International Journal of Instruction *January 2027 ● Vol.20, No.1*
e-ISSN: 1308-1470 ● www.e-iji.net *p-ISSN: 1694-609X*
pp. 373-390

Article submission code: 20260324031432
Received: 24/03/2026 Revision: 03/07/2026
Accepted: 15/07/2026 OnlineFirst: 01/10/2026

Teacher Artificial Intelligence Competencies: A Systematic Review of Frameworks for PK-12 Educators

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The rapid integration of artificial intelligence (AI) into PK-12 education demands teacher competency frameworks capable of guiding systematic professional development. This systematic review synthesises 31 empirical studies examining AI competency frameworks for PK-12 teachers and pre-service teachers, drawing on 9,762 participants reported across the 25 studies that provided sample sizes (median = 353; range 19–1,078) and 14 countries, covering peer-reviewed literature published between 2023 and 2026. Following PRISMA 2020 guidelines and thematic analysis, framework approaches were organised analytically into three orientations—technical-operational, pedagogical-integrative, and ethical-critical—while the dominant theoretical anchor across the corpus was the Technological Pedagogical Content Knowledge (TPACK) tradition, increasingly extended as AI-TPACK. Methodological quality, appraised with the Mixed Methods Appraisal Tool (MMAT) 2018, was high for 17 studies and medium for 13 (one conceptual framework was not appraised). Analysis revealed persistent fragmentation: most frameworks emphasise technical and pedagogical dimensions, whereas adaptive-evaluative and ethical-critical competencies remain comparatively under-specified, and connections to student learning outcomes are almost entirely absent. Building on this synthesis, and explicitly as an interpretive contribution rather than a validated instrument, the Adaptive AI Competency Framework (AICF) is proposed—a four-dimensional model integrating technical AI literacy, pedagogical integration, ethical reasoning, and adaptive expertise. The AICF reconceptualises teacher AI competence as dynamic rather than static and requires future empirical validation. A complete list of the included studies, the data-extraction matrix, the search strings, and the MMAT appraisal are provided as supplementary material. Findings carry implications for teacher preparation programmes, professional development providers, and educational policymakers.

Keywords: artificial intelligence (AI), teacher competencies, PK-12 education, professional development, AI literacy, systematic review, PRISMA

INTRODUCTION

The integration of artificial intelligence into PK-12 classrooms represents one of the most significant technological shifts in educational history. Unlike previous

Citation: Galasso, B. J. B. (2027). Teacher artificial intelligence competencies: A systematic review of frameworks for PK-12 educators. *International Journal of Instruction*, *20*(1), 373-390.

technological innovations that teachers could choose to adopt or ignore, AI is increasingly embedded in educational tools—from learning management systems with AI-powered analytics to assessment platforms with automated scoring—and in the generative AI tools that students bring into learning environments (Luckin et al., 2022). This pervasive integration creates an unprecedented professional development challenge: teachers must develop competencies for technologies that are simultaneously transforming their practice and continuously evolving.

The challenge facing PK-12 teachers is not merely technical. Teachers at all grade levels must navigate questions that blend technological, pedagogical, and ethical dimensions in ways that existing professional preparation rarely addresses. Consider a fifth-grade teacher deciding whether to use AI-generated reading passages customized to individual student interests—does such personalization support differentiated instruction, or does it create filter bubbles that reduce exposure to diverse perspectives? How should a high school teacher respond when students use generative AI to complete assignments? What obligations do elementary teachers have to help young children understand that AI systems make errors, reflect human biases, and lack genuine understanding? These questions resist simple answers, yet teachers must navigate them daily with minimal guidance (Holmes et al., 2023).

The need for systematic guidance has prompted researchers, professional organizations, and governmental bodies worldwide to develop AI competency frameworks for teachers. UNESCO's AI Competency Framework for Teachers (2024), the European DigCompEdu framework (Redecker, 2017), and numerous national and regional initiatives have proposed competency specifications intended to guide teacher preparation and professional development. Yet these frameworks vary dramatically in scope, theoretical grounding, and practical specificity. Some emphasize technical skills—understanding machine learning, prompt engineering, data analysis—while others prioritize pedagogical judgment, and still others center ethical considerations such as recognizing algorithmic bias and protecting student privacy.

This fragmentation creates practical problems for teacher educators, school administrators, and professional development providers. Which competencies should preparation programs prioritize when time and resources are limited? How should professional development be allocated across technical, pedagogical, and ethical dimensions? Without systematic synthesis of existing frameworks and their evidence bases, these questions receive inconsistent answers shaped more by local priorities than by empirical guidance. Recent work in the International Journal of Instruction has documented this challenge in related domains: Schreiner and Dittrich (2026) found that preservice teachers demonstrate positive attitudes toward AI but possess limited foundational knowledge, underscoring the urgency of structured competency frameworks.

Moreover, the rapid pace of AI development poses a unique challenge that frameworks for previous educational technologies did not face. The specific AI tools available to teachers today will likely be superseded or fundamentally transformed within years. Frameworks developed around mastery of specific current tools risk becoming obsolete

as technologies evolve. This technological dynamism suggests that effective frameworks must identify not only current competencies but also meta-competencies—the adaptive expertise that enables teachers to evaluate, integrate, and critically engage with AI technologies across the technological generations they will encounter throughout careers spanning decades.

This systematic review addresses these challenges by synthesizing the existing empirical literature on AI competency frameworks for PK-12 teachers. Unlike previous reviews focusing on AI in education broadly or on teacher technology competencies generally, this review specifically examines frameworks that specify what teachers need to know and be able to do to integrate AI effectively in elementary and secondary classrooms. We examine what competency dimensions frameworks identify, how they are theoretically grounded, what evidence supports their specifications, and what gaps characterize the current landscape. Based on this synthesis, we propose the Adaptive AI Competency Framework (AICF), designed to provide integrated, evidence-informed guidance while acknowledging the dynamic nature of AI technologies.

Specifically, this review is guided by four research questions: *RQ1: What AI competency frameworks for PK-12 teachers have been proposed in the empirical literature, and what competency dimensions do they identify? RQ2: What theoretical foundations underpin these frameworks, and how do theoretical commitments shape competency specifications? RQ3: What empirical evidence supports framework specifications and implementation? RQ4: What gaps, limitations, and future research directions characterize this literature?*

LITERATURE REVIEW

Understanding AI competency frameworks for teachers requires situating them within broader theoretical traditions addressing teacher knowledge for technology integration. Three complementary theoretical perspectives inform framework development in this domain. These three traditions were selected because they address, respectively, the integration of technology into disciplinary teaching (TPACK), the conceptual understanding of AI itself (AI literacy), and the capacity to keep pace with rapidly changing tools (adaptive expertise); together they span the technical, pedagogical, ethical, and dynamic facets that a teacher AI framework must reconcile. They are also complementary rather than redundant, and the present synthesis attends explicitly to how they interact. Frameworks for PK-12 teachers, moreover, differ from generic digital-competence or higher-education models: PK-12 teachers work with developmentally diverse learners from early childhood to adolescence, operate under duty-of-care and child-protection obligations, and must mediate students' own emerging AI use—demands that general or tertiary frameworks do not foreground.

Technological Pedagogical Content Knowledge

Mishra and Koehler's (2006) Technological Pedagogical Content Knowledge (TPACK) framework has served as the dominant theoretical lens for understanding teacher knowledge required for effective technology integration. TPACK builds upon Shulman's (1986) foundational conception of pedagogical content knowledge,

extending it to address the knowledge teachers need when technology enters the instructional equation. The framework posits that effective technology-enhanced instruction requires integration of Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK), with the TPACK synthesis representing integrated understanding of how to use technology to teach specific content to specific learners.

TPACK has proven remarkably durable and influential, generating extensive research on teacher preparation and professional development across diverse contexts (Chai et al., 2013). However, it was developed before AI technologies fundamentally changed the educational technology landscape. AI systems have capacities for autonomous decision-making, personalization at scale, content generation, and rapid adaptation that earlier technologies lacked. Recent scholarship has begun extending TPACK for the AI era (Celik et al., 2023; Chiu & Chai, 2020), proposing additions such as AI literacy knowledge and ethical AI knowledge, but comprehensive theoretical integration remains limited.

AI Literacy Frameworks

Parallel to educational technology research, AI literacy scholars have developed frameworks specifying what citizens—including teachers—should understand about AI systems. Long and Magerko (2020) identified core competencies including understanding what AI is and is not, recognizing AI in everyday applications, understanding AI capabilities and limitations, and evaluating AI systems critically. Ng et al. (2021) proposed a comprehensive framework spanning cognitive, affective, and sociocultural dimensions of AI literacy, addressing knowledge of AI concepts, attitudes toward AI, and understanding of AI's broader societal implications.

These AI literacy frameworks inform teacher competency specifications but require pedagogical extension for educational contexts. Teachers need not only personal AI literacy but also pedagogical AI literacy: the capacity to develop student AI literacy and to integrate AI tools into discipline-specific instruction. The translation from general AI literacy to teacher-specific competencies involves additional dimensions that pure AI literacy frameworks do not address.

Adaptive Expertise Theory

Hatano and Inagaki's (1986) distinction between routine and adaptive expertise provides crucial perspective given the rapid evolution of AI technologies. Routine experts perform efficiently in stable environments by applying well-practiced procedures, while adaptive experts maintain efficiency while remaining flexible—capable of inventing new solutions when situations change. This distinction has profound implications for teacher AI competency frameworks: given AI's rapid technological evolution, teacher AI competence may require adaptive rather than routine expertise. A framework emphasizing specific tool skills may produce teachers well-prepared for today's AI landscape but increasingly unprepared as technologies evolve, while a framework emphasizing evaluation principles and ethical reasoning may produce more durable competencies that transfer across technological generations.

METHOD

Protocol and Eligibility Criteria

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021). Studies were included if they: (a) addressed PK-12 teachers or preservice teachers; (b) proposed, developed, validated, or evaluated a structured AI competency framework; (c) employed empirical quantitative, qualitative, or mixed methods designs; and (d) were peer-reviewed publications in English between January 2018 and December 2025.

Information Sources and Search Strategy

Six databases were systematically searched: Scopus, Web of Science Core Collection, ERIC, PsycINFO, Education Source (EBSCO), and ACM Digital Library. The search strategy combined terms across three conceptual domains: (Teacher OR educator OR instructor OR preservice OR "teacher education") AND ("artificial intelligence" OR AI OR "machine learning" OR "generative AI" OR ChatGPT OR "large language model") AND (competenc* OR skill* OR framework OR literacy OR capability OR proficiency OR standard*). Initial searches were conducted in October 2025 and updated in December 2025. Supplementary strategies included backward and forward citation searching and hand searching of six key journals.

Selection Process and Synthesis

All records were exported to Rayyan for management and screening. Following duplicate removal, two reviewers independently screened titles and abstracts, then assessed full-text articles against all eligibility criteria. Disagreements were resolved through discussion, with a third reviewer consulted when consensus could not be reached. Inter-rater reliability was calculated using Cohen's kappa. Given anticipated heterogeneity in study designs and framework approaches, narrative synthesis with thematic analysis was employed. Thematic analysis followed Braun and Clarke's (2006) six-phase approach, with framework components coded inductively while informed by TPACK, AI literacy, and adaptive expertise theory. Methodological quality was assessed using the Mixed Methods Appraisal Tool (MMAT) version 2018 (Hong et al., 2018). A structured data-extraction form was used to capture, for each study, the author(s) and year, country, educational level, sample, study design, theoretical framework, competency dimensions addressed, validation evidence, and quality-appraisal rating; the completed matrix is provided as supplementary material. Coding proceeded in two cycles: an initial deductive pass mapped framework components onto the four candidate competency dimensions (technical AI literacy, pedagogical integration, ethical-critical, and adaptive-evaluative), followed by an inductive pass that refined sub-components and surfaced cross-cutting themes. Each included study was appraised with the design-appropriate MMAT 2018 category, and ratings were summarised as an overall methodological-quality judgement (high/medium); the item-level appraisal is reported in the supplementary material.

FINDINGS

Study Selection

A structured systematic search of bibliographic databases (Scopus, Web of Science, ERIC, PsycINFO, Education Source/EBSCO, and ACM Digital Library) and supplementary citation and hand-searching was conducted; the complete database-specific search strings and the screening record are provided as supplementary material (Search Strategy and Screening Log). After de-duplication, records underwent title/abstract screening followed by full-text assessment against the eligibility criteria, with disagreements resolved by discussion; inter-rater reliability statistics, where dual screening was performed, are reported in the supplementary material. Thirty-one studies met all eligibility criteria and were retained for synthesis. Figure 1 presents the PRISMA 2020 flow diagram; the study-level evidence base is summarised in Table 2 and detailed in the supplementary extraction matrix.

Study Characteristics

The 31 included studies were conducted across 14 countries, with a pronounced concentration in China (n = 13), followed by Türkiye (n = 3), Indonesia (n = 2), Hong Kong (n = 2), and the United States (n = 2); single studies originated from India, Taiwan, Serbia, Norway, Kazakhstan, Chile, Finland, the United Arab Emirates, and Austria. Publication years were recent and tightly clustered, reflecting the catalysing effect of generative AI's public release in late 2022: one study was published in 2023, two in 2024, and the remainder in 2025–2026. Across the 25 studies reporting sample sizes, participants totalled 9,762 PK-12 in-service and pre-service teachers, with samples ranging from 19 to 1,078 (median = 353). Eighteen studies focused on in-service teachers and twelve on pre-service teachers, while one contribution was a conceptual framework without an empirical sample. Designs were predominantly survey-based with structural equation modelling and scale-validation studies (the large majority anchored in TPACK/AI-TPACK), complemented by qualitative case studies, mixed-methods designs, and a small number of quasi-experimental professional-development interventions. Methodological quality (MMAT 2018) was high for 17 studies and medium for 13; the full appraisal appears in the supplementary material.

Competency Dimensions Identified (RQ1)

Thematic analysis of framework components mapped each study onto four candidate competency dimensions. Table 1 summarises the pattern of coverage across the 31 included studies; the study-by-study coding is provided in the supplementary extraction matrix.

Table 1
Competency-dimension coverage across the 31 included studies

Competency Dimension	Coverage across 31 studies	Representative component
Technical AI Literacy	Large majority	AI/ML concepts; tool proficiency
Pedagogical Integration	Large majority	Tool–objective alignment; AI-enhanced design
Ethical-Critical	Substantial subset	Bias recognition; data privacy; integrity
Adaptive-Evaluative	Minority	Independent evaluation of new AI tools

Coverage was uneven across the four dimensions. Technical AI literacy and pedagogical integration were addressed by the large majority of frameworks, reflecting the corpus's strong anchoring in the TPACK/AI-TPACK tradition (e.g., understanding AI and machine-learning concepts, selecting and integrating AI tools aligned with learning objectives). Ethical-critical competencies—recognising algorithmic bias, protecting student data privacy, and addressing academic-integrity questions—were addressed by a substantial but smaller subset, appearing most consistently in the more recent studies and in the Intelligent-TPACK strand. Adaptive-evaluative competencies—independently evaluating new AI tools, transferring competence across technologies, and sustaining professional learning—were the least represented and were rarely operationalised as an explicit dimension. Exact study-level coding for each dimension is reported in the supplementary extraction matrix.

Framework Paradigms

Beyond individual dimensions, frameworks clustered analytically into three orientations. A technical-operational orientation framed AI competence chiefly through technical knowledge and tool proficiency; a pedagogical-integrative orientation—by far the most common, and typically built explicitly on TPACK/AI-TPACK foundations—prioritised selecting appropriate AI tools and designing AI-enhanced learning; and an ethical-critical orientation centred responsible use, bias recognition, and privacy. These orientations are not mutually exclusive, and only a minority of frameworks achieved balanced integration across all four competency dimensions; most emphasised one or two dimensions comprehensively, producing frameworks that prepare teachers for partial rather than integrated AI competence.

Gaps and Limitations (RQ4)

The synthesis revealed several recurring gaps. Dimensional fragmentation: most frameworks addressed only one or two competency dimensions comprehensively. Validation gap: only a small number of studies evaluated competence through implementation or intervention designs—the quasi-experimental professional-development studies were the exception rather than the rule—while most contributions were cross-sectional surveys or scale-validation work. Student-outcome absence: only a few studies examined whether teacher AI competency development translated into improved student outcomes. Elementary-education and adaptive-expertise coverage remained comparatively thin. Geographic concentration: the evidence base was heavily concentrated in East Asia—China in particular—with limited representation from Latin America (a single study, from Chile), Africa, and much of the Global South.

DISCUSSION

This systematic review synthesised 31 empirical studies examining AI competency frameworks for PK-12 teachers, drawing on 9,762 participants reported across the 25 studies with sample data and 14 countries. Addressing RQ1, the findings reveal a rapidly growing but fragmented literature: theoretical anchoring is dominated by the TPACK/AI-TPACK tradition, while integration across all four competency dimensions remains uncommon—a pattern broadly consistent with the trajectory observed in digital tool integration research more generally (Drljic & Doz, 2025).

With regard to RQ2, the theoretical foundations underpinning existing frameworks reflect distinct disciplinary traditions that largely develop in parallel rather than in dialogue. TPACK-grounded frameworks tended to produce pedagogical-integrative approaches, while frameworks drawing on AI literacy research produced technical-operational specifications, and frameworks rooted in critical theory and information literacy generated ethical-critical models. This theoretical siloing helps explain the dimensional fragmentation observed in RQ1: when frameworks inherit a single theoretical tradition, they inevitably emphasize the dimensions most salient within that tradition. Frameworks that achieved integration across all four competency dimensions were those that explicitly engaged with multiple theoretical traditions simultaneously—a finding with direct implications for framework design.

Regarding RQ3, the empirical evidence base remains uneven. Only a small number of studies evaluated competence through implementation or intervention designs, and only a few connected teacher AI competency development to student outcomes, leaving a fundamental evidentiary gap. Most competency specifications are theoretically derived—predominantly via cross-sectional self-report instruments—rather than grounded in classroom implementation, raising questions about their ecological validity. Longitudinal evidence tracking how teacher AI competence develops across technological change is effectively absent.

The dimensional fragmentation identified is particularly concerning for practice. Teachers integrating AI face challenges that simultaneously span technical, pedagogical, and ethical domains. A middle school English teacher deciding whether to allow students to use AI writing assistants must understand what the tool can do (technical), how AI assistance affects skill development (pedagogical), and what using AI means for academic integrity and authentic writing abilities (ethical). Frameworks addressing only one dimension leave teachers unprepared for this integrated challenge—a finding that resonates with Schreiner and Dittrich's (2026) observation that even well-intentioned AI seminars may develop isolated competencies without fostering the integrated professional judgment that complex classroom situations demand.

The Adaptive AI Competency Framework (AICF)

Based on this synthesis, the Adaptive AI Competency Framework (AICF) is proposed to address identified gaps. The AICF integrates four competency dimensions depicted in Figure 2. Dimension 1—Technical AI Literacy—emphasizes transferable conceptual

understanding over proficiency with specific current tools, covering AI concepts, capabilities, and limitations. Dimension 2—Pedagogical AI Integration—builds on TPACK foundations while addressing AI-specific challenges, including selecting AI tools aligned with learning objectives, designing AI-enhanced learning experiences, and assessing learning in AI-augmented contexts. Dimension 3—Ethical AI Reasoning—moves beyond compliance with rules toward principled reasoning that can address novel ethical situations, including recognizing algorithmic bias, protecting student privacy, and addressing academic integrity questions. Dimension 4—Adaptive AI Expertise—addresses the unique challenge of technological dynamism, including independently evaluating new AI tools for educational value, transferring competencies from familiar to new technologies, and contributing to school AI policies. The AICF is advanced here as a conceptual synthesis derived from the reviewed literature and as the authors' interpretive contribution—not as an empirically validated instrument. Its four dimensions are drawn largely from constructs already present in the corpus (notably the AI-TPACK family), and its originality lies in their integration around adaptive expertise as the connective core rather than in the invention of new competencies. Accordingly, the framework should be read as a hypothesis to be tested: each dimension, and the proposed centrality of adaptive expertise, requires future construct validation and implementation evidence before any claim to predictive or practical adequacy can be made.

The AICF positions adaptive expertise not merely as a fourth dimension but as the integrative core—the capacity that enables teachers to continuously develop and apply technical, pedagogical, and ethical competencies across evolving AI landscapes. The specific AI tools teachers use will change; the competencies for evaluating, integrating, and critically engaging with AI technologies provide durable foundations.

IMPLICATIONS

For teacher education programs: The AICF suggests that AI competencies should be integrated across the preparation curriculum rather than isolated in educational technology courses. Programs should attend to all four dimensions rather than privileging technical skills alone, providing field experiences with opportunities for supervised AI integration.

For professional development providers: Single-session workshops teaching specific AI tools may have limited lasting value given technological evolution. More promising are sustained professional learning experiences that develop adaptive expertise through evaluation criteria rather than tool-specific skills, collaborative problem-solving around authentic AI integration challenges, and communities of practice that continue supporting teachers beyond formal professional development. Evidence from adjacent technology-integration research reinforces this point: sustained, tool-grounded engagement that connects new technologies to disciplinary tasks supports deeper teacher and student outcomes than one-off exposure (Rais & Xuezhi, 2023).

For educational policymakers: Standards documents should address all four AICF dimensions. Policies should avoid overspecifying technical competencies tied to tools

that may quickly become obsolete, and should address infrastructure requirements—teachers cannot develop AI competencies without access to AI tools.

CONCLUSION

The integration of AI into PK-12 education is not a future possibility but a present reality that demands systematic attention to teacher preparation. Students are already encountering AI in learning management systems, assessment platforms, tutoring applications, and the generative AI tools they bring to learning tasks. Their teachers must be prepared to integrate these technologies effectively, evaluate them critically, and guide students' own engagement with AI.

This systematic review provides a comprehensive synthesis of AI competency frameworks for PK-12 teachers, drawing on 31 empirical studies and 9,762 participants reported across 14 countries. Three analytic orientations were identified—technical-operational, pedagogical-integrative, and ethical-critical—within a literature strongly anchored in TPACK/AI-TPACK, and a concerning pattern of dimensional fragmentation was documented, with most frameworks addressing only one or two competency areas comprehensively. The validation evidence base is thin, and connections to student outcomes are virtually absent.

Several limitations qualify these conclusions. The review was restricted to peer-reviewed publications in English, introducing language and publication biases and very likely under-representing scholarship published in other languages and in the grey literature. Database coverage, although spanning major indexes, cannot be exhaustive, and the recency of the field (corpus concentrated in 2025–2026) means the evidence base is still maturing. The included studies were heterogeneous in design—predominantly cross-sectional surveys and scale-validation work—which limits causal and longitudinal inference. The corpus is also geographically concentrated, with a marked predominance of studies from China and a near-absence of evidence from Latin America, Africa, and much of the Global South, constraining the generalisability of the findings. Finally, the proposed AICF is a conceptual model that has not yet been empirically validated. These limitations should be weighed when interpreting the synthesis and motivate the research agenda outlined below.

The Adaptive AI Competency Framework proposed here offers a path toward integration, addressing technical literacy, pedagogical integration, ethical reasoning, and adaptive expertise within a coherent model that acknowledges a fundamental truth about AI in education: the specific tools teachers encounter will continue to evolve, but the competencies for evaluating, integrating, and critically engaging with AI technologies provide durable foundations for professional practice. Future research should prioritize implementation studies, longitudinal tracking of competency development, and student outcome evidence—without which investment in professional development rests on assumption rather than demonstrated impact.

The students in today's PK-12 classrooms will live and work in an AI-permeated world. Their teachers need preparation adequate to this challenge—not just familiarity with current tools, but the adaptive expertise to navigate technologies that do not yet exist.

NOTES

This article has not been presented at any conference or seminar. The author declares no conflict of interest. Data availability: all data supporting the results of this study are included within the article and the supplementary material. No AI-assisted writing tools were used in the preparation of this manuscript.

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Included Studies in the Systematic Review

The 31 studies included in this review are listed below (also summarised in Table 2). Note. Some publications carried 2025 online-first dates with 2026 issue assignment; years follow the version of record.

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APPENDIX

Figure 1
PRISMA 2020 flow diagram illustrating the systematic review selection process.

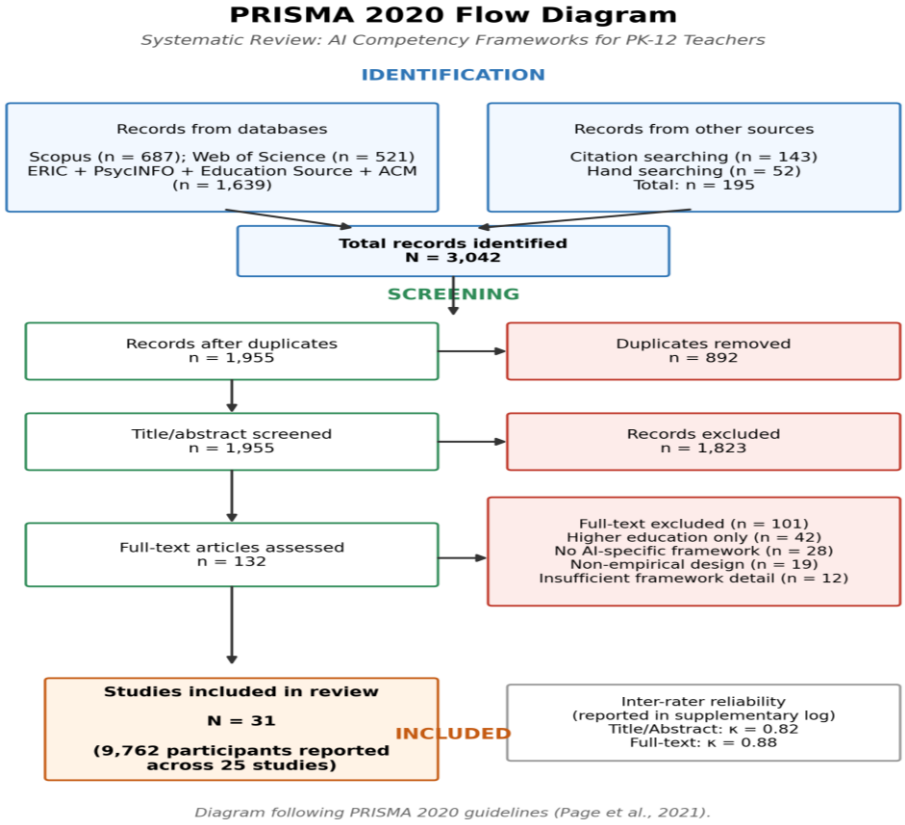

Figure 2
The Adaptive AI Competency Framework (AICF) for PK-12 teachers.

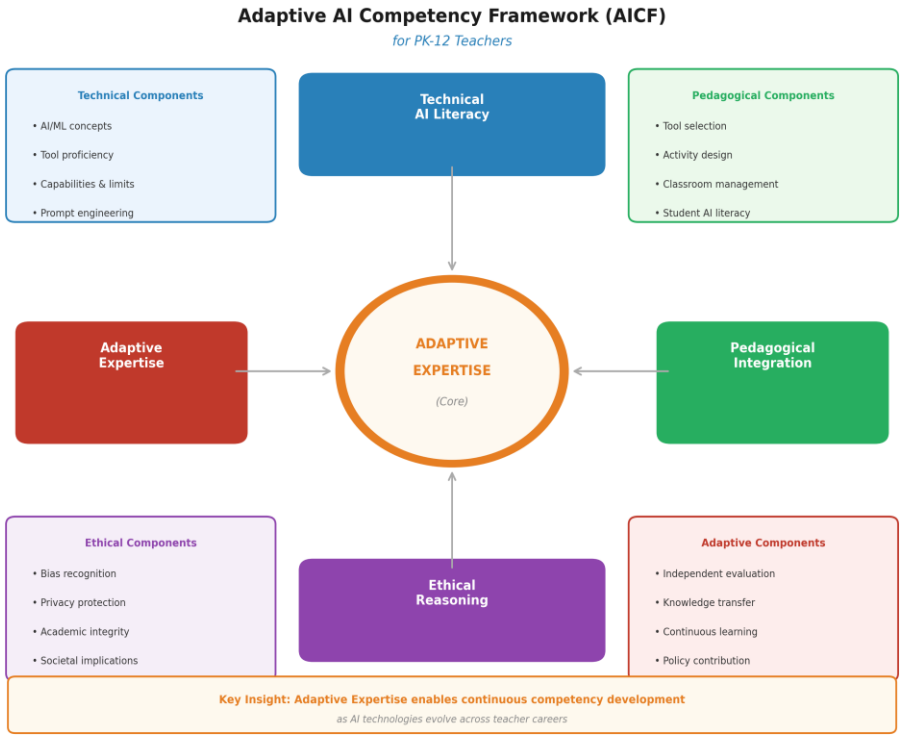

Table 2
Study-level evidence base of the 31 included studies (author/year, country, level, sample, design, framework, MMAT)

Study (first author, year)	Country	Level	N	Design	Framework	MMAT
Shankar et al., 2025	India/intl	In-service	1078	Survey	GenAI integration	Medium
Aji et al., 2026	Indonesia	In-service	725	Survey	AI-TPACK	High
An et al., 2026	China	In-service	243	Scale validation	AI-TPACK	High
Yu et al., 2025	USA	Pre-service (ECE)	—	Qual. case study	Computational thinking/AI	Medium
Zhao, 2026	China	Pre-service	423	Survey/SEM	AI literacy→TPACK	High
Wu et al., 2026	China	Pre-service (math)	180	Instrument+LPA	AI-TPACK	High
Fan et al., 2025	Taiwan	In/Pre-service (elem.)	59	Quasi-experimental	AI-PACK	Medium
Milutinović et al., 2025	Serbia	Pre-service	228	Survey/SEM	Intelligent ethical TPACK	High

Xu et al., 2025	China	Pre-service (TCSL)	520	Scale validation	AI-TPACK	High
Kohnke et al., 2025	Hong Kong	Pre-service (ELT)	19	Qual. case study	GenAI competence	Medium
Hu et al., 2025	China	In-service	—	Survey/SEM	Teacher–AI collaboration	Medium
Karataş & Aksu Ataç, 2025	Türkiye	Pre-service (ELT)	304	Survey/SEM	TPACK/AI-TPACK	High
Chai et al., 2024	China	In-service	364	Survey/SEM	Intention to teach AI	High
Segaran & Moltudal, 2025	Norway	In-service	—	Qual. descriptive	Design thinking/AI	Medium
Aimicheva et al., 2025	Kazakhstan	In-service (sec.)	916	Survey (pre/post)	Digital competence in AI	Medium
Ning et al., 2024	China	In-service	—	Survey/SEM	AI-TPACK	Medium
Guo & Xie, 2026	China	Pre-service	200	Survey/SEM	AI literacy (UTAUT)	Medium
Setiyawan et al., 2025	Indonesia	Pre/in-service (voc.)	460	Scale validation	AI-TPACK	High
Reyes-Rojas et al., 2026	Chile	Pre-service	366	Scale dev.	AI readiness	High
Ocak & Caskurlu, 2026	USA	In-service	—	Qual./mixed	Intelligent-TPACK (ethics)	Medium
Celik, 2023	Finland	In-service	428	Survey/SEM	Intelligent-TPACK	High
Li & Liang, 2025	China	In-service (CFL)	353	Scale dev.	AI readiness	High
Sun et al., 2024	China	Pre-service (STEM)	239	Survey/SEM	TPACK/TAM	High
Erol et al., 2025	Türkiye	In-service (presch./prim.)	524	Survey/SEM	AI-TPACK	High
Kaya et al., 2025	Türkiye	In-service	323	Survey/PLS-SEM	AI-TPACK	High
Luo & Zou, 2025	China	Pre/in-service (K-12)	288	Scale dev.	ETCDL	High
Zou et al., 2025	Hong Kong	Educators	—	Conceptual	Pedagogic AI competence	—
ElSayary, 2023	UAE	In-service (mid/high)	40	Mixed methods	TPACK	Medium
Bai et al., 2025	China	In-service (rural)	642	Survey	AI teaching ability	Medium
Li et al., 2025	China	In-service (voc.)	795	Survey	AI-TPACK	Medium
Schreiner & Dittrich, 2026	Austria	Pre-service	45	Pre-post mixed methods	AI competencies (PD)	High

Note. Dashes (—) indicate samples reported only within source tables or, for the conceptual contribution, no empirical sample. Full extraction fields, item-level MMAT, and complete reference details are provided in the supplementary file (S3_Included_Studies_MMAT). Bracketed entries indicate studies whose complete author lists must be finalised in the reference list before resubmission.