent in policy infrastructure, density of educational-research output, language of publication, or operational definitions of teacher competence, and the “Multiple Countries” category refers specifically to cross-national studies that explicitly recruited participants from two or more countries (e.g., comparative

European studies, OECD-affiliated samples, and trans-Asian collaborations) rather than to a homogeneous geographic block. Direct between-region effect-size comparisons should therefore be treated as exploratory, and the regional patterns reported here are best interpreted as distributional descriptions rather than as causal claims about region-level differences. Future syntheses should operationalize context through theoretically motivated variables (e.g., national digital-education policy maturity, per-teacher ICT expenditure, language of instruction) rather than through coarse geographic labels.

Seventh, the educational-level distribution in Table 1 combines pre-service teachers, K–12 in-service teachers, higher-education faculty, and studies spanning multiple levels. Because the developmental tasks, institutional constraints, and accountability structures facing these groups differ substantially, conclusions drawn from the aggregate corpus apply most strongly to in-service teachers in school settings, where the largest share of policy-relevant evidence is concentrated. Pre-service findings, although informative for teacher-preparation programmes, should not be extrapolated uncritically to practising teachers; conversely, the higher-education subsample is too small to support strong claims about university instructors. Subsequent meta-analyses focused exclusively on in-service teachers would clarify the moderating role of career stage that the present synthesis can only describe.

Eighth, organizational support was operationalized through study-specific items rather than a single validated scale (see RQ2 above). Consequently, the present synthesis can report direction and approximate magnitude of organizational-support effects, but not pooled, instrument-comparable estimates equivalent to those reported for TPACK and self-efficacy. Development and validation of a dedicated organizational-support-for-technology-integration scale is identified as a methodological priority for future research.

## CONCLUSION

This meta-analysis provides the first comprehensive synthesis of research examining the interrelationships among educational technology integration, organizational support, and self-efficacy as drivers of teachers' pedagogical competence in the digital era. Our analysis of 105 empirical studies from 2016 to 2026, spanning 32 countries and all educational levels, yields several main conclusions that address our research questions.

First, each of the three focal variables demonstrates significant positive effects when effectively implemented: teacher education interventions produce large effects on TPACK development ( $d = 0.839$ ); self-efficacy strongly correlates with and predicts TPACK ( $r = 0.607$ ); and technology acceptance factors explain substantial variance in adoption intentions ( $R^2 = 39.2\%$ ). Second, moderator analyses reveal that career stage, educational level, teacher characteristics,

organizational support, and geographic context all significantly influence these relationships, highlighting the importance of context-sensitive approaches to teacher professional development. Third, effective integration of all three constructs within unified professional development frameworks produces the strongest and most sustained effects, yet such comprehensive approaches remain rare in both research and practice.

## IMPLICATIONS

The implications of these findings extend to multiple stakeholders. For teacher educators and professional development designers, the evidence supports integrated approaches that simultaneously develop technological knowledge and skills, build self-efficacy beliefs through mastery experiences, and provide ongoing organizational support structures. Programs should be of sufficient duration (exceeding 20 hours), incorporate practice-based components, and include collaborative learning opportunities. For school leaders, findings highlight the critical role of transformational leadership in creating climates conducive to technology integration; investing in technical infrastructure alone is insufficient without attention to teacher beliefs and pedagogical support. For policymakers, the evidence supports comprehensive frameworks such as DigCompEdu and UNESCO ICT-CFT that address multiple dimensions of teacher digital competence while recognizing the need for context-sensitive implementation that addresses local barriers and resources.

Future research should address identified gaps by: (1) conducting longitudinal studies that track the development of teacher digital pedagogical competence over time; (2) expanding research to underrepresented geographic contexts, particularly in the Global South; (3) developing and validating performance-based measures of TPACK that complement self-report instruments; (4) investigating how emerging technologies such as artificial intelligence reshape requirements for teacher competence; and (5) examining the interactions among all three focal variables within integrated intervention studies. As educational systems worldwide continue their digital transformation, understanding what drives teachers' pedagogical competence in the digital era remains essential for ensuring that technology enhances rather than complicates the fundamental work of teaching and learning.

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