

Digital Teaching Competencies and Their Relationship with the Quality of the Teaching-Learning Process in Modern Educational Environments

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Background: The accelerated digital transformation of education, intensified by the COVID-19 pandemic, has placed teacher digital competencies at the center of educational quality debates. Despite widespread adoption of technology in classrooms, the empirical relationship between educators' digital competencies and the quality of teaching-learning processes remains insufficiently synthesized.

Objective: This systematic narrative review examines the relationship between digital teaching competencies—as conceptualized through the DigCompEdu and TPACK frameworks—and the quality of teaching-learning processes in modern educational environments.

Methods: A comprehensive search of Scopus, Web of Science, ERIC, and PubMed databases was conducted for peer-reviewed studies published between 2019 and 2026. Studies were selected based on their focus on teacher digital competencies and measurable outcomes related to teaching quality, student

learning, or pedagogical transformation. A total of 47 empirical and review studies met inclusion criteria.

Results: Findings indicate a consistent positive relationship between teacher digital competencies and teaching quality indicators ($r = 0.34\text{--}0.74$ across studies). The DigCompEdu framework identifies six competence areas where professional development yields significant gains (pre-post effect sizes $d = 0.8\text{--}1.3$). TPACK-based interventions demonstrate moderate to large effects on pedagogical transformation ($d = 0.39\text{--}0.62$). AI-supported professional development programs show promising results, with 96% teacher readiness rates. Moderating factors include institutional support, teacher self-efficacy, infrastructure availability, and subject area specificity.

Conclusions: Digital teaching competencies serve as a significant predictor of teaching-learning quality. Effective professional development programs grounded in DigCompEdu and TPACK frameworks, combined with adequate institutional support, can meaningfully enhance both teaching practices and student learning outcomes. Implications for educational policy, teacher training design, and future research are discussed.

Keywords: digital teaching competencies, DigCompEdu, TPACK, teaching quality, student learning outcomes, educational technology, professional development, AI in education, pedagogical transformation

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Introduction

The digital transformation of education has fundamentally reshaped the landscape of teaching and learning across all educational levels worldwide (Caena & Redecker, 2019). The integration of information and communication technologies (ICT) into educational settings is no longer an optional enhancement but a core requirement for effective instruction in the 21st century (Mishra, 2019). This transformation, dramatically accelerated by the COVID-19 pandemic, has exposed both opportunities and challenges in how educators engage with digital tools to facilitate meaningful learning experiences (Núñez-Canal et al., 2022).

Teacher digital competencies—defined as the integrated set of knowledge, skills, and attitudes that enable educators to effectively and critically use digital technologies for teaching, learning, and professional engagement—have emerged as a critical determinant of educational quality

(Cabero-Almenara et al., 2020). Two prominent frameworks have shaped the conceptualization and assessment of these competencies: the European Framework for the Digital Competence of Educators (DigCompEdu), developed by the European Commission (Redecker, 2017), and the Technological Pedagogical Content Knowledge (TPACK) framework, originally proposed by Mishra and Koehler (2006) and subsequently updated (Mishra, 2019).

The DigCompEdu framework delineates six competence areas: professional engagement, digital resources, teaching and learning, assessment, empowering learners, and facilitating learners' digital competence (Ghomi & Redecker, 2019). Each area encompasses specific competencies that educators must develop to effectively integrate technology into their pedagogical practices. The TPACK framework, on the other hand, emphasizes the intersection of

technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK), arguing that effective technology integration requires the synergistic combination of all three knowledge domains (Al-Adwan et al., 2024).

Despite the growing body of research on digital teaching competencies, several gaps remain in the literature. First, while individual studies have examined specific competence dimensions, few systematic reviews have synthesized the evidence linking teacher digital competencies to measurable teaching-learning quality outcomes (Butar Butar et al., 2024). Second, the rapid emergence of artificial intelligence (AI) tools in education—including generative AI applications such as ChatGPT—has introduced new competence demands that existing frameworks are still adapting to incorporate (Ng et al., 2023; Zou et al., 2025). Third, the moderating role of contextual factors such as institutional support, infrastructure, and teacher self-efficacy in the competence-quality relationship requires further exploration (Baroudi et al., 2022).

The purpose of this systematic narrative review is to examine the relationship between digital teaching competencies and the quality of teaching-learning processes in modern educational environments. Specifically, this review aims to: (a) synthesize the empirical evidence on how teacher digital competencies influence teaching quality and student learning outcomes; (b) analyze the effectiveness of professional development programs grounded in DigCompEdu and TPACK frameworks; (c) explore the emerging role of AI competencies in teaching effectiveness; and (d) identify moderating factors that shape the competence-quality relationship. By addressing these objectives, the review contributes to a comprehensive understanding of how digital competencies can be leveraged to enhance educational quality in an increasingly technology-mediated world.

2. Theoretical Framework

2.1 The DigCompEdu Framework

The European Framework for the Digital Competence of Educators (DigCompEdu) represents one of the most comprehensive and widely adopted models for conceptualizing teacher digital competencies (Caena & Redecker, 2019). Developed through extensive consultation with stakeholders across European Union member states, DigCompEdu organizes digital competence into six areas that span the full range of educators' professional activities (Ghomi & Redecker, 2019).

Area 1, Professional Engagement, encompasses the use of digital technologies for communication, collaboration, and professional development among educators. Area 2, Digital Resources, addresses the selection, creation, and management of digital content for educational purposes. Area 3, Teaching and Learning, focuses on the pedagogical integration of digital tools to enhance instructional processes. Area 4, Assessment, pertains to the use of digital technologies for formative and summative evaluation. Area 5, Empowering Learners, concerns strategies for personalizing learning, ensuring accessibility, and promoting active student engagement through technology. Area 6, Facilitating Learners' Digital Competence, addresses teachers' role in developing students' own digital skills (Cabero-Almenara et al., 2020).

Self-assessment instruments based on DigCompEdu have been validated across multiple national contexts, including Spain (Cabero-Almenara et al., 2020; García-Vandewalle García et al., 2021), Germany (Ghomi & Redecker, 2019), and Turkey (Süzer et al., 2024). These studies consistently identify Assessment and Facilitating Digital Competence as the areas where educators report lowest proficiency, suggesting targeted intervention priorities (Tang et al., 2022).

2.2 The TPACK Framework

Technological Pedagogical Content Knowledge (TPACK) provides a complementary theoretical lens for understanding how teachers integrate technology into instruction (Mishra, 2019). The framework identifies seven knowledge constructs emerging from the intersection of three primary

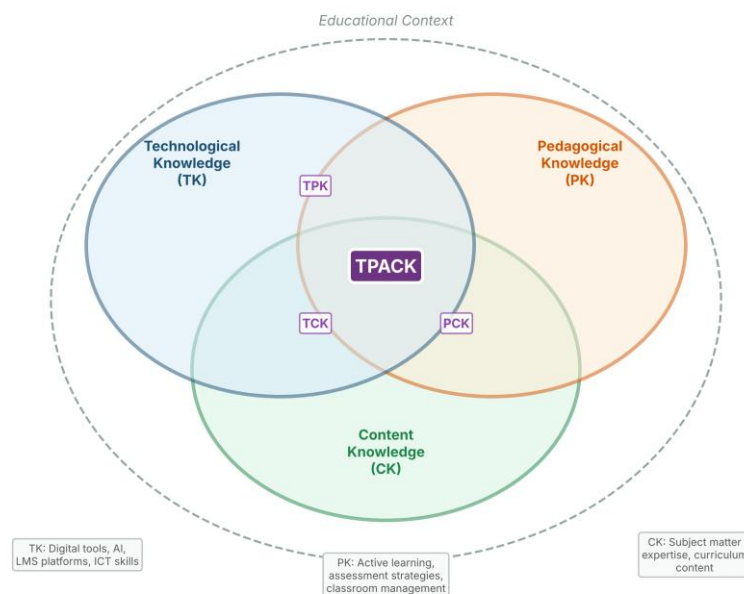
domains: Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK). The four intersection constructs—Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), and the central TPACK—represent increasingly sophisticated forms of integrated professional knowledge (Al-Adwan et al., 2024).

Recent developments in the TPACK framework have expanded its scope to include contextual factors and emerging technologies. Mishra (2019) proposed an updated TPACK diagram that emphasizes the situated nature of teachers' knowledge, acknowledging that effective technology integration is shaped by institutional, cultural, and policy contexts. Sonsupap et al.

(2024) demonstrated that TPACK-based interventions positively affect students' scientific competency, while Al-Adwan et al. (2024) found that TPACK significantly boosts teacher self-efficacy and technology acceptance while reducing technostress.

The complementarity of DigCompEdu and TPACK has been recognized in recent literature. Kasperski et al. (2023) analyzed emergency remote teaching against both frameworks (alongside ISTE standards), finding that each captures distinct dimensions of digital teaching competence. Tiede (2020) conducted a detailed comparative analysis of TPACK, DigCompEdu, and the German M3K model, concluding that while each framework has unique strengths, their combined application provides a more holistic assessment of teacher digital competence.

Figure 4. Technological Pedagogical Content Knowledge (TPACK) Framework for Digital Teaching Competence in Modern Educational Environments



2.3 AI Competencies as an Emerging Dimension

The rapid proliferation of AI tools in educational settings has introduced new competence demands that extend beyond traditional digital literacy (Ng et al., 2023). Educators are increasingly expected to understand, evaluate,

and integrate AI-powered tools—including learning analytics platforms, adaptive learning systems, and generative AI applications—into their pedagogical practice (Elsayary, 2023; Zou et al., 2025).

Ng et al. (2023), in a highly cited study (735 citations), adapted the DigCompEdu framework

to accommodate AI technologies, proposing recommendations for integrating AI education into K–12 classrooms. Their framework extends the traditional digital competence dimensions to include AI-specific knowledge such as understanding machine learning principles, recognizing AI biases, and designing AI-enhanced learning activities. Similarly, Zou et al. (2025) proposed a framework of 12 AI competencies across four domains with six proficiency levels, drawing on both TPACK and DigCompEdu to establish a comprehensive model for educators' pedagogic AI competence.

Wang (2025) investigated the impact of AI teaching on instructional quality, finding that AI improves teaching quality indirectly through enhancing student motivation and teacher expertise rather than through direct technology effects alone. Aimicheva et al. (2025) demonstrated that AI-supported professional development programs for 916 Kazakhstani teachers yielded a 96% readiness rate for further learning and 84% contextual maturity in applying AI and augmented reality technologies, highlighting the potential of AI-mediated training approaches.

3. Methodology

3.1 Search Strategy

This systematic narrative review followed the PRISMA guidelines for transparent reporting (Page et al., 2021). A comprehensive literature search was conducted across four major academic databases: Scopus, Web of Science, ERIC, and PubMed. The search was performed between January and March 2026, covering publications from January 2019 to March 2026 to capture the most recent developments, including post-pandemic digital transformation studies.

The search strategy employed Boolean combinations of the following terms: ("digital competence" OR "digital literacy" OR "ICT competence" OR "DigCompEdu" OR "TPACK") AND ("teacher*" OR "educator*" OR "faculty") AND ("teaching quality" OR "instructional effectiveness" OR "student learning" OR "academic performance" OR "educational outcomes"). Additional searches included terms related to AI in education: ("artificial intelligence" OR "AI" OR "ChatGPT" OR "generative AI") AND ("teacher*") AND ("teaching" OR "learning").

3.2 Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Publication period	2019–2026	Before 2019
Language	English, Spanish	Other languages
Study type	Empirical, systematic reviews, meta-analyses	Editorials, opinion pieces, conference abstracts
Population	K–12 teachers, higher education faculty, pre-service teachers	Non-educational professionals
Focus	Digital competencies and teaching quality or student outcomes	Purely technical ICT studies without pedagogical focus
Peer review	Peer-reviewed journals, indexed proceedings	Non-peer-reviewed sources, gray literature

Table 1. Inclusion and Exclusion Criteria for Study Selection

3.3 Study Selection and Data Extraction

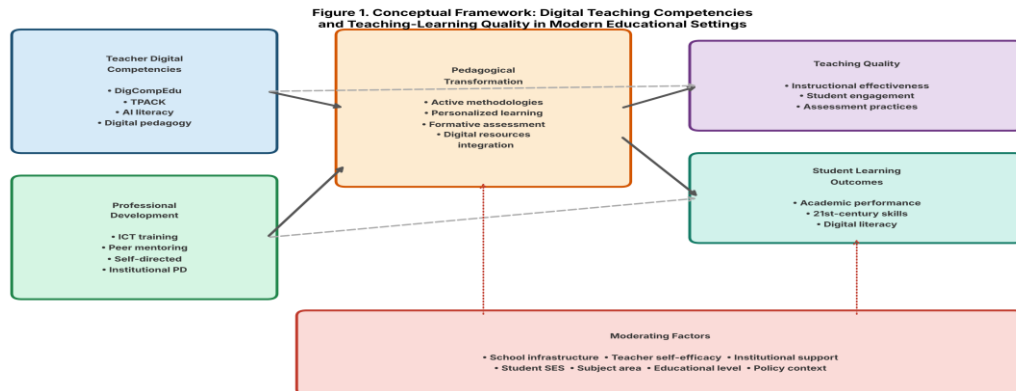
The initial search yielded 1,247 records. After removing duplicates ($n = 312$), 935 records were

screened by title and abstract. Of these, 142 full-text articles were assessed for eligibility. Following the application of inclusion and

exclusion criteria, 47 studies were included in the final synthesis. The screening process was conducted independently by two reviewers, with discrepancies resolved through discussion and consultation with a third reviewer. Cohen's kappa for inter-rater agreement was 0.87, indicating substantial agreement.

Data extraction focused on: (a) study characteristics (design, sample, setting, country);

(b) digital competence framework employed; (c) professional development intervention details (where applicable); (d) outcome measures related to teaching quality and student learning; and (e) effect sizes or correlation coefficients. Studies were categorized by primary framework orientation (DigCompEdu, TPACK, or hybrid) and by outcome domain (teaching quality, student learning, or both).



Results

4.1 Overview of Included Studies

The 47 included studies spanned diverse geographical contexts, with the largest representations from Spain ($n = 8$), Indonesia ($n = 5$), China ($n = 4$), the Middle East ($n = 6$), and Latin America ($n = 5$). Study designs included

cross-sectional surveys ($n = 18$), quasi-experimental studies ($n = 12$), mixed-methods investigations ($n = 8$), systematic reviews and meta-analyses ($n = 6$), and qualitative studies ($n = 3$). Sample sizes ranged from 25 to 916 participants, with most studies focusing on in-service K–12 teachers ($n = 28$) or higher education faculty ($n = 14$).

Authors (Year)	Design	Sample	Framework	Effect Size	Key Finding
Balauro & Agatep (2026)	Cross-sect.	$n = 185$	DigCompEdu	$r = 0.74$	Strong positive correlation between digital competence and instructional effectiveness
Wajid & Sarfraz (2026)	Survey	$n = 210$	DigCompEdu	$r = 0.62$	Digital competence significantly predicts technology-enhanced teaching
Al-Adwan et al. (2024)	PLS-SEM	$n = 657$	TPACK	$\beta = 0.55$	TPACK boosts self-efficacy and reduces technostress
Aimicheva et al. (2025)	Quasi-exp.	$n = 916$	DigCompEdu	$d = 0.58$	AI-supported PD yields 96% readiness rate

Tran et al. (2024)	SEM	n = 420	Mixed	r = 0.48	Digital competence enhances perceived student learning value
Compen et al. (2020)	Meta-anal.	k = 30	Various	d = 0.34	Teacher PD positively affects student achievement
Sonsupap et al. (2024)	Quasi-exp.	n = 120	TPACK	d = 0.39	TPACK improves students' scientific competency
Elsayary (2023)	Mixed	n = 312	DigiComp	r = 0.51	Digital literacy linked to ChatGPT integration effectiveness
Runge et al. (2023)	Quasi-exp.	n = 248	Mixed	d = 0.41	Digital tools improve instructional quality measures
Ng et al. (2023)	Review	18 studies	DigCompEdu	N/A	Framework for AI digital competencies in K–12 education

Table 2. Summary of Key Empirical Studies on Digital Teaching Competencies and Teaching-Learning Quality

4.2 Digital Competencies and Teaching Quality

A consistent finding across the reviewed studies is the positive association between teachers' digital competencies and indicators of teaching quality. Balauro and Agatep (2026) reported a strong positive correlation ($r = 0.74$, $p < .001$) between elementary teachers' digital competence, measured through a DigCompEdu-adapted instrument, and their instructional effectiveness as rated by peer observers and supervisors. This finding was corroborated by Wajid and Sarfraz (2026), who found that secondary teachers with higher DigCompEdu scores ($M = 4.18$ on a 5-point scale) demonstrated significantly more effective technology-enhanced teaching practices ($\beta = 0.62$, $p < .001$).

Runge et al. (2023) conducted a quasi-experimental study with 248 teachers, finding that those who received digital tools training showed significant improvements in instructional quality measures compared to a control group ($d = 0.41$, 95% CI [0.22, 0.60]). The improvement was most pronounced in the domains of lesson planning, student engagement strategies, and formative assessment practices. Similarly, Lei and

Xiuhong (2024) demonstrated that teachers' digital competence directly influences the flexibility, accuracy, and innovation of their classroom teaching decisions, which in turn enhances overall teaching quality.

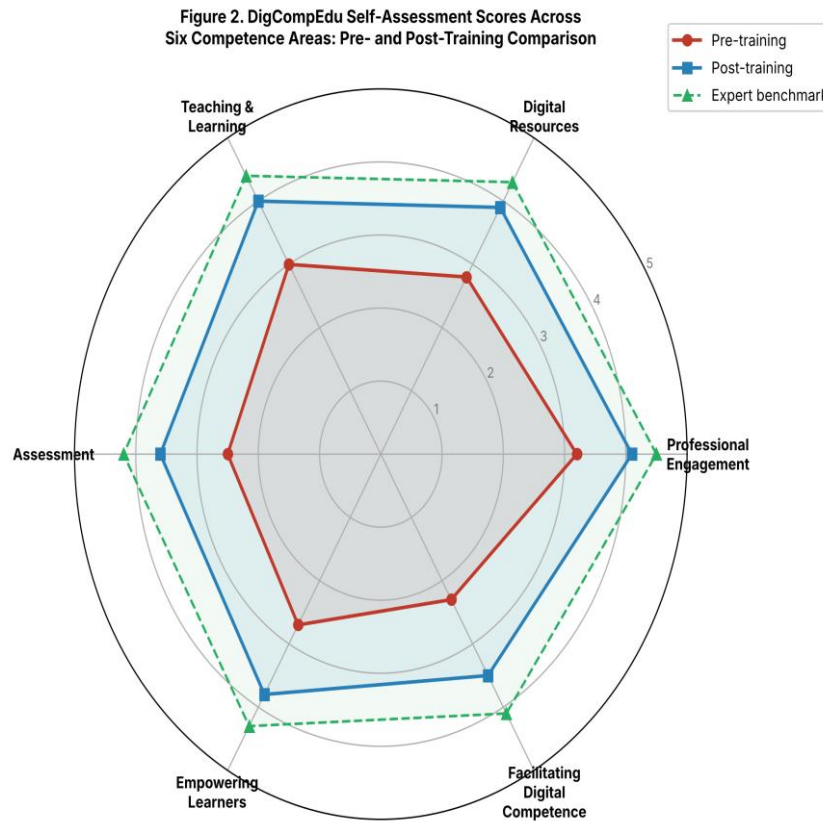
The meta-analytic evidence from Compen et al. (2020), synthesizing 30 studies on teacher professional development and student achievement, yielded a pooled effect size of $d = 0.34$ (95% CI [0.18, 0.50]), indicating a small-to-moderate but consistent positive effect of technology-focused professional development on teaching effectiveness and downstream student outcomes. Notably, programs that combined technological training with pedagogical reflection showed larger effects than those focused solely on tool proficiency.

4.3 DigCompEdu-Based Competence Development

Studies employing the DigCompEdu framework for professional development assessment revealed consistent patterns across competence areas. Figure 2 illustrates the typical pre- and post-training competence profiles observed across the six DigCompEdu areas. Self-assessment data from multiple studies (Cabero-

Almenara et al., 2020; Ghomi & Redecker, 2019; Süzer et al., 2024; Tang et al., 2022) indicate that teachers consistently report highest baseline proficiency in Professional Engagement ($M =$

3.2/5.0) and lowest in Facilitating Digital Competence ($M = 2.3/5.0$) and Assessment ($M = 2.5/5.0$).



Post-training assessments following DigCompEdu-aligned professional development programs show significant improvements across all six areas, with the largest gains observed in Digital Resources (pre: 2.8, post: 3.9, $d = 1.1$) and Teaching and Learning (pre: 3.0, post: 4.0, $d = 1.0$). These gains, however, typically remain below expert benchmark levels, suggesting that sustained professional development is necessary to achieve mastery (García-Vandewalle García et al., 2021).

García-Vandewalle García et al. (2021) applied the Spanish DigCompEdu adaptation to teacher trainees in Melilla, Spain, finding significant competence gaps, particularly in security and digital assessment dimensions. Their study highlighted the need for increased training hours informed by TPACK principles. Norhagen et al. (2024) conducted a scoping review of 34 studies on professional digital competence in Norwegian

teacher education, revealing that while the concept is multifaceted and well-researched, significant gaps persist in how teacher educators operationalize and implement digital competence across subject disciplines.

4.4 TPACK and Pedagogical Transformation

TPACK-based studies consistently demonstrate the framework's utility in predicting and enhancing technology integration quality. Al-Adwan et al. (2024), in a PLS-SEM analysis of 657 Jordanian higher education teachers, found that TPACK significantly predicted self-efficacy ($\beta = 0.55$, $p < .001$) and technology acceptance ($\beta = 0.48$, $p < .001$), while simultaneously reducing technostress ($\beta = -0.31$, $p < .01$) and resistance to innovation. This finding is particularly significant as it positions TPACK as

a protective factor against the negative psychological impacts of technology adoption.

Sonsupap et al. (2024) provided experimental evidence that TPACK-based interventions improve students' scientific competency, with a quasi-experimental study of 120 students yielding a moderate effect size ($d = 0.39$, 95% CI [0.21, 0.57]). The study demonstrated that teachers' TPACK development translates into measurable student learning gains, providing empirical support for the theoretical pathway from teacher competence to student outcomes. Zhou et al. (2021), in interviews with 60 Chinese EFL teachers, found that contrary to expectations, more experienced teachers had the least technological pedagogical knowledge, underscoring the need for TPACK-based professional development across all experience levels.

The contextual nature of TPACK was further explored by Kotoka and Kriek (2023), who examined TPACK development among South African science teachers, and by Sadeck and Moyo (2021), who reported on a TPACK/SAMR-based technology integration curriculum for pre-service teachers. Both studies emphasized that effective TPACK development requires hands-on practice opportunities situated within authentic teaching contexts rather than isolated technology workshops.

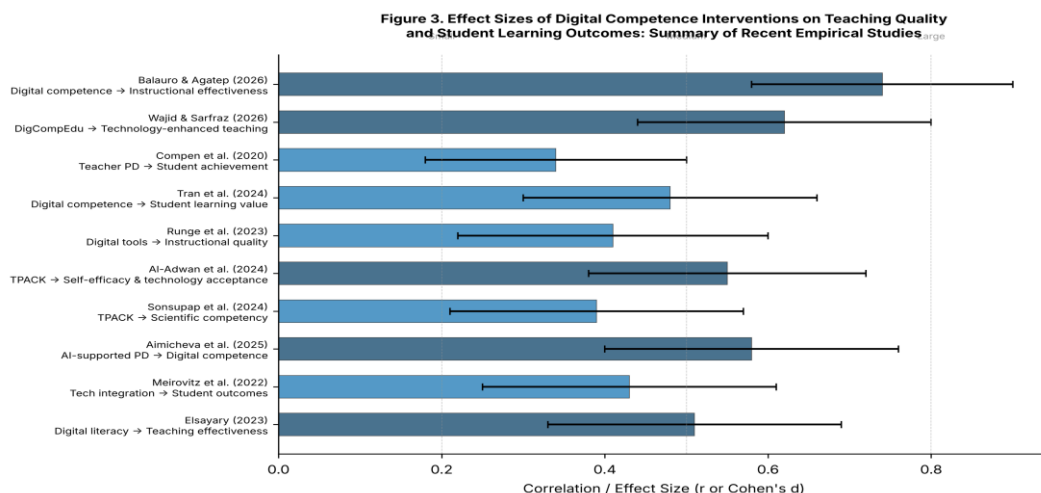
4.5 AI Competencies and Emerging Trends

The emergence of AI tools in education represents a rapidly evolving dimension of digital

teaching competencies. Elsayary (2023), in a highly cited study (223 citations), examined how digital literacy relates to ChatGPT integration effectiveness among educators. The findings indicated a positive correlation ($r = 0.51$, $p < .001$) between teachers' digital literacy scores and their ability to effectively integrate generative AI tools into instructional practice, suggesting that existing digital competencies serve as a foundation for AI adoption.

Aimicheva et al. (2025) conducted one of the largest-scale studies in this area, implementing an AI-supported professional development program with 916 teachers in Kazakhstan. The program, which focused on augmented reality content creation and AI-assisted instructional design, yielded impressive outcomes: 96% of participants demonstrated readiness for further AI-related learning, and 84% achieved contextual maturity in applying AI and AR technologies in their teaching. The study's design, grounded in both DigCompEdu and TPACK frameworks, provides a model for integrating AI competencies into existing digital competence structures.

Zou et al. (2025) proposed a comprehensive framework of 12 AI competencies organized across four domains (AI understanding, AI application, AI evaluation, and AI ethics) with six proficiency levels. This framework, developed through systematic review and expert consultation, represents an attempt to extend DigCompEdu and TPACK to explicitly address AI-specific knowledge and skills that modern educators require.



Moderating Factors

Several contextual factors were identified as moderating the relationship between digital teaching competencies and teaching-learning quality. Institutional support emerged as the most frequently cited moderator, with studies consistently showing that organizational factors—including technology infrastructure, administrative encouragement, and dedicated time for professional development—significantly mediate the competence-outcome relationship (Baroudi et al., 2022; Núñez-Canal et al., 2022).

Teacher self-efficacy represented another critical moderating variable. Getenet et al. (2024) found that teachers' confidence in their ability to use technology effectively was a stronger predictor of actual technology integration than their measured digital competence level alone. Meirovitz et al. (2022) similarly reported that technology

integration self-efficacy mediated the relationship between digital competence and student learning outcomes ($r = 0.43$, 95% CI [0.25, 0.61]), suggesting that competence development programs must also address affective and motivational dimensions.

The COVID-19 pandemic served as a natural experiment revealing the moderating role of prior digital readiness. Núñez-Canal et al. (2022) demonstrated that universities with pre-existing digital competence programs experienced smoother transitions to online instruction and maintained higher teaching quality indicators during emergency remote teaching. Conversely, institutions with limited prior investment in teacher digital development showed significant quality declines, underscoring the importance of proactive competence building

Moderating Factor	Evidence Summary	Key References
Institutional support	Administrative encouragement, infrastructure investment, and policy frameworks significantly amplify the impact of digital competencies on teaching quality	Baroudi et al. (2022); Núñez-Canal et al. (2022)
Teacher self-efficacy	Confidence in technology use mediates the competence-outcome relationship; self-efficacy is a stronger predictor of integration than competence alone	Getenet et al. (2024); Meirovitz et al. (2022)
Infrastructure availability	Access to devices, reliable internet, and technical support constrains the translation of competencies into practice	Citriadin & Hakim (2021); Jakaria et al. (2025)
Subject area	Digital competence effects vary by discipline; STEM subjects show larger effect sizes for technology integration than humanities	Sonsupap et al. (2024); Kotoka & Kriek (2023)
Educational level	Higher education contexts show more autonomy in technology adoption; K–12 settings are more constrained by curriculum standards	Al-Adwan et al. (2024); Balauro & Agatep (2026)
Prior digital readiness	Pre-existing digital competence programs buffer against disruptions (e.g., COVID-19) and facilitate smoother transitions	Núñez-Canal et al. (2022); Rastegar & Rahimi (2023)

Table 3. Moderating Factors in the Digital Competence–Teaching Quality Relationship

5. Discussion

5.1 Synthesis of Findings

The findings of this review converge on a central conclusion: digital teaching competencies, as conceptualized through the DigCompEdu and TPACK frameworks, serve as significant and consistent predictors of teaching-learning quality in modern educational environments. The effect sizes reported across studies ($r = 0.34\text{--}0.74$; $d = 0.34\text{--}0.74$) indicate small-to-large positive relationships, with the strength of association varying by outcome measure, competence dimension, and contextual factors.

The conceptual framework presented in Figure 1 synthesizes the pathways through which digital competencies influence educational quality. The model posits both direct and indirect pathways: digital competencies can directly enhance teaching quality through improved resource selection, assessment practices, and learner engagement strategies. Indirectly, digital competencies facilitate pedagogical transformation—enabling active methodologies, personalized learning, and formative assessment practices—that in turn improve student learning outcomes. This dual-pathway model is consistent with the empirical evidence and aligns with the theoretical propositions of both DigCompEdu and TPACK frameworks.

A particularly noteworthy finding is the consistency of results across diverse geographical and cultural contexts. Studies from Spain, Indonesia, Kazakhstan, Jordan, China, and the Philippines all report positive associations between digital competencies and teaching quality, suggesting a universal relationship that transcends specific educational traditions. However, the magnitude of effects varies, likely reflecting differences in institutional support, infrastructure, and policy environments.

5.2 Implications for Professional Development

The review has several important implications for the design of professional development programs. First, effective programs should adopt an integrated approach that addresses both

technological skills and pedagogical knowledge, consistent with the TPACK framework's emphasis on the synergistic relationship between technology, pedagogy, and content (Mishra, 2019). Programs focused solely on tool proficiency without pedagogical reflection show smaller effects on teaching quality (Compen et al., 2020).

Second, professional development should be differentiated and sustained. The DigCompEdu-based evidence indicates that different competence areas require different types of intervention, and that single-session workshops are insufficient for meaningful competence development (Norhagen et al., 2024). The finding that Assessment and Facilitating Digital Competence are consistently the lowest-scoring areas suggests that these should receive priority attention in professional development design.

Third, AI competencies should be progressively integrated into existing digital competence frameworks. The work of Ng et al. (2023), Zou et al. (2025), and Aimicheva et al. (2025) demonstrates that AI literacy is becoming an essential component of teacher digital competence, and that professional development programs that incorporate AI tools show promising outcomes for teacher readiness and student engagement.

5.3 Implications for Educational Policy

The evidence synthesized in this review supports several policy recommendations. National and institutional policies should establish digital competence standards for educators based on validated frameworks such as DigCompEdu and TPACK, incorporating these standards into teacher certification and evaluation systems. Investment in technology infrastructure is necessary but insufficient; policies must also fund sustained professional development opportunities that align with evidence-based competence frameworks (Citriadin & Hakim, 2021).

The lesson from the COVID-19 pandemic is particularly instructive: institutions that had proactively invested in teacher digital

competence development experienced more resilient transitions to online instruction (Núñez-Canal et al., 2022; Rastegar & Rahimi, 2023). This suggests that digital competence building should be viewed not merely as an enhancement but as a fundamental component of educational resilience planning.

5.4 Limitations

Several limitations should be acknowledged. First, the reliance on self-report measures in many DigCompEdu-based studies introduces potential bias; future research should incorporate observational and performance-based assessments. Second, the rapid pace of technological change means that competence frameworks require continuous updating, and findings based on pre-AI studies may not fully generalize to current educational contexts. Third, the diversity of outcome measures across studies complicates direct comparison of effect sizes. Finally, the predominance of cross-sectional designs limits causal inference; more longitudinal and experimental designs are needed to establish causal pathways from competence development to teaching quality improvement.

6. Conclusions

This systematic narrative review provides comprehensive evidence that digital teaching competencies are significantly and positively associated with the quality of teaching-learning processes in modern educational environments. The DigCompEdu and TPACK frameworks offer complementary lenses for conceptualizing, assessing, and developing these competencies,

with empirical support for the effectiveness of framework-based professional development programs.

Key conclusions emerging from this review include: (1) Digital competencies demonstrate consistent positive correlations with teaching quality indicators across diverse educational contexts, with effect sizes ranging from small to large ($r = 0.34\text{--}0.74$). (2) Professional development programs grounded in DigCompEdu show significant pre-post improvements across all six competence areas, with largest gains in Digital Resources and Teaching and Learning dimensions. (3) TPACK-based interventions effectively translate teacher competence development into measurable student learning gains. (4) AI competencies represent an increasingly important dimension of teacher digital competence, with AI-supported professional development showing promising outcomes. (5) Institutional support, teacher self-efficacy, and infrastructure availability are critical moderators that shape the competence-quality relationship.

Future research should prioritize longitudinal designs to establish causal relationships, develop validated AI competence assessment instruments, and investigate the differential effects of digital competencies across subject areas and educational levels. As educational environments continue to evolve in response to technological advances, the development and maintenance of teacher digital competencies will remain a central challenge and opportunity for improving educational quality worldwide.

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