FROM AI LITERACY TO RESPONSIBLE CLASSROOM INTEGRATION: A SYSTEMATIC REVIEW OF TEACHERS' PEDAGOGICAL AND ETHICAL COMPETENCE

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Abstract

The rapid integration of artificial intelligence into education has intensified the need for teachers who can use AI not only proficiently but also pedagogically and ethically. However, the evidence remains fragmented across overlapping constructs, measurement approaches, teacher populations, and adoption outcomes. This systematic review examined how AI literacy and AI competence are conceptualized and operationalized among pre-service and in-service teachers, how these capacities relate to pedagogical and ethical competence, and which factors facilitate or hinder responsible AI integration. Following PRISMA 2020, the review synthesized 51 empirical studies identified through Scopus. Qualitative content analysis and descriptive mapping were used to examine construct definitions and operationalization, narrative relationship synthesis was applied to analyse associations with pedagogical and ethical competence, and thematic synthesis was conducted to identify facilitators and barriers. The findings show that teachers' AI literacy and competence are multidimensional constructs comprising AI knowledge, technical application, critical evaluation, pedagogical integration, ethical and responsible use, and reflective professional judgement. AI literacy generally functions as a foundational capacity, whereas AI competence represents the professional ability to translate this foundation into instructional design, assessment, classroom integration, and ethical decision-making. Stronger AI literacy was consistently associated with more developed pedagogical and ethical competence, although this relationship was frequently mediated or conditioned by TPACK, self-efficacy, attitudes, professional development, and institutional support. Professional development emerged as the most consistent facilitator, while anxiety, weak pedagogical alignment, unreliable technology, insufficient infrastructure, workload, and unclear policy constrained adoption. The review proposes an integrated evidence architecture in which AI literacy supports pedagogical and ethical competence, which subsequently shapes readiness, intention, ability, and responsible classroom integration. These findings provide a theoretical and practical basis for teacher education, professional development, institutional governance, and future measurement research.

Keywords : Teacher AI literacy; AI competence; pedagogical integration; ethical competence; responsible AI adoption

1. Introduction

The rapid expansion of artificial intelligence (AI) in education is reshaping instructional design, assessment, feedback, content creation, and access to knowledge, thereby requiring teachers to develop new professional capacities for critically and responsibly engaging with AI-enabled technologies. AI systems can support personalized learning, automate routine instructional tasks, generate teaching materials, and provide immediate feedback, yet their outputs may also contain factual inaccuracies, embedded biases, and pedagogically inappropriate recommendations (Kasneci et al., 2023). Earlier reviews of AI applications in education found that research concentrated heavily on technological systems and student-facing applications, whereas teachers' professional roles and pedagogical expertise received comparatively limited attention (Buils et al., 2022). This imbalance has become increasingly consequential because the educational value of AI does not arise automatically from the availability or sophistication of the technology. Instead, its value depends on teachers' capacity to judge when, why, and how AI should support particular learners, curricular objectives, and instructional contexts (Celik, 2023).

Teachers occupy a pivotal position in educational AI adoption because they mediate between technological affordances and the social, disciplinary, and pedagogical realities of classroom practice. Effective integration requires more than the operational ability to access an AI platform; teachers must evaluate the relevance, accuracy, limitations, and educational consequences of AI-generated outputs before embedding them in instruction (Celik, 2023). Evidence from pre-service teacher education similarly indicates that positive perceptions of AI do not necessarily correspond to a sophisticated understanding of AI mechanisms or an ability to apply them pedagogically (Pei et al., 2025). Teachers must therefore act simultaneously as technology users, instructional designers, critical evaluators, ethical decision-makers, and guides for students' engagement with AI. These responsibilities position teacher competence as a central condition for transforming AI from a convenient content-generation tool into a meaningful and educationally defensible resource (Chiu et al., 2025).

Within this changing professional landscape, AI literacy and AI competence have emerged as multidimensional but partially overlapping constructs. Long & Magerko (2020) conceptualized AI literacy as a set of competencies that enables individuals to use, communicate with, and critically evaluate AI technologies, while Ng et al., (2021) organized AI literacy around understanding, application, evaluation and creation, and ethical considerations. These perspectives move beyond narrow technical knowledge by recognizing that meaningful engagement with AI also requires critical judgement and awareness of its social consequences (Ng et al., 2021). Teacher-focused competence models extend this conceptualization by incorporating AI pedagogy, assessment, human-centered education, professional engagement, and ethical responsibility (Chiu et al., 2025). However, studies continue to use related terms such as *AI literacy*, *AI competence*, *GenAI competence*, *AI readiness*, and *AI self-efficacy* with different theoretical boundaries and measurement dimensions (Shi, 2025). Such conceptual variation makes it difficult to determine whether existing instruments assess equivalent capabilities or merely attach different labels to partially connected constructs.

Teachers' AI literacy becomes educationally consequential when it supports pedagogical judgement rather than remaining detached knowledge about technological functions. The technological pedagogical content knowledge framework established that effective technology integration depends on the interaction of technological, pedagogical, and content knowledge rather than on technological expertise alone (Mishra & Koehler, 2006). Building on this premise, Intelligent-TPACK incorporates AI-specific knowledge and ethical assessment into teachers' professional knowledge for instructional decision-making (Celik, 2023). Empirical evidence suggests that technological knowledge alone does not guarantee effective educational integration; teachers must connect their understanding of AI with learning objectives, subject content, teaching strategies, assessment practices, and student characteristics (Celik, 2023). Recent intervention research supports this relationship, showing that sustained professional development grounded in Intelligent-TPACK can significantly strengthen teachers' AI technological and technological-pedagogical knowledge (Tan et al., 2025). Accordingly, pedagogical AI competence involves selecting appropriate tools, designing AI-supported activities, evaluating generated resources, and preserving the teacher's role in guiding learning.

Alongside pedagogical capability, responsible AI integration requires teachers to address ethical concerns involving bias, fairness, privacy, transparency, accountability, academic integrity, data protection, and human oversight. Generative AI systems may produce plausible but inaccurate content, reproduce social stereotypes, conceal the origins of generated information, or encourage uncritical reliance on automated outputs (Kasneci et al., 2023). Teachers therefore need the knowledge and judgement to verify AI-generated information, protect student data, explain system limitations, and determine when human intervention must override automated recommendations (Celik, 2023). Ethical competence should not be treated as an optional addition that follows technical training because ethical decisions are embedded in the selection, adaptation, and classroom use of AI tools. Tagare et al. (2025) showed that ethics-driven AI literacy requires an integrated configuration of knowledge, skills, and dispositions that enables teachers to recognize potential harm and design equitable, inclusive, and accountable learning practices. Pedagogical effectiveness and ethical responsibility must consequently be understood as interdependent dimensions of teachers' professional AI competence.

Teachers' readiness, intention, and ability to adopt AI are also shaped by interacting individual, pedagogical, technological, ethical, institutional, and professional-development conditions rather than by AI knowledge alone. Studies based on technology-acceptance models identify perceived usefulness, perceived ease of use, confidence, anxiety, social influence, and prior experience as relevant determinants of teachers' behavioural intentions (Ayanwale et al., 2022; Zhang et al., 2023). Among pre-service teachers, perceived usefulness and ease of use significantly predict intention to use AI, while anxiety and enjoyment may vary across demographic groups (Zhang et al., 2023). Teacher readiness has also been operationalized through technological self-efficacy, interaction with students, and ethical awareness, illustrating that readiness combines technical, interpersonal, and normative capacities (Ramazanoglu & Akin, 2025). More recent evidence indicates that AI literacy, perceived usefulness, Intelligent Ethical TPACK, motivational variables, and willingness to use AI are associated with teachers' perceived competence and adoption-related outcomes (Deshen et al., 2026; Milutinović, 2025). Institutional support, training relevance, time, infrastructure, and policy guidance may therefore determine whether individual literacy translates into sustained classroom practice.

The rapid advancement of artificial intelligence in education fundamentally transforms teaching practices, with generative AI tools and adaptive learning systems presenting both opportunities and challenges for classroom instruction. This shift necessitates re-examining teachers' competencies, particularly the gap between basic AI literacy and responsible pedagogical integration. AI literacy broadens digital competence into a holistic framework encompassing technical skills, critical evaluation, and data privacy awareness. Ethical responsibility becomes central in navigating fairness, transparency, student welfare, and academic integrity within AI-mediated instruction, addressing risks of algorithmic bias, data protection concerns, and diminished critical thinking. The imperatives of prohibiting uncritical AI adoption, safeguarding student privacy, and preserving teacher professional judgment reflect concerns for educational sustainability and humanistic values. This systematic review synthesises evidence on teachers' pedagogical and ethical competence, bridging technological literacy with universal educational values to illuminate the pathway from foundational AI literacy to principled classroom practice (Rusdi et al, 2024).

The state of the art shows that research on teachers' AI literacy has progressed from broad discussions of AI-related knowledge toward multidimensional, empirically operationalized competence models. Early systematic evidence primarily mapped AI-literacy curricula, learning activities, and assessment in K–12 education, while teacher education remained comparatively underrepresented and teachers' professional knowledge was frequently framed through technical or computer-science-oriented perspectives (Casal-Otero et al., 2023; Sperling et al., 2024). More recent reviews have identified the ethical knowledge, skills, and dispositions required for K–12 AI-literacy instruction and synthesized teachers' pedagogical uses of ChatGPT within specialized domains such as English language teaching (Tagare et al., 2025; Xodabande, 2026). Concurrently, empirical research has diversified to include instrument development, cross-sectional surveys, structural equation modelling, mixed-methods research, and quasi-experimental professional-development interventions. Available instruments now represent teacher AI capacity through varying combinations of technological self-efficacy, pedagogical integration, student preparation, professional learning, ethical awareness, and risk evaluation (Chiu et al., 2025; Ramazanoglu & Akin, 2025; Shi, 2025). Structured training has also demonstrated the potential to improve teachers' technological and pedagogical AI knowledge, although the content, duration, and contextual grounding of such interventions remain uneven (Kushki et al., 2026; Tan et al., 2025).

Despite this progress, the evidence base remains fragmented across constructs, measurements, teacher populations, educational settings, and analytical purposes. Existing reviews examine AI literacy broadly in K–12 education, conceptualizations of AI literacy in teacher education, ethical competence for AI-literacy instruction, or teachers' use of a specific generative AI tool, but they do not integrate the complete empirical pathway connecting conceptualization and measurement with pedagogical ethical competence and responsible adoption among both pre-service and in-service teachers (Casal-Otero et al., 2023; Sperling et al., 2024; Tagare et al., 2025; Xodabande, 2026). The present systematic literature review addresses this scope, construct-measurement, and evidence-chain gap by examining how AI literacy and competence are conceptualized and operationalized, how these capacities relate to teachers' pedagogical and ethical competence, and which factors facilitate or hinder responsible AI integration. Its theoretical novelty lies in positioning AI literacy as a foundational capacity that connects technical understanding with pedagogical judgement, ethical responsibility, and adoption behaviour rather than treating literacy, competence, readiness, and acceptance as isolated constructs. Methodologically, the review integrates definitions, dimensions, instruments, relationship patterns, and multilevel facilitators and barriers across quantitative, qualitative, and mixed-methods evidence. Practically, it aims to produce an evidence-based taxonomy and conceptual framework to inform teacher-education curricula, professional-development programmes, institutional policies, and future instrument development.

2. Methods

2.1 Review Design and Reporting Framework

This study employed a systematic review design to identify, appraise, and synthesize empirical evidence on artificial intelligence literacy and competence among pre-service and in-service teachers. The review specifically examined how teachers' AI literacy and competence have been conceptualized and operationalized, how these constructs relate to pedagogical and ethical competence, and which factors facilitate or constrain the responsible adoption and integration of AI in educational practice.

The review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 statement (Hoque et al., 2022; Malapane et al., 2022). PRISMA 2020 was used to structure the identification, screening, eligibility assessment, and inclusion of studies and to ensure transparent reporting of the review process. Because the eligible literature was expected to include quantitative, qualitative, mixed-methods, intervention, instrument-development, and design-based studies, the review employed a heterogeneous evidence-synthesis strategy. The synthesis combined qualitative content analysis, descriptive mapping, narrative relationship synthesis, and thematic synthesis rather than statistical meta-analysis. The protocol was developed before the final screening and synthesis stages to establish the research questions, eligibility criteria, data-extraction categories, methodological appraisal procedures, and synthesis strategies.

2.2 Research Questions

The review was guided by three research questions that represented a sequential evidence pathway from conceptualization and measurement to professional competence and responsible classroom adoption.

Table 1. Research questions and analytical focus

Research question	Analytical focus
RQ1. How are AI literacy and AI competence conceptualized and operationalized among pre-service and in-service teachers in empirical studies?	Definitions, theoretical frameworks, dimensions, indicators, instruments, and qualitative operationalizations of AI literacy and AI competence
RQ2. How do AI literacy and AI competence relate to teachers' pedagogical and ethical competence in the adoption and integration of AI into educational practices?	Direction, form, consistency, and mechanisms of relationships between AI literacy or competence and pedagogical or ethical competence
RQ3. What factors facilitate or hinder teachers' readiness, intention, and ability to adopt and integrate AI responsibly into teaching practices?	Individual, pedagogical, ethical, technological, institutional, and professional-development facilitators and barriers

Together, the research questions were intended to determine whether AI literacy functions merely as technical knowledge or constitutes a broader professional capacity that underpins pedagogical judgement, ethical responsibility, and responsible AI integration.

2.3 Information Source and Search Strategy

A systematic literature search was conducted in Scopus from database inception to July 11, 2026. No lower publication-year boundary was imposed because empirical research on teachers' AI literacy and competence constitutes a relatively recent and rapidly developing field. The search was limited to publications with a final publication status. The Scopus open-access option was set to "all," meaning that open-access status did not operate as an eligibility restriction.

The search strategy combined four principal concept blocks. The first block represented AI literacy and AI competence; the second identified teacher populations; the third covered pedagogical and ethical competence; and the fourth represented AI adoption, readiness, implementation, and educational integration. Synonyms, spelling variants, quotation marks, truncation, and Boolean operators were used to improve retrieval sensitivity and precision. Terms associated with secondary reviews, meta-analyses, and bibliometric studies were excluded because the review focused on primary empirical evidence.

The following query was executed in Scopus:

(("AI literacy" OR "artificial intelligence literacy" OR "AI competence" OR "AI competency" OR "artificial intelligence competence" OR "artificial intelligence competency") AND (teacher OR "pre-service teacher*" OR "preservice teacher*" OR "in-service teacher*" OR "inservice teacher*" OR "student*

teacher") AND (("pedagogical competence" OR "pedagogical competency" OR "pedagogical integration" OR TPACK OR "AI-TPACK" OR "ethical competence" OR "ethical competency" OR "ethical awareness" OR "responsible AI") AND (adoption OR integration OR implementation OR readiness OR "intention to use" OR "educational practice*" OR "teaching practice*"))) AND NOT ("systematic review" OR "systematic literature review" OR "meta-analysis" OR "meta analysis" OR bibliometric*)*

2.4 Eligibility Criteria

Eligibility criteria were defined according to study design, population, focal constructs, educational relevance, publication characteristics, and contribution to the research questions. Studies were required to provide sufficient methodological and empirical information to permit eligibility assessment, data extraction, and quality appraisal.

Table 2. Eligibility criteria

Domain	Inclusion criteria	Exclusion criteria
Study type	Primary empirical studies using quantitative, qualitative, mixed-methods, intervention, survey, case-study, observational, document-analysis, design-based, instrument-development, or instrument-validation designs	Systematic, scoping, narrative, critical, or rapid reviews; meta-analyses; bibliometric or scientometric studies; protocols; editorials; commentaries; perspectives; conceptual papers; position papers; and theoretical papers without empirical data
Population	Pre-service teachers, in-service teachers, student teachers, teacher educators, and higher education educators who perform a substantive teaching role	Studies involving only school students, non-education university students, administrators, school leaders, librarians, technology developers, or the general public, unless teacher-specific results were reported separately
Core construct	Explicit investigation, measurement, development, or operationalization of AI literacy, artificial intelligence literacy, AI competence, AI competency, GenAI literacy, GenAI competence, or clearly specified teacher competence related to AI use	General digital literacy, ICT competence, digital competence, or technology integration without explicit AI-related constructs, indicators, findings, or interpretation
Pedagogical relevance	Lesson planning, instructional design, classroom integration, assessment, feedback, differentiation, content creation, TPACK, AI-TPACK, Intelligent-TPACK, or critical evaluation of AI-generated outputs	Technical development of algorithms, chatbots, machine-learning systems, applications, or learning analytics without examining teachers' pedagogical competence or decisions
Ethical relevance	Ethical awareness, responsible AI use, bias, fairness, privacy, transparency, accountability, academic integrity, data protection, safety, or human oversight	General perceptions of AI that were not connected to ethical competence, literacy, readiness, use, or educational integration
Adoption relevance	Readiness, acceptance, intention to use, actual use, implementation, pedagogical integration, AI-assisted teaching practices, or facilitators and barriers to adoption	Studies in which AI was used only as a research, analytical, automated assessment, or content-delivery tool and teachers' AI literacy, competence, readiness, or practice was not examined
Educational context	Formal education, teacher education, professional development, or teaching practice in primary, secondary, vocational, or higher education	Studies outside an educational or teacher-development context
Contribution to the review	Data capable of answering at least one research question	Studies that did not provide relevant evidence for any research question
Publication type	Peer-reviewed journal articles and full conference papers reporting adequate empirical methods, participant information, analyses, and findings	Abstract-only records, posters, extended abstracts, presentations, workshop descriptions, panel proposals, and brief reports lacking sufficient empirical detail

Publication status and access	Final publications for which the full text could be obtained	In-press records without final content, unavailable full texts, or publications containing insufficient information for eligibility assessment
Language	Publications written in English or accompanied by a complete English-language version	Publications for which no complete English-language text was available
Mixed populations	Studies reporting teacher, pre-service teacher, or teacher-educator findings separately	Studies in which relevant educator data could not be separated from data concerning students or other populations

Instrument-development and validation studies were eligible when they operationalized AI literacy or AI competence among relevant teacher populations and reported sufficient evidence regarding construct definition, dimensionality, item development, validity, or reliability. Studies proposing a competence model or framework without empirical testing were excluded.

Studies reporting only general attitudes toward AI were included only when those attitudes were analytically connected to AI literacy, competence, readiness, intention, pedagogical integration, ethical awareness, or responsible use. This distinction prevented the evidence base from being diluted by studies in which AI was merely discussed as a broad educational trend.

2.5 Study Selection

The Scopus search identified 133 records. No duplicates or records outside the 2015–2026 publication period were removed before screening. Following title-and-abstract screening, 54 records were excluded, and 79 reports were sought for retrieval. Nineteen reports were excluded because they did not address the science-education context. The remaining 60 full-text reports were assessed for eligibility, of which nine were excluded because they were not journal articles (n = 4) or were outside the social-science domain (n = 5). Consequently, 51 studies met the eligibility criteria and were included in the final synthesis. The selection process is presented in the PRISMA 2020 flow diagram.

2.6 Data Extraction and Management

A standardized data-extraction form was developed before full extraction to ensure consistency across heterogeneous study designs. The form was aligned with the research questions and captured bibliographic details, study context, participant characteristics, methodological features, construct definitions, measurement approaches, pedagogical and ethical outcomes, adoption factors, and principal findings.

The extraction form was tested using the review of the titles and abstracts of the studies included by the authors. After the trial, the category descriptions and decision rules were revised if necessary. Data is independently extracted by the writing and compared for consistency. Differences are resolved through discussion, referencing complete publications. The extracted information is managed in Microsoft Excel.

Table 3. Data-extraction framework

Extraction component	Information recorded	Primary analytical purpose
Author and publication year	Surname of the first author and publication year	Study identification and chronological mapping
Country and educational context	Country, education system, institutional setting, teacher-education setting, professional-development context, or teaching level	Contextual and geographical comparison
Participant characteristics	Participant group, sample size, educational level, subject area, professional status, and distinction between pre-service, in-service, student teachers, and teacher educators	Population comparison
Research design and data collection	Study design, sampling strategy, survey, interview, focus group, observation, intervention, document analysis, or mixed-methods procedures	Methodological mapping and quality appraisal
Conceptualization of AI literacy or competence	Explicit definition, theoretical source, framework, or implicit meaning derived from indicators and measures	Response to RQ1
Dimensions and indicators	Technical, cognitive, critical, ethical, pedagogical, data-related, communicative, reflective, or other dimensions reported by the study	Development of the conceptual taxonomy

Instrument or operationalization	Instrument name, source, item number, response format, dimensional structure, reliability, validity, or qualitative operationalization	Comparison of measurement practices
Pedagogical and ethical competence	Lesson planning, instructional design, assessment, feedback, classroom integration, TPACK-related competence, bias awareness, privacy, fairness, transparency, integrity, accountability, and human oversight	Response to RQ2
Adoption facilitators and barriers	Individual, pedagogical, ethical, technological, institutional, and professional-development factors, including their direction as facilitator, barrier, or mixed	Response to RQ3
Main findings relevant to the RQs	Statistical relationships, group differences, themes, explanatory mechanisms, intervention findings, and context-dependent patterns	Evidence synthesis

When studies did not provide an explicit definition of AI literacy or competence, the construct was interpreted cautiously from the dimensions, indicators, measurement items, interview domains, or activities used by the original authors. Such cases were labelled "not explicitly defined" to distinguish researcher interpretation from an author-provided definition.

For quantitative findings, effect directions, correlation coefficients, regression coefficients, standardized coefficients, p-values, confidence intervals, mediation effects, moderation effects, and structural-equation-model estimates were extracted when available. For qualitative studies, the extraction focused on themes, participant experiences, explanatory mechanisms, and interpretations directly relevant to the research questions.

2.7 Methodological Quality Appraisal

The methodological quality of all included empirical studies was assessed using the Mixed Methods Appraisal Tool 2018 (MMAT 2018), which supports the appraisal of qualitative, randomized quantitative, nonrandomized quantitative, quantitative descriptive, and mixed-methods designs (Hong et al., 2018). Each study was first examined using the two MMAT screening questions and subsequently evaluated against the five criteria corresponding to its methodological category. Following MMAT guidance, appraisal results were reported at the criterion level rather than converted into an overall numerical score, thereby preserving the visibility of design-specific strengths and limitations (Hong et al., 2018).

Studies primarily concerned with the development, adaptation, or validation of instruments measuring AI literacy, AI competence, AI readiness, or related constructs were additionally appraised using an adapted COSMIN Risk of Bias Checklist (Mokkink et al., 2024). The appraisal covered only the measurement properties reported in each study, including content validity, structural validity, internal consistency, reliability, measurement invariance, and construct validity. Each applicable property was rated as very good, adequate, doubtful, or inadequate according to the COSMIN worst-score-counts principle, while unreported properties were recorded as not applicable rather than treated as methodological deficiencies (Mokkink et al., 2018).

Two reviewers independently completed the quality appraisal using standardized forms, and disagreements were resolved through discussion and consensus, with a third reviewer consulted when necessary. No study was excluded solely on the basis of its quality rating because the appraisal was intended to inform evidence interpretation rather than serve as an additional eligibility criterion. Instead, studies with stronger methodological support received greater interpretive weight during the synthesis, whereas findings from studies with substantial limitations were retained but interpreted cautiously. Quality ratings were therefore used to identify recurrent methodological weaknesses, assess confidence in emerging evidence patterns, and distinguish robust conclusions from claims supported by weaker designs or insufficiently validated measures. This procedure aligns with the methodological framework established in the SLR protocol.

2.8 Data Synthesis

Statistical meta-analysis was not undertaken because substantial heterogeneity was anticipated across construct definitions, measurement instruments, teacher populations, research designs, educational contexts, technologies, and reported outcomes. Combining such evidence into a single pooled effect could create a misleading impression of conceptual and methodological equivalence. The review therefore employed synthesis methods tailored to each research question.

The overall synthesis proceeded iteratively. Original terminology was retained during initial extraction and coding to preserve conceptual fidelity. Semantically similar terms were subsequently compared and consolidated into higher-order analytical categories. Category definitions were revised through repeated comparison with the primary studies. Frequency counts were used to describe how often particular dimensions, relationships, facilitators, or barriers appeared across studies, but frequency was not interpreted as evidence of effect size, causal strength, or methodological quality.

Table 4. Alignment between research questions and synthesis strategies

Research question	Primary synthesis method	Main units of analysis	Intended output
RQ1	Qualitative content analysis and descriptive mapping	Definitions, frameworks, dimensions, indicators, instruments, and operationalization procedures	Conceptual taxonomy and instrument map of teachers' AI literacy and competence
RQ2	Narrative relationship synthesis	Quantitative associations, qualitative mechanisms, pedagogical outcomes, and ethical outcomes	Relationship matrix and empirically derived conceptual model
RQ3	Thematic synthesis using deductive and inductive coding	Facilitators, barriers, context-dependent conditions, and multilevel influences	Facilitator–barrier matrix and multilevel adoption framework

2.9 Synthesis of Conceptualizations and Operationalizations

RQ1 was addressed through qualitative content analysis combined with descriptive mapping. The analysis began by identifying explicit definitions of AI literacy, AI competence, GenAI literacy, GenAI competence, and related teacher-AI constructs. Each definition was recorded together with its theoretical source, intended scope, participant population, and educational context. When an explicit definition was absent, the underlying conceptualization was inferred from the indicators, measurement items, interview questions, learning activities, or outcomes used in the study.

Definitions were compared to identify conceptual convergence and divergence. Initial codes preserved the terms used by the original authors. Through constant comparison, semantically related concepts were grouped into broader categories, such as AI knowledge and understanding, technical use, critical evaluation of AI-generated content, pedagogical application, ethical awareness, data literacy, human–AI communication or collaboration, reflective competence, and professional decision-making. The categories remained open to revision when the evidence revealed dimensions not represented in the preliminary coding structure.

Dimensions and indicators were analysed in the same manner. For example, terms such as "critical evaluation," "evaluation of AI outputs," and "assessment of AI-generated content" could be grouped under a broader critical-evaluation category when their meanings and operational boundaries were sufficiently similar. Differences were retained when apparently similar terms represented substantively distinct capabilities.

Measurement instruments were descriptively mapped according to instrument name, theoretical origin, target population, number of dimensions, number of items, response scale, validation procedures, reliability evidence, and whether the instrument was adapted, newly developed, or previously established. Qualitative operationalizations were mapped according to the interview, observation, document-analysis, or intervention procedures through which AI literacy or competence was explored.

Cross-study comparisons examined whether conceptualization and measurement varied between pre-service and in-service teachers, educational levels, geographical contexts, subject areas, and research designs. The final synthesis was used to develop an empirically grounded conceptual taxonomy of teachers' AI literacy and competence rather than imposing a predetermined model on the evidence.

2.10 Synthesis of Relationships with Pedagogical and Ethical Competence

RQ2 was examined using narrative relationship synthesis. The purpose was to identify the direction, consistency, conditions, and explanatory mechanisms of relationships between AI literacy or competence and teachers' pedagogical and ethical competence. Because the included studies were expected to employ heterogeneous measures and analytical designs, statistical estimates were not pooled.

For quantitative studies, relationships were coded as positive, negative, nonsignificant, indirect, mediated, moderated, or conditional. Relevant statistical information, including correlation coefficients, regression coefficients, standardized beta values, p-values, confidence intervals, structural-equation-model estimates, and mediation or moderation effects, was retained to support interpretation. These values were used to compare direction and consistency across studies rather than to calculate a combined effect.

For qualitative and mixed-methods studies, relationships were synthesized from themes, participant explanations, reported practices, experiences, and mechanisms. Particular attention was given to how AI knowledge and competence enabled or constrained the selection of AI tools, evaluation of output accuracy, lesson planning, instructional design, classroom integration, assessment, feedback, differentiation, academic integrity, privacy protection, bias recognition, transparency, accountability, and human oversight.

Pedagogical competence was organized into categories such as lesson planning, instructional design, classroom integration, assessment, feedback, differentiation, content creation, TPACK or AI-TPACK, and evaluation of AI-generated content. Ethical competence was organized around bias awareness, fairness, privacy, transparency, accountability, academic integrity, data protection, responsible use, and human oversight. These categories were refined when the included evidence indicated different or additional competence domains.

A relationship matrix was developed to connect specific dimensions of AI literacy or competence with the pedagogical and ethical outcomes reported in each study. Comparisons were then conducted across teacher status, educational context, AI technology, study design, and methodological quality. The resulting conceptual relationship model was developed after the evidence had been synthesized and was not treated as a predetermined causal framework.

2.11 Synthesis of Facilitators and Barriers

RQ3 was addressed through thematic synthesis combining deductive and inductive coding. Each facilitator or barrier was initially coded using the terminology of the original study and classified according to its reported direction as a facilitator, barrier, or mixed and context-dependent factor.

The initial deductive framework included individual, pedagogical, ethical, technological, institutional, and professional-development factors. Individual factors included AI literacy, self-efficacy, confidence, anxiety, previous experience, perceived usefulness, perceived ease of use, motivation, attitude, and willingness to experiment. Pedagogical factors included pedagogical knowledge, alignment with learning objectives, assessment competence, classroom management, educational relevance, and the capacity to evaluate AI-generated content.

Ethical factors included concerns or competencies related to bias, privacy, academic integrity, misinformation, transparency, accountability, data protection, responsible use, and overdependence on AI. Technological factors included access, usability, system reliability, output quality, infrastructure, internet connectivity, technical support, and data security. Institutional factors included leadership, policy, infrastructure, organizational culture, curriculum expectations, workload, time, funding, and available resources. Professional-development factors included access to training, training relevance, practical experience, peer collaboration, mentoring, and continuing professional learning.

These categories functioned as provisional analytical domains rather than fixed classifications. Factors that did not fit the initial framework were incorporated inductively, and category boundaries were revised in response to the data. When a factor operated as a facilitator in one context and as a barrier in another, it was coded as mixed, and the contextual conditions associated with the change in direction were examined.

Frequency mapping was used to indicate the number of studies reporting each factor. These frequencies were interpreted as indicators of thematic prevalence rather than as measures of causal importance or effect strength. The synthesis also examined differences between pre-service and in-service teachers and between educational and national contexts. Particular attention was given to interactions between individual capacity and institutional conditions, such as whether high AI self-efficacy translated into classroom adoption when teachers lacked time, infrastructure, policy guidance, or pedagogically relevant professional development.

The final synthesis was used to construct a multilevel framework explaining how individual, instructional, ethical, technological, institutional, and contextual conditions influence teachers' readiness, intention, ability, and responsible integration of AI.

2.12 Integration and Interpretation of Evidence

Findings from the three research questions were integrated after the separate synthesis stages. Integration involved comparing the conceptual and measurement patterns identified in RQ1 with the competence relationships identified in RQ2 and the adoption conditions identified in RQ3. The review examined whether AI literacy dimensions that were frequently included in definitions and instruments also appeared as meaningful predictors or explanatory mechanisms of pedagogical competence, ethical competence, readiness, and AI adoption.

The integration further examined whether the evidence supported a sequential relationship in which AI literacy and competence provide a foundation for pedagogical and ethical judgement, which subsequently influences responsible AI readiness, adoption, and classroom integration. This pathway was treated as an empirically testable synthesis proposition rather than an assumed causal sequence. Relationships were incorporated into the final model only when supported by patterns across the included studies.

Methodological quality, design type, population, and context were considered during interpretation. Greater interpretive weight was assigned to findings supported by multiple studies, stronger methodological designs, validated measures, and evidence from different contexts. Isolated findings, inconsistent relationships, and conclusions derived from methodologically limited studies were explicitly identified as tentative.

3. Results and Discussion

3.1 Results

A. Study Selection

The database search and subsequent screening process resulted in 51 empirical studies that met all predefined eligibility criteria and were included in the final synthesis. The complete process of study identification, duplicate removal, title-and-abstract screening, full-text eligibility assessment, and final inclusion, together with the reasons for full-text exclusion, is presented in Figure 1.

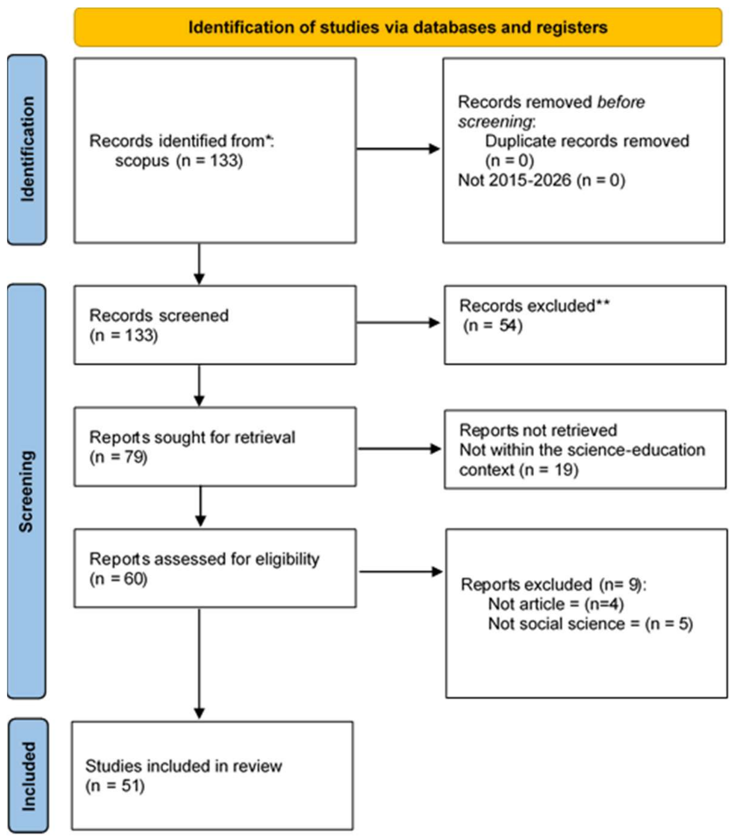

Figure 1. PRISMA 2020 flow diagram of study identification, screening, eligibility assessment, and inclusion

B. Characteristics of the Included Studies

The 51 studies were published between 2023 and 2026, indicating that research on teachers' AI literacy and competence represents a recent and rapidly expanding field. Only one study was published in 2023 and four in 2024, whereas 18 studies appeared in 2025 and 28 in 2026. Thus, 90.2% of the included studies were published during the final two years of the review period.

The evidence base covered at least 32 explicitly identified national or territorial contexts. Forty-six studies were conducted within a single country or territory, while five involved participants from multiple countries. Asian contexts were particularly prominent, including China, Hong Kong, Indonesia, Israel, Kazakhstan, Nepal, the Philippines, Saudi Arabia, Singapore, South Korea, Thailand, Türkiye, Uzbekistan, and Vietnam. European, African, North American, and Latin American contexts were also represented, although less frequently.

In-service teachers and educators constituted the dominant population, accounting for 29 studies. Sixteen studies focused exclusively on pre-service teachers, four involved mixed teacher populations, and two examined teacher educators, experts, or framework-development participants. Reported sample sizes ranged from three pre-service teacher candidates in a multiple-case study to 11,818 pre-service teachers in a large-scale survey. Some studies analysed alternative units of evidence, including assessment artefacts, lesson plans, interview narratives, AI interaction logs, and expert validation cases.

Mixed-methods designs represented the most frequently used methodological category. Quantitative studies predominantly employed cross-sectional surveys, regression, structural equation modelling, mediation analysis, exploratory factor analysis, and confirmatory factor analysis. Qualitative studies used focus groups, interviews, narratives, document analysis, phenomenological inquiry, workshop observation, and analysis of AI-supported teaching artefacts. A smaller group of studies adopted intervention, quasi-experimental, instrument-development, or framework-validation designs.

Table 5. Characteristics of the included studies

Characteristic	Category	*n*	%
Publication year	2023	1	2.0
	2024	4	7.8
	2025	18	35.3
	2026	28	54.9
Population	In-service teachers or educators	29	56.9
	Pre-service teachers	16	31.4
	Mixed teacher populations	4	7.8
	Teacher educators, experts, or framework participants	2	3.9
Dominant research design	Mixed methods	20	39.2
	Qualitative	12	23.5
	Quantitative observational	11	21.6
	Instrument or framework development and validation	5	9.8
	Intervention or pre-experimental	3	5.9
Geographical scope	Single-country or single-territory study	46	90.2
	Multicountry study	5	9.8

Note. Studies were classified according to their dominant methodological design. Intervention and instrument-development studies may also have incorporated quantitative, qualitative, or mixed-methods components.

The concentration of publications in 2025 and 2026 illustrates the substantial acceleration of empirical research following the widespread educational availability of generative AI.

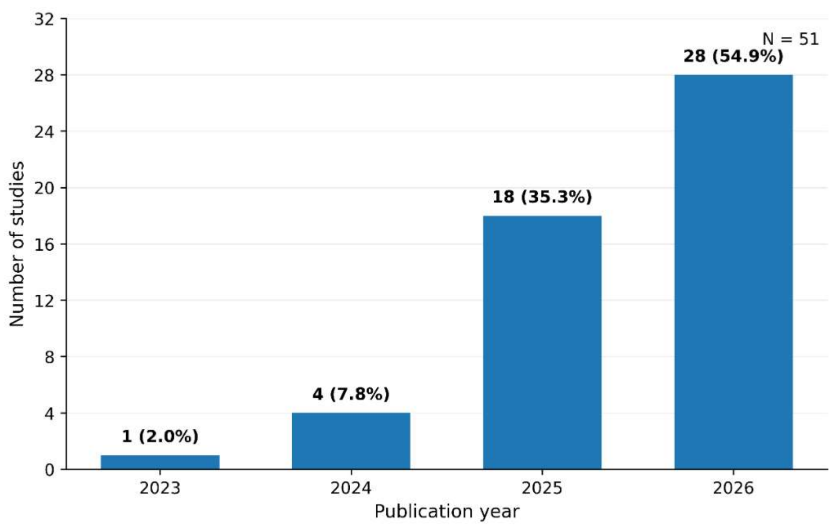

Figure 2. Annual distribution of the included studies published between 2023 and 2026

C. Conceptualization and Operationalization of Teachers' AI Literacy and AI Competence

1. Conceptual orientations

The synthesis identified broad agreement that teachers' AI literacy and AI competence extend beyond basic awareness of AI or the operational use of digital tools. Across the included studies, AI literacy was generally conceptualized as a foundational capacity to understand AI concepts and limitations, use AI systems, evaluate generated outputs, and engage with AI in ethically responsible ways. AI competence was more frequently framed as a practice-oriented professional capacity through which teachers translate AI-related knowledge into lesson planning, instructional design, assessment, classroom implementation, and professional decision-making.

Although this distinction appeared across the evidence base, the two terms were not consistently separated. Several studies labelled a construct as AI literacy while measuring pedagogical integration, readiness, or adoption behaviour. Conversely, some AI competence instruments incorporated foundational knowledge and awareness that other studies classified as AI literacy. Consequently, the boundary between literacy and competence remained permeable rather than categorical.

Six recurring domains emerged from the conceptual coding. Pedagogical integration was the most frequently represented domain, appearing in 45 studies, followed by AI knowledge and understanding in 37 studies and ethical and responsible use in 35 studies. Technical operation or application appeared in 25 studies. Reflective or professional judgement and critical evaluation appeared less frequently, although these domains became increasingly visible in recent studies examining AI-supported lesson planning, assessment design, bias detection, and teacher agency.

Table 6. Synthesized domains of teachers' AI literacy and AI competence

Synthesized domain	Representative indicators	Studies, *n*	%
Pedagogical integration	Lesson planning, instructional design, assessment, feedback, differentiation, curriculum alignment, classroom integration, TPACK, and AI-TPACK	45	88.2
AI knowledge and understanding	Understanding AI concepts, capabilities, limitations, applications, and underlying principles	37	72.5
Ethical and responsible use	Privacy, bias, transparency, fairness, accountability, academic integrity, data protection, and human oversight	35	68.6
Technical operation and application	Operating AI tools, prompt construction, generating materials, technological proficiency, and practical application	25	49.0
Reflective and professional judgement	Teacher agency, reflective thinking, AI mindset, metacognitive regulation, and professional decision-making	18	35.3
Critical evaluation	Assessing accuracy, detecting errors and bias, evaluating AI-generated content, and questioning recommendations	17	33.3

Note. Categories were non-exclusive because an individual study could address several competence domains. Percentages were calculated using the 51 included studies as the denominator.

Pedagogical integration therefore functioned as the principal feature differentiating general AI literacy from teacher-specific AI competence. While foundational literacy emphasized understanding and responsible interaction, professional competence required teachers to align AI with subject matter, learning objectives, student characteristics, assessment requirements, and classroom conditions.

Critical evaluation and reflective judgement were not as frequently formalized in measurement models as knowledge, pedagogy, and ethics. Nevertheless, qualitative and process-oriented studies showed that these capacities distinguished superficial tool use from deliberate professional practice. Abrahams (2026), for example, operationalized AI pedagogical judgement through teachers' decisions to accept, adapt, or reject AI-generated assessment content. Tran et al. (2026) similarly examined iterative cycles of prompting, reviewing, and refining as observable indicators of reflective AI competence.

2. Operationalization and measurement

Three principal operationalization approaches were identified. The first involved standardized or adapted Likert-type scales measuring AI literacy, AI competence, readiness, self-efficacy, or related constructs. These studies commonly used exploratory factor analysis, confirmatory factor analysis, regression, or structural equation modelling. The second approach adapted existing professional frameworks, particularly TPACK, Intelligent-TPACK, UNESCO competency frameworks, technology-acceptance models, digital competence frameworks, and social cognitive theory. The third operationalized competence through qualitative or performance-based evidence, including interviews, reflective narratives, lesson plans, assessment artefacts, classroom observations, task performance, and screen-recorded interactions with generative AI.

The instruments also differed considerably in their construct boundaries. Some measured general knowledge, application, evaluation, and ethics, whereas teacher-specific instruments incorporated pedagogical compatibility, student preparation, professional communication, assessment, subject-specific application, and risk management. Table 7 presents representative examples of the measurement approaches identified in the review.

Table 7. Representative instruments used to operationalize teachers' AI literacy and competence

Study	Instrument or operationalization	Structure	Reported psychometric or analytical evidence

Deshen et al. (2026)	AI Literacy Scale adapted from Wang et al. and aligned with the framework of Ng et al.	Knowing and understanding AI; using and applying AI; evaluating and creating with AI; AI ethics	Five-point response format; Cronbach's α = .95
Han et al. (2026)	Discipline-specific AI competence questionnaire	Five factors; 32 final items following expert review	Overall α = .972; KMO = .931; cumulative variance explained = 73.50%
Tukhtaeva et al. (2026)	AI Literacy Scale for English Language Teachers	Understanding AI in education; proficiency; pedagogical alignment; ethical awareness; AI for feedback and assessment; 28 final items	CFI = .949; TLI = .938; RMSEA = .032
Choudhury et al. (2026)	Artificial Intelligence Literacy Scale for Teachers	Four subscales; 36 items	α = .961 in the study sample
Cubillas et al. (2026)	Adapted AI literacy instrument	Knowing and understanding; applying; evaluating; AI ethics; 20 items	Subscale α = .732–.961; McDonald's ω also examined
Shi (2025)	Teachers' Generative AI Competencies Instrument	Technological proficiency; pedagogical compatibility; student preparation; professional development and communication; risk and ethical awareness; 36 items	KMO = .970; total α > .90; CFI = .946; TLI = .934; RMSEA = .078
Abrahams (2026)	Analysis of AI-supported assessment artefacts	Efficiency-oriented use; critical evaluation and adaptation; pedagogical judgement; ethical considerations	Qualitative document analysis of 63 assessment artefacts
Tran et al. (2026)	Process mining of screen-recorded GenAI interaction	Prompting, reviewing, refining, metacognitive regulation, and shared regulation	Behavioural comparison of reflective-iterative and linear-extraction patterns

Note. The table presents selected examples rather than an exhaustive inventory of all instruments.

Population-specific differences were also apparent. Studies involving pre-service teachers more frequently emphasized AI awareness, readiness, professional identity, pedagogical judgement, and ethical reflection. Studies involving in-service teachers placed greater emphasis on classroom integration, assessment, curriculum alignment, professional competence, institutional conditions, and continuing professional-development needs.

D. Relationships Between AI Literacy, Pedagogical Competence, and Ethical Competence

Across studies that examined relationships among constructs, stronger AI literacy and AI competence were generally associated with more developed pedagogical application. The most consistently reported outcomes concerned lesson planning, instructional design, assessment, feedback, personalization, differentiation, curriculum alignment, and AI-related TPACK. However, the evidence also showed that technological proficiency alone did not guarantee deeper pedagogical integration.

Several quantitative studies reported direct positive relationships. Choudhury et al. (2026) found that AI literacy was positively correlated with ICT self-efficacy, $r = .443$, TPACK, $r = .484$, and digital transformation, $r = .671$, with all relationships significant at $p < .01$. TPACK functioned as a stronger mediator than ICT self-efficacy, and the serial pathway from AI literacy through ICT self-efficacy and TPACK to digital transformation was also significant.

Intervention findings supported the contribution of structured learning experiences. Antonio (2025) reported significant improvement across all AI-TPACK dimensions following an AI-focused pedagogical course, with a large overall effect, $z = -6.900$, $p < .001$, $r = .76$. The largest improvement occurred in AI-related technological pedagogical knowledge, $r = .78$. In contrast, Tran et al. (2026) found that tool-only training produced comparatively linear and extractive AI use, whereas mindset-oriented training resulted in more frequent cycles of prompting, reviewing, and refining and higher-quality lesson plans.

The relationship between AI literacy and adoption was also indirect or conditional in several studies. Cubillas et al. (2026) reported a total effect of AI literacy on behavioural intention of .62, $p = .001$, alongside an indirect effect through attitude of .35, $p = .002$. Attitude independently predicted behavioural intention, β = .41, p = .001. Liu et al. (2026) similarly found that institutional ICT and AI support were positively associated with TPACK development and that ICT self-efficacy provided an important indirect pathway.

Ethical competence operated both as a dimension of AI literacy and as a regulatory mechanism influencing the quality of implementation. Ethical domains included bias recognition, privacy protection, transparency, fairness, authorship, accountability, academic integrity, data security, and human oversight. Thuy et al. (2025) found that ethical awareness positively influenced pedagogical competence, β = .289, although its direct effect on application behaviour was not significant. This finding indicated that ethical awareness may influence AI practice indirectly through pedagogical judgement rather than functioning as an independent predictor of use.

The evidence also identified an implementation gap between technical use and pedagogical transformation. Mešková (2026) found that technical applications constituted 67.9% of coded AI-use segments, while deeper pedagogical applications accounted for 32.0%, producing a ratio of approximately 2.1:1. Preparation of teaching materials was reported by 42.6% of participants, whereas differentiation was reported by only 13.2%. Similarly, Pozo- Pozo-Sánchez et al. (2026) found that ethical and inclusive use received the highest competence score, M = 3.54, SD = 0.78, while integration into teaching and learning received the lowest, M = 2.39, SD = 0.94. Training was strongly correlated with integration, r = .75, p < .01.

Table 8. Representative relationship patterns between AI literacy, pedagogical competence, ethical competence, and adoption

Study	AI-related construct	Outcome or competence	Relationship pattern	Principal evidence
Chen et al. (2025)	AI literacy and TPACK-related knowledge	Differentiated instruction and ICT integration	Direct positive	Higher AI literacy supported more developed instructional adaptation
Antonio (2025)	AI-TPACK competence	Science lesson design, inquiry, monitoring, and feedback	Intervention effect	Large improvement after structured pedagogical instruction
Choudhury et al. (2026)	AI literacy	ICT self-efficacy, TPACK, and digital transformation	Direct and mediated positive	TPACK was the strongest mediator between literacy and transformation
Liu et al. (2026)	ICT and AI support	TPACK development	Indirect positive	ICT self-efficacy mediated part of the relationship
Cubillas et al. (2026)	AI literacy	Attitude and behavioural intention	Direct and mediated positive	AI literacy influenced intention partly through attitude
Thuy et al. (2025)	Ethical awareness and AI competence	Pedagogical competence and application behaviour	Indirect or conditional	Ethical awareness predicted pedagogical competence but not application directly
Tran et al. (2026)	Reflective AI mindset	AI-supported lesson planning	Conditional positive	Mindset-oriented training outperformed tool-only training
Mešková (2026)	Intelligent-TPACK competence	Classroom AI use	Uneven or incomplete	Technical use substantially exceeded deeper pedagogical application
Deshen et al. (2026)	AI literacy	Acceptance and willingness to use AI	Positive	Motivational and attitudinal factors were stronger than demographic predictors
Ribes-Lafoz et al. (2026)	Critical AI literacy	Bias recognition and evaluation	Positive but uneven	Explicit instruction improved awareness, although some forms of bias remained difficult to detect

Overall, the relationship evidence supported three patterns. First, foundational AI knowledge and technical proficiency enabled initial engagement with AI. Second, pedagogical knowledge and reflective judgement determined whether such engagement became instructionally meaningful. Third, ethical competence regulated whether AI-supported practices remained responsible, transparent, and appropriately subject to human judgement.

E. Factors Facilitating and Hindering Responsible AI Adoption

The thematic synthesis identified six interrelated categories shaping teachers' readiness, intention, ability, and responsible adoption of AI: professional development, individual factors, pedagogical factors, ethical factors, technological conditions, and institutional conditions. Because many studies identified more than one factor, the categories were not mutually exclusive.

Professional development was the most frequently coded category, appearing in 32 studies. Pedagogical factors appeared in 24 studies, while individual, ethical, and technological factors each appeared in 17 studies. Institutional factors were explicitly represented in 13 studies. The lower frequency of institutional coding did not indicate lesser importance; rather, institutional factors were more commonly examined in studies of practising teachers than in studies of pre-service teachers.

Table 9. Facilitators and barriers to teachers' responsible AI adoption

Factor category	Studies, *n*	Principal facilitators	Principal barriers
Professional development	32	Structured training, hands-on practice, mentoring, collaborative lesson design, reflection, continuing support, and discipline-specific professional learning	One-off workshops, overly technical training, limited opportunities, weak contextual relevance, and training disconnected from classroom practice
Pedagogical	24	TPACK and AI-TPACK, curriculum alignment, lesson-planning competence, assessment knowledge, output evaluation, reflective practice, and perceived instructional relevance	Surface-level tool use, weak alignment with learning objectives, uncertainty about instructional value, and limited competence in adapting AI outputs
Individual	17	AI literacy, self-efficacy, confidence, prior experience, perceived usefulness, trust, motivation, positive attitudes, and willingness to experiment	AI anxiety, low confidence, insufficient knowledge, limited prior experience, stress, and uncertainty
Ethical	17	Ethical awareness, critical evaluation, bias recognition, responsible use, data protection, transparency, and human oversight	Privacy concerns, misinformation, academic-integrity risks, bias, unclear authorship, overreliance, and fear of professional displacement
Technological	17	Tool availability, ease of use, accessibility, reliable feedback, technical assistance, and adequate connectivity	Infrastructure limitations, unequal access, internet instability, subscription costs, firewalls, unreliable outputs, and technical restrictions
Institutional	13	Leadership support, clear policy, organizational encouragement, resources, infrastructure, workload recognition, and implementation guidance	Unclear policy, absent guidance, limited resources, workload, lack of leadership support, and inconsistent institutional norms

Note. A study could contribute to several categories; therefore, the total exceeds 51.

1. Professional-development factors

Professional development represented the most consistent facilitator across populations and contexts. Effective programmes combined technical knowledge with practical application, pedagogical reasoning, ethical reflection, collaboration, and opportunities to evaluate AI-generated outputs. Antonio

(2025) showed that structured instruction, hands-on activities, and collaborative lesson design improved AI-TPACK competence. Velander (2026) similarly found that practice-based workshops enabled teachers to develop more deliberate interactions with generative AI during lesson planning.

Training quality was more important than the mere availability of training. Tran et al. (2026) found that mindset-oriented preparation produced deeper reflective integration than tool-only instruction. Zhang et al. (2023) likewise reported that techno-centric training was insufficient when it was detached from disciplinary pedagogy and classroom conditions. Professional development therefore functioned as a facilitator when it was sustained, contextualized, reflective, and practice oriented, but became inadequate when delivered as isolated tool demonstrations.

2. Individual factors

Individual readiness was shaped by AI literacy, self-efficacy, confidence, motivation, prior experience, perceived usefulness, and willingness to experiment. Al-Abdullatif (2024) identified AI literacy, perceived usefulness, and trust as important adoption facilitators. Deshen et al. (2026) found positive relationships between AI literacy and several acceptance-related variables, with hedonic motivation and willingness to use AI emerging as particularly strong predictors.

Conversely, low confidence, anxiety, insufficient knowledge, and limited exposure constrained readiness. Kim & Kwon (2023) reported particularly low teacher confidence in AI content and technological knowledge. Cubillas et al. (2026) also identified anxiety, stress, and confidence gaps as adoption constraints despite generally high reported AI literacy. Individual readiness therefore reflected an interaction between competence and affective responses rather than knowledge alone.

3. Pedagogical factors

Pedagogical competence determined whether adoption remained limited to efficiency-oriented tasks or developed into substantive instructional integration. Facilitating factors included TPACK, AI-TPACK, curriculum alignment, assessment competence, differentiation, lesson-planning ability, and critical evaluation of AI outputs. Mohebi & ElSayary (2026) found that pedagogical and technological-pedagogical knowledge provided key pathways linking general AI proficiency with classroom implementation.

A recurring barrier was the gap between frequent AI use and pedagogically transformative use. Teachers often used AI to create materials, summarize content, or reduce preparation time but showed less frequent use for differentiation, inquiry, formative assessment, or redesigned learning activities. This pattern was particularly visible in which technical uses substantially exceeded integrated pedagogical applications (Mešková, 2026).

4. Ethical factors

Ethical considerations displayed a dual function. Ethical awareness facilitated responsible adoption by enabling teachers to identify bias, verify information, protect privacy, preserve academic integrity, and maintain human oversight. Ribes-Lafoz et al. (2026) found that explicit critical AI-literacy instruction strengthened participants' ability to recognize AI non-neutrality and identify some forms of bias.

At the same time, unresolved ethical risks reduced willingness to adopt AI. Common concerns included data privacy, inaccurate information, plagiarism, cheating, unclear authorship, algorithmic bias, overdependence, and diminished human interaction. Karataş & Yüce (2024) found that pre-service teachers valued the accessibility and efficiency of generative AI while remaining concerned about information accuracy, data security, academic integrity, and dependence. Ethical factors therefore affected not only whether teachers used AI but also the conditions under which they considered its use professionally acceptable.

5. Technological and institutional conditions

Technological access enabled initial adoption but did not independently ensure meaningful implementation. Tool availability, usability, connectivity, and technical support facilitated use, whereas unreliable outputs, subscription costs, limited internet access, infrastructure gaps, and unequal access acted as barriers. These challenges were particularly prominent in rural, mountainous, crisis-affected, and resource-constrained settings.

Institutional conditions determined whether individual readiness could be converted into sustained practice. Supportive leadership, clear policies, aligned curricula, adequate infrastructure, and professional-learning opportunities facilitated implementation. In contrast, absent or ambiguous policies, workload, limited resources, inconsistent guidance, and conflicting organizational norms constrained teachers' capacity to adopt AI confidently. Uğur (2026), for example, identified leadership, institutional policy, differentiated professional development, and explicit prompt training as enabling conditions, while workload and lack of guidance remained substantial barriers.

6. Differences between pre-service and in-service teachers

The pattern of barriers varied according to teachers' professional status. Pre-service teachers more frequently faced limited classroom experience, uncertainty, developing professional identity, weak pedagogical judgement, and limited opportunities to test AI in authentic settings. Their readiness was strengthened by scaffolded experimentation, reflective assignments, guided lesson design, and explicit discussion of professional responsibility.

In-service teachers more frequently encountered workload, institutional policy, infrastructure, access, technical support, curriculum requirements, and organizational expectations. Although practising teachers often recognized the usefulness of AI, their implementation depended on whether institutional conditions supported classroom experimentation and whether professional development addressed immediate disciplinary and instructional needs.

F. Integrated Evidence Architecture

The integration of findings across the three research questions produced an evidence architecture in which AI literacy and AI competence formed a foundational layer rather than an immediate guarantee of effective adoption. Foundational AI knowledge and technical capability enabled teachers to interact with AI systems, while critical evaluation and reflective judgement allowed them to assess the reliability and appropriateness of AI outputs. Pedagogical competence translated these capabilities into curriculum-aligned lesson planning, assessment, feedback, differentiation, and classroom implementation. Ethical competence regulated this translation through attention to privacy, bias, transparency, academic integrity, accountability, and human oversight.

Adoption outcomes included readiness, intention, confidence, actual use, instructional integration, and responsible professional practice. However, the pathway was shaped by individual self-efficacy and motivation and enabled or constrained by professional development, technological access, leadership, policy, workload, and institutional support. The evidence therefore supported a conditional rather than deterministic relationship:

> **AI literacy and AI competence ⟶ pedagogical and ethical competence ⟶ readiness, intention, ability, and responsible AI integration**

Professional-development, technological, and institutional factors influenced each stage of this pathway. AI literacy was most likely to translate into responsible classroom integration when teachers possessed pedagogical knowledge, opportunities for reflective practice, ethical guidance, and adequate organizational support.

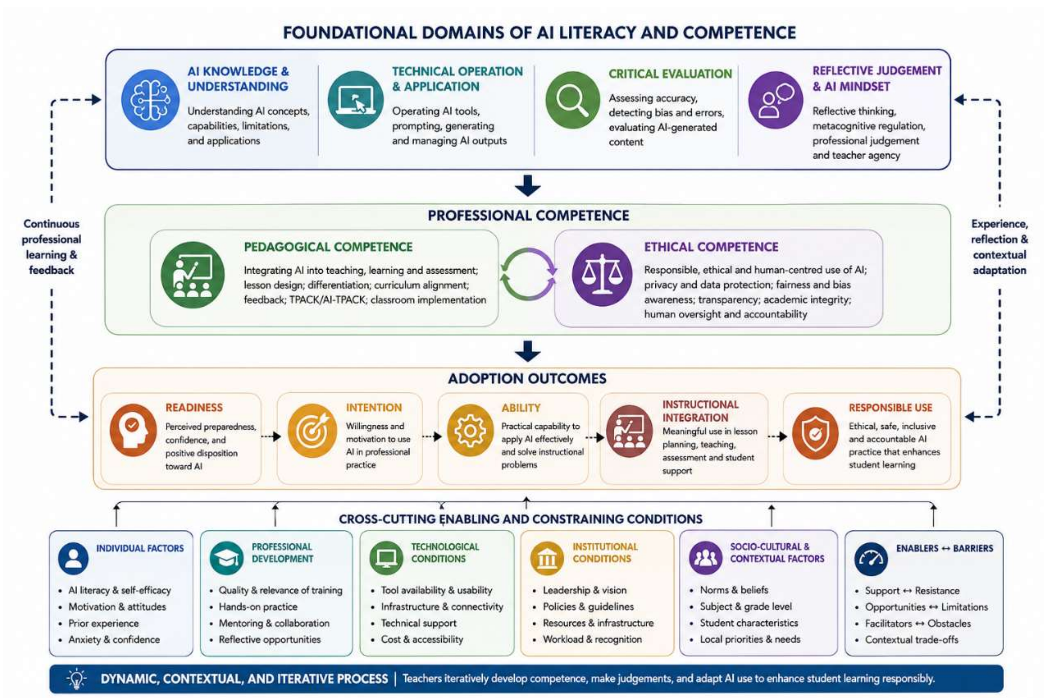

Figure 3. Integrated evidence architecture linking teachers' AI literacy and competence with pedagogical competence, ethical competence, and responsible AI adoption

3.2 Discussion

A. Overview of the Principal Findings

This systematic review demonstrates that teachers' responsible AI adoption is best understood as a developmental and context-dependent process in which foundational AI literacy is translated into pedagogical and ethical competence before it can support meaningful classroom integration. Across the 51 included studies, AI literacy consistently extended beyond awareness of AI or the ability to operate particular applications. It encompassed knowledge of AI, technical application, critical evaluation, pedagogical integration, ethical responsibility, and reflective professional judgement. This interpretation corresponds with broader AI-literacy frameworks that distinguish understanding and evaluating AI from merely using it, while also recognising that competence involves applying knowledge purposefully in specific contexts (Chiu et al., 2024; Long & Magerko, 2020; Ng et al., 2021). The evidence therefore supports the pathway presented in Figure 3, in which foundational capabilities contribute to pedagogical and ethical competence, which in turn shape readiness, intention, instructional integration, and responsible use. However, the pathway should be interpreted as an evidence-informed explanatory architecture rather than a confirmed causal sequence, because much of the available evidence remains cross-sectional and self-reported.

Taken together, the findings challenge technology-centred accounts of teacher readiness by showing that access to AI tools and technical proficiency are insufficient without pedagogical judgement, critical evaluation, ethical regulation, and supportive professional conditions. The synthesis identified a recurrent discrepancy between teachers' reported use of AI and their ability to embed it deeply in curriculum, assessment, differentiation, and learner-centred instruction. Similar evidence shows that teachers may report relatively extensive technological uses while demonstrating a substantially narrower range of pedagogically transformative practices (Mešková, 2026). Professional-development studies likewise indicate that competence growth depends less on exposure to tools than on sustained engagement with pedagogical cases, reflective tasks, and AI-specific professional knowledge (Ding et al., 2024; Tan et al., 2025; Tran et al., 2026). Responsible integration should therefore be distinguished from simple adoption: adoption concerns whether teachers use AI, whereas responsible pedagogical integration concerns whether they use it purposefully, critically, ethically, and in ways that improve rather than merely accelerate existing teaching routines.

B. From AI Literacy to Professional AI Competence

The evidence supports a functional distinction in which AI literacy represents a foundational capacity for understanding, using, and evaluating AI, whereas AI competence reflects the professional ability to apply these capacities in pedagogically and ethically appropriate teaching practices. This distinction resembles the differentiation proposed by Chiu et al. (2024), who describe literacy as knowing what AI is and competency as applying such knowledge beneficially and confidently. Foundational formulations of AI literacy typically include recognising AI, understanding its basic mechanisms, interacting with AI systems, evaluating outputs, and considering ethical implications (Chiu et al., 2024; Long & Magerko, 2020; Ng et al., 2021). Teacher competence adds a professional layer by requiring educators to align AI with curriculum, subject content, assessment, student needs, and institutional responsibilities. The reviewed evidence nevertheless showed that primary studies frequently used *literacy* and *competence* interchangeably. Some AI-literacy instruments incorporated pedagogical integration and adoption, whereas some competence models included basic knowledge and awareness. The distinction is thus analytically useful, but the current literature has not yet established stable and universally accepted construct boundaries.

The six-domain taxonomy identified in this review indicates a broader shift from tool-oriented AI literacy toward a socio-pedagogical conception of teacher competence that integrates knowledge, technical application, critical evaluation, pedagogy, ethics, and reflective professional judgement. This multidimensional structure closely resembles emerging teacher-specific frameworks. The Teacher AI Competence Self-Efficacy Scale, for example, incorporates AI knowledge, pedagogy, assessment, ethics, human-centred education, and professional engagement (Chiu et al., 2024). Similarly, the Teachers' Generative AI Competencies Instrument includes technological proficiency, pedagogical compatibility, student preparation, professional communication, and ethical-risk awareness (Shi, 2025). The prominence of pedagogical integration in the present synthesis confirms that teacher AI competence is profession-specific rather than a generic form of digital skill. At the same time, critical evaluation and reflective judgement appeared less frequently in formal instruments than knowledge, technical use, and pedagogy. This imbalance suggests that current measurement models may underrepresent teachers' capacity to interrogate outputs, recognise uncertainty, reject inappropriate recommendations, and exercise professional agency.

The substantial variation in instruments and operational definitions raises concerns about construct equivalence, as studies labelled as measuring AI literacy may in fact assess different combinations of knowledge, confidence, pedagogy, ethics, readiness, and technology acceptance. The reviewed studies employed self-report Likert scales, adapted competency frameworks, interviews, reflective narratives, performance tasks, teaching artefacts, and recorded AI interactions. These methods do not simply provide different ways to measure one stable construct; they often capture different aspects of teachers' knowledge and practice. The AI Readiness Scale for Teachers, for instance, assesses technological self-efficacy, interaction with students, and ethical awareness, while other instruments focus on AI knowledge, instructional design, or generative-AI risk management (Ramazanoglu & Akin, 2025; Shi, 2025). Objective assessment research further shows that self-perceived competence may not correspond directly with demonstrated AI knowledge (Ding et al., 2024). Future instrument development should therefore report explicit construct definitions, establish discriminant validity between AI literacy, self-efficacy, readiness, and acceptance, and supplement self-reports with performance-based evidence. Otherwise, excellent reliability coefficients may merely confirm that respondents consistently answered questions about several different constructs bundled under one fashionable label.

C. AI Literacy as a Foundation for Pedagogical and Ethical Competence

The consistently positive association between AI literacy and pedagogical competence suggests that AI-related knowledge becomes educationally valuable only when teachers can connect it with instructional goals, disciplinary content, assessment, and learner needs. This finding extends the central argument of the TPACK framework that technological knowledge cannot produce effective integration independently of pedagogy and content knowledge (Mishra & Koehler, 2006). Intelligent-TPACK adapts this logic to AI by adding knowledge needed to interpret AI processes, assess algorithmic recommendations, and make ethically informed decisions about their classroom use (Celik, 2023). Within the reviewed studies, higher AI-related competence was associated with stronger lesson planning, feedback, assessment design, differentiation, material development, and curriculum integration. The relationship was particularly strong when studies framed AI competence through pedagogical knowledge rather than technical confidence alone. Intervention evidence supports this interpretation: a six-month Intelligent-TPACK-based programme significantly improved teachers' technological and technological-pedagogical AI knowledge, demonstrating that teachers can develop AI competence through deliberately structured professional learning (Tan et al., 2025).

The reviewed evidence further indicates that the influence of AI literacy on instructional integration is frequently mediated or conditioned by TPACK, ICT self-efficacy, attitudes, perceived usefulness, professional development, and institutional support. Technology-acceptance research has consistently shown that perceived usefulness and perceived ease of use influence teachers' intentions to use AI, while anxiety and enjoyment can modify these relationships (Ayanwale et al., 2022; Zhang et al., 2023). More recent research positions AI literacy within a wider system of motivation, willingness to use AI, computational thinking, and anxiety rather than treating it as an independent technical variable (Deshen et al., 2026). Milutinović (2025) likewise integrates AI competence, Intelligent Ethical TPACK, and adoption-related factors into a comprehensive model for pre-service teachers. The present findings therefore indicate that AI literacy is a necessary but insufficient condition for pedagogical integration. Teachers may understand AI yet avoid using it because of anxiety, low confidence, limited usefulness, or institutional restrictions; conversely, positive attitudes may encourage adoption without ensuring pedagogical quality. Meaningful enactment emerges when knowledge, confidence, professional judgement, and supportive conditions converge.

Ethical competence emerged not as an additional component appended to technical competence but as a regulatory capacity that determines whether AI-supported teaching remains fair, transparent, accountable, and subject to meaningful human oversight. The reviewed studies repeatedly identified bias, privacy, transparency, misinformation, authorship, academic integrity, fairness, accountability, and data protection as central domains of teacher competence. Tagare et al., (2025) similarly conceptualise teachers' ethical AI competence through interdependent knowledge, skills, and dispositions, including awareness of AI limitations, critical analysis, explainability, inclusivity, and sensitivity to ethical consequences. Intelligent-TPACK also places ethical decision-making within teachers' professional knowledge rather than outside pedagogical integration (Celik, 2023). Ethical concerns should therefore not automatically be interpreted as barriers or resistance. Concern about bias, privacy, or inappropriate reliance may indicate critical literacy and responsible caution. Such concern becomes restrictive mainly when teachers lack the knowledge, institutional guidance, or practical strategies needed to manage perceived risks. In this sense, ethical competence regulates adoption by helping teachers distinguish productive caution from unexamined rejection and responsible experimentation from indiscriminate use.

The gap between frequent AI use and deeper pedagogical transformation indicates that operational proficiency may support efficiency-oriented practices without necessarily changing the quality, design, or inclusiveness of teaching. The reviewed evidence showed that teachers frequently used AI to generate materials, summarise information, prepare lessons, or automate routine tasks, yet they used it less often for differentiation, inquiry, formative assessment, and learner-centred redesign. Mešková (2026) similarly identifies an Intelligent-TPACK gap between teachers' reported AI uses and the deeper integration expected by professional competence frameworks. Training design helps explain this difference. Case-based professional development encourages teachers to consider multiple pedagogical options and transfer ideas into integration strategies, whereas tool demonstrations may produce procedural knowledge without instructional reasoning (Ding et al., 2024). Process-mining evidence further shows that mindset-oriented training promotes iterative cycles of prompting, reviewing, and refining, while tool-only preparation encourages more linear and extractive interaction patterns (Tran et al., 2026). Pedagogical transformation therefore requires teachers to question not only how AI can complete a task, but whether the task, output, and learning design should be changed at all.

D. A Multilevel Explanation of Responsible AI Adoption

Teachers' readiness and ability to adopt AI responsibly are produced through interactions among individual, pedagogical, ethical, technological, institutional, and professional-development conditions rather than through individual motivation alone. At the individual level, the review identified AI literacy, self-efficacy, confidence, perceived usefulness, prior experience, motivation, anxiety, and willingness to experiment. These findings correspond with research showing that perceived usefulness and ease of use strongly predict pre-service teachers' behavioural intentions, while anxiety may influence their perceptions of AI applications (Zhang et al., 2023). Readiness instruments similarly combine technological self-efficacy with student interaction and ethical awareness, demonstrating that readiness is already broader than personal enthusiasm for technology (Ramazanoglu & Akin, 2025). At the organisational level, infrastructure, leadership, policy clarity, workload, technical support, and access determined whether teachers could act on their intentions. The findings therefore caution against placing responsibility for adoption entirely on individual teachers. A highly motivated and competent teacher may still be unable to integrate AI when institutional policies prohibit its use, infrastructure is unreliable, or workload leaves no time for experimentation and reflection.

Professional development emerged as the most consistent facilitator because it can simultaneously strengthen technical proficiency, pedagogical reasoning, critical evaluation, ethical awareness, and confidence. However, the review indicates that the quality and design of professional learning matter more than its mere existence. Case-based AI professional development improved teachers' self-reported literacy and supported more sophisticated consideration of AI-integration problems, particularly when model cases preceded less structured problems (Ding et al., 2024). Professional-development programmes based on instructional-design and Intelligent-TPACK principles have also improved pre-service and in-service teachers' AI literacy and competence (Tan et al., 2025; Younis, 2024). Pei et al. (2025) found that pre-service teachers particularly valued practical, hands-on training and collaborative learning. These findings favour professional development that is sustained, subject-specific, practice-based, collaborative, and ethically reflective. One-off workshops focused on changing prompts or showcasing new tools may generate immediate enthusiasm, but they are unlikely to build the judgement required for curriculum alignment, risk evaluation, or durable pedagogical change.

Differences between pre-service and in-service teachers indicate that AI competence development must be differentiated according to professional experience, institutional responsibility, and opportunities for authentic classroom application. Studies of pre-service teachers more frequently emphasised awareness, readiness, identity formation, AI mindset, and ethical reflection. These teachers may possess broad digital familiarity yet lack sufficient classroom experience to judge whether AI-generated materials suit particular learners, curricula, or assessment purposes. Pei et al. (2025) identified a notable gap in pre-service teachers' understanding of AI mechanisms, despite generally positive perceptions of its educational potential. Objective assessment also suggests that in-service teachers may perform slightly better than pre-service teachers, although both groups display substantial knowledge gaps ((Ding et al., 2024). In-service teachers, by contrast, face immediate implementation constraints involving workload, curriculum expectations, infrastructure, student data, and institutional policy. Initial teacher education should therefore provide scaffolded experimentation and pedagogical judgement, whereas continuing professional development should focus more directly on authentic classroom integration, governance, and context-specific problem solving.

E. Integrated Theoretical Contribution

The integrated evidence architecture developed in this review conceptualizes responsible AI integration as a conditional pathway in which foundational literacy supports professional competence, while contextual conditions determine whether competence can be enacted in practice. As depicted in Figure 3, AI knowledge, technical application, critical evaluation, and reflective judgement constitute the foundational layer. Pedagogical and ethical competence form the professional layer through which teachers connect AI with teaching purposes and regulate its use. Readiness, intention, ability, instructional integration, and responsible use represent distinct but related outcomes. The model also includes professional development, technological conditions, institutional support, and sociocultural context as cross-cutting influences rather than variables situated only at the end of the adoption process. This positioning aligns with Intelligent-TPACK, which treats ethical and pedagogical knowledge as integral to AI-related professional capability (Celik, 2023), and with models showing that AI competence, ethical TPACK, and adoption factors operate in combination (Milutinović, 2025). Nevertheless, longitudinal and intervention evidence remains necessary before the directional relationships in Figure 3 can be treated as causal.

The principal theoretical contribution of this review lies in repositioning AI literacy from an isolated individual attribute to a foundational professional capability embedded within pedagogical, ethical, and organizational systems. Existing AI-literacy frameworks clarify the knowledge and skills needed to understand and evaluate AI, while TPACK explains how technology knowledge interacts with pedagogy and content (Chiu et al., 2024; Mishra & Koehler, 2006; Ng et al., 2021). Technology-acceptance models clarify why teachers may intend to use AI, but intention does not demonstrate that use is pedagogically meaningful or ethically responsible (Zhang et al., 2023). Ethical-competence research, meanwhile, explains how teachers recognise and manage risks relating to bias, transparency, inclusion, and human oversight (Tagare et al., 2025). The proposed architecture assigns these perspectives complementary functions: AI literacy explains foundational capacity, TPACK explains pedagogical translation, ethics regulates professional action, acceptance explains intention, and institutional conditions explain enactment. Its novelty does not lie in blending every available framework into a conceptual stew, but in showing how previously separated constructs occupy different positions within a coherent professional-development pathway.

F. Implications for Teacher Education, Professional Development, and Policy

Teacher-education curricula and professional-development programmes should be redesigned around integrated learning progressions that combine AI knowledge, practical experimentation, pedagogical design, critical evaluation, ethical reasoning, and reflective judgement. Stand-alone sessions on operating particular platforms are unlikely to remain useful as tools and interfaces change rapidly. Programmes should instead engage teachers in authentic tasks such as designing lessons, comparing AI-generated altrnatives, identifying inaccuracies and bias, revising assessments, disclosing AI use, and deciding when AI should be rejected. Case-based professional development can support such reasoning by confronting teachers with increasingly complex and ill-structured instructional problems (Ding et al., 2024). Structured programmes should also include collaborative design, mentoring, repeated practice, and opportunities to evaluate the consequences of implementation (Tan et al., 2025; Tran et al., 2026; Younis, 2024). Ethical competence should be embedded throughout these activities rather than confined to a final module, because privacy, fairness, authorship, accountability, and human oversight arise during every stage of AI-supported teaching design (Tagare et al., 2025).

Educational institutions and policymakers must complement individual capacity-building with clear governance, equitable infrastructure, workload recognition, technical support, and context-sensitive standards for responsible AI use. The review showed that teacher competence alone cannot overcome unavailable tools, poor connectivity, inaccessible subscriptions, absent policy, or uncertainty about data protection and academic integrity. Governance should clarify approved uses, disclosure expectations, human review responsibilities, privacy safeguards, and procedures for responding to unreliable or biased outputs. At the same time, policy should avoid reducing responsible AI use to prohibition, because excessive restriction may prevent teachers from developing the informed judgement that responsible practice requires. Institutions should also distinguish between competence, self-efficacy, readiness, and actual performance when evaluating professional capacity. Available instruments provide useful frameworks, but they measure different constructs and should not be treated as interchangeable (Chiu et al., 2025; Ramazanoglu & Akin, 2025; Shi, 2025). Equitable implementation further requires sustained support for schools and educators operating in resource-constrained contexts, lest AI competence become another polished term for opportunities available only to already advantaged institutions.

G. Strengths, Limitations, and Future Research

The review offers a broad integration of heterogeneous empirical evidence, but its conclusions should be interpreted in light of conceptual inconsistency, reliance on self-reported measures, rapidly evolving technologies, uneven geographical representation, and the limitations of a single-database search. Its principal strength lies in connecting three evidence layers that previous reviews commonly examined separately: how teacher AI literacy and competence are conceptualised and measured, how they relate to pedagogical and ethical competence, and which factors determine responsible adoption. Earlier reviews have mapped AI literacy in K–12 education or examined its conceptualisation within teacher education, but the present review extends this work by integrating constructs, relationships, and implementation conditions (Casal-Otero et al., 2023; Sperling et al., 2024). Nevertheless, the dominance of studies published in 2025 and 2026 means that the evidence base reflects a field still responding to rapidly changing generative-AI systems. Many studies used cross-sectional surveys and self-reports, limiting causal inference and leaving uncertainty about whether perceived competence corresponds with classroom behaviour. Restriction to Scopus and English-language publications may also have excluded locally relevant evidence and intensified geographical imbalance.

Future research should test the proposed evidence architecture through longitudinal, cross-cultural, intervention, and performance-based studies capable of determining when and how AI literacy develops into responsible professional practice. Longitudinal designs should examine whether gains in literacy precede changes in pedagogical judgement, ethical decision-making, and observed classroom integration. Experimental and quasi-experimental studies should compare technical, case-based, mindset-oriented, and discipline-specific professional-development models rather than merely reporting pre–post improvement. Measurement research should test discriminant validity and measurement invariance across cultures, subjects, school levels, and professional stages. Performance-based assessments, lesson artefacts, observations, and AI-interaction logs should supplement self-reports, as emerging objective and process-based studies already demonstrate their analytical value (Ding et al., 2024; Tan et al., 2025; Tran et al., 2026). Research should also connect teacher competence with student outcomes, including learning quality, equity, critical AI literacy, and academic integrity. Such work would allow Figure 3 to develop from an explanatory synthesis into an empirically tested model of responsible professional AI integration.

4. Conclusion

This systematic review synthesised 51 empirical studies to clarify how AI literacy and AI competence are conceptualised and operationalised among pre-service and in-service teachers, how these capacities relate to pedagogical and ethical competence, and which conditions facilitate or hinder responsible AI adoption. The findings show that teacher AI literacy is a multidimensional foundational capacity comprising AI knowledge, technical application, critical evaluation, pedagogical understanding, ethical awareness, and reflective judgement. AI competence extends this foundation into professional practice by enabling teachers to align AI with curriculum, instructional design, assessment, learner needs, and professional responsibilities. Although the two constructs overlap substantially across the literature, their functional distinction helps clarify the difference between understanding AI and applying it purposefully within teaching.

The evidence further indicates that AI literacy supports pedagogical and ethical competence but does not automatically generate meaningful integration. Its influence depends on teachers' self-efficacy, attitudes, perceived usefulness, TPACK-related knowledge, professional learning, and access to supportive institutional conditions. Ethical competence regulates this process by enabling teachers to recognise bias, protect privacy, preserve academic integrity, maintain transparency, and exercise human oversight. Professional development emerged as the most consistent facilitator, particularly when it combined practical experimentation, pedagogical design, collaboration, critical evaluation, and ethical reflection. Conversely, anxiety, weak pedagogical alignment, unreliable technology, inadequate infrastructure, workload, unclear policy, and fragmented training constrained responsible implementation.

The review therefore proposes an integrated evidence architecture in which AI literacy and competence provide the foundation for pedagogical and ethical competence, which subsequently supports readiness, intention, ability, instructional integration, and responsible use. This pathway remains dynamic and context dependent, with professional-development, technological, institutional, and sociocultural conditions influencing every stage. Theoretically, the model integrates literacy, professional competence, ethics, and adoption within one evidence-informed structure. Practically, it provides a basis for designing teacher-education curricula, continuing professional-development programmes, institutional governance, and more coherent measurement instruments. Future research should validate this architecture using longitudinal, intervention, cross-cultural, and performance-based designs and should examine whether teacher AI competence ultimately improves student learning, equity, critical judgement, and responsible participation in AI-mediated education.

5. Declaration of AI Use

The authors used SciSpace and ChatGPT Pro (GPT-5.5) to assist with literature exploration, language editing, and manuscript organization. All AI-generated suggestions were critically reviewed and revised by the authors. The tools were not used to generate research data, results, or conclusions, and the authors remain fully responsible for the final content of the manuscript.

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