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AI Literacy Among Pre-Service Teachers: A New Dimension of Teacher Professional Development

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Abstract

The rapid diffusion of artificial intelligence (AI) technologies — including generative tools, intelligent tutoring systems, and adaptive learning platforms — is reshaping the teacher–student relationship into a teacher–AI–student dynamic (UNESCO, 2024). Despite this shift, teacher education programmes have been slow to embed AI literacy as a core professional competency, leaving pre-service teachers to enter classrooms with fragmented and largely self-acquired understanding of AI. Purpose: This review synthesises conceptualisations and empirical evidence on AI literacy among pre-service teachers and positions it as an emerging, distinct dimension of teacher professional development. Review methodology: Following a systematic narrative-review protocol, fifteen peer-reviewed studies published between 2020 and 2025 were retrieved from Scopus, Web of Science, ERIC, Frontiers, and Elsevier/Springer databases and analysed thematically alongside foundational policy documents (UNESCO, NEP 2020). Major findings: Pre-service teachers generally demonstrate moderate AI awareness and ethical sensitivity but weaker pedagogical-integration and problem-solving competencies; structured, TPACK-aligned coursework produces measurable gains, though most evidence remains cross-sectional and geographically concentrated. Practical implications: Teacher-education institutions, particularly those regulated by India's National Council for Teacher Education, require embedded — rather than elective — AI-literacy modules, faculty capacity-building, and revised practicum assessment. Conclusion: AI literacy should be formally recognised as a fourth pillar of teacher professional development alongside content, pedagogical, and technological knowledge, warranting coordinated policy, curricular, and institutional action.

1. Introduction

Artificial intelligence has moved from a peripheral technological curiosity to a structural feature of contemporary education systems. Generative AI applications, intelligent tutoring systems, automated assessment engines, and adaptive learning platforms are increasingly embedded in classroom routines, transforming what UNESCO (2024) describes as a shift from a teacher-student relationship to a teacher-AI-student dynamic. This transformation carries profound implications for how future teachers are prepared, since the competencies required to teach effectively in an AI-mediated classroom differ substantially from those emphasised in conventional teacher-education curricula.

The need for this study arises from a persistent mismatch between the pace of AI adoption in schools and the pace of curricular reform in teacher-preparation programmes. While in-service teachers have received growing attention through professional-development initiatives, pre-service teachers — who are simultaneously learning to teach and learning about AI for the first time — remain comparatively underserved by structured training (Ayanwale et al., 2024). This is a critical oversight, since attitudes and competencies formed during initial teacher education tend to persist into professional practice, making the pre-service stage a strategically important point of intervention.

The current scenario reflects both momentum and unevenness. UNESCO's (2024) AI Competency Framework for Teachers represents a landmark effort to define fifteen competencies across five dimensions, yet, as UNESCO itself has noted, only a small number of countries had incorporated AI-related learning objectives into official curricula as of 2022. India's National Education Policy 2020 gestures toward technology-enabled teacher preparation but stops short of prescribing a dedicated AI-literacy curriculum for B.Ed. and M.Ed. programmes regulated by the National Council for Teacher Education. The importance of addressing this gap is therefore twofold: pedagogically, because AI-literate teachers are better positioned to model critical, ethical technology use for students; and systemically, because teacher-education institutions function as the primary gatekeepers through which national AI-in-education policy is ultimately translated into classroom practice.

Despite an expanding body of research on AI in education broadly, a specific research gap persists around pre-service teachers as a distinct population: much existing work either targets in-service teachers already engaged in classroom practice or K-12 students as end users of AI tools, leaving the formative teacher-education stage comparatively unexamined (Casal-Otero et al., 2023; Zawacki-Richter et al., 2019). Moreover, terminological inconsistency between "AI literacy," "AI competency," and "digital literacy" complicates cross-study comparison, and empirical evidence from South Asian, and specifically Indian, contexts remains sparse relative to East Asian and African contributions.

Against this background, the present review pursues four objectives: (1) to synthesise how AI literacy is conceptualised within teacher-education scholarship; (2) to map empirical findings on pre-service teachers' AI literacy published between 2020 and 2025; (3) to critically evaluate the strengths, limitations, and emerging trends within this literature; and (4) to propose an integrative framework and actionable recommendations for teacher-education institutions, with particular reference to the Indian policy context under NEP 2020.

2. Conceptual Framework

AI literacy is most usefully understood not as a single skill but as a composite construct spanning cognitive, technical, pedagogical, ethical, and affective domains. Casal-Otero et al. (2023), in a systematic review of AI literacy scholarship, characterise it as the capacity to critically evaluate AI technologies, communicate and collaborate effectively with AI systems, and use AI as a tool across contexts – a definition that extends beyond mere technical operation to encompass critical and ethical engagement. Ayanwale et al. (2024) further distinguish AI literacy from the related but broader notion of AI competency, arguing that literacy denotes foundational awareness and evaluative capacity, whereas competency implies the applied, classroom-ready ability to design and deliver AI-integrated instruction.

The theoretical anchoring of AI literacy in teacher education draws heavily on the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006), which conceptualises effective technology-integrated teaching as the intersection of technological, pedagogical, and content knowledge. Celik (2023) extended this model into an "Intelligent-TPACK" formulation, adding an explicit ethics dimension to account

for the unique risks – bias, opacity, and data misuse – that AI tools introduce relative to earlier educational technologies. This extension is conceptually significant because it signals that AI literacy cannot be treated as a simple technological add-on to existing digital-literacy frameworks; it requires distinct ethical and epistemic reasoning that general digital-competence models do not fully capture (Zhang et al., 2026).

At the policy level, UNESCO's (2024) AI Competency Framework for Teachers offers the most comprehensive scaffolding currently available, organising fifteen competencies across five aspects – a human-centred mindset, AI ethics, AI foundations and applications, AI pedagogy, and AI for professional learning – and three progression levels (Acquire, Deepen, Create). This structure is valuable for teacher-education institutions because it allows AI literacy to be scaffolded developmentally rather than treated as a binary trained/untrained status, and it explicitly foregrounds human agency and accountability, addressing a recurring concern in the literature that overreliance on AI risks eroding teachers' professional judgement. For the purposes of this review, AI literacy among pre-

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service teachers is conceptualised as an integrative construct comprising five interacting dimensions – cognitive, pedagogical, ethical, affective, and professional-development-oriented – situated within, but distinct from, general digital competence. This conceptualisation, summarised in Table 1 and depicted in Figure 1, provides the analytic lens applied throughout the remainder of this review.

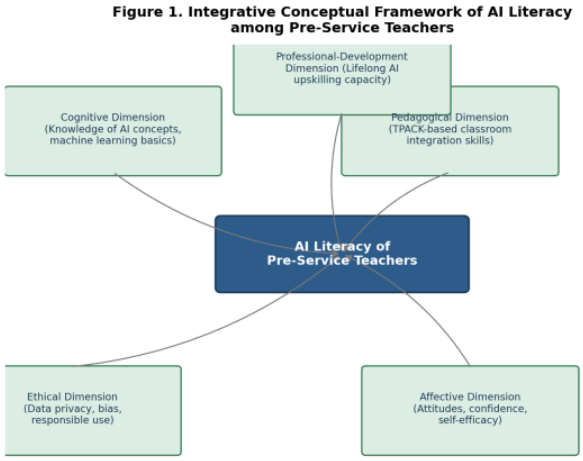


Figure 1. Integrative conceptual framework of AI literacy among pre-service teachers, synthesising cognitive, pedagogical, ethical, affective, and professional-development dimensions.

Table 1. Comparative Definitions of Core Concepts

AI Competency Framework for Teachers (AI CFT)	A five-dimension, three-level structure (Acquire, Deepen, Create) defining fifteen teacher competencies for ethical, effective AI use.	UNESCO (2024)
AI Literacy	The ability to critically evaluate AI technologies, communicate and collaborate with AI systems, and use AI as a tool across academic and everyday contexts.	Casal-Otero et al. (2023)
AI Competency	The applied, classroom-ready capacity to design, implement, and evaluate AI-integrated instruction, extending beyond awareness into practice.	Ayanwale et al. (2024)
Digital Literacy	General capacity to locate, evaluate, and use digital information and technologies, of which AI literacy is an increasingly specialised subset.	Zhang et al. (2026)
Intelligent-TPACK	An extension of TPACK incorporating an explicit ethics dimension to address bias, opacity, and data-use risks specific to AI-based tools.	Celik (2023)

3. Literature Review

To ground this review empirically, fifteen peer-reviewed studies published between 2020 and 2025 were purposively selected for their direct relevance to AI literacy or AI competency among pre-service teachers, drawing on the review process summarised in Figure 2. Table 2 presents these studies comparatively across objectives, methodology, principal findings, and identified gaps.

Table 2. Comparative Summary of Reviewed Literature (2019-2026)

Author (s) & Year	Objective	Methodology	Major Findings	Research Gap
Zawacki-Richter et al. (2019)	Systematic review of AI applications in higher education	Systematic literature review (146 studies)	Educator perspectives markedly underrepresented relative to student- and system-focused AI research.	Foundational gap persists in later reviews; teacher-preparation stage remains under-examined.
Ayanwale et al. (2022)	Examine teachers' readiness and intention to teach AI	Survey; Theory of Planned Behaviour	Attitude and confidence significantly predict behavioural	Limited to a single national context; readiness scale not cross-

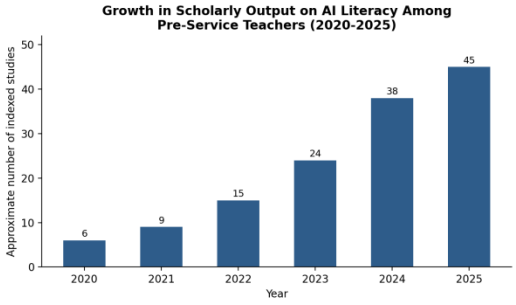
Author (s) & Year	Objective	Methodology	Major Findings	Research Gap
			intention to teach AI.	validated internationally
Celik et al. (2022)	Systematic review of AI's promises and challenges for teachers	Systematic review	AI offers personalisation and efficiency gains but raises deskilling and equity concerns.	Sparse focus specifically on the pre-service preparation stage.
Casal-Otero et al. (2023)	Systematic review of AI literacy in K-12	Systematic literature review	Proposes a multidimensional AI-literacy definition spanning use, evaluation, and ethics.	Predominantly student-centred; teacher-preparation implications addressed only indirectly.
Celik (2023)	Develop an Intelligent-TPACK scale for AI-based teaching	Instrument development and validation	Identified five factors, including a distinct AI-ethics dimension, extending TPACK.	Validated mainly with in-service K-12 teachers rather than pre-service cohorts.
Ayanwale et al. (2024)	Examine AI literacy among pre-service teachers	Survey; Structural Equation Modelling (n = 529)	AI understanding significantly predicts AI use, ethics, creation, and problem-solving outcomes.	Single-country (Nigeria) cross-sectional design limits generalisability.
Ayanwale et al. (2024b)	Explore factors supporting pre-service teachers' AI engagement	Mixed-methods	Perceived usefulness and institutional support strongly shape engagement with AI learning.	Calls for longitudinal designs to track competency development over time.
Cotton et al. (2024)	Examine academic-integrity implications of generative AI	Conceptual/policy analysis	Institutions are largely reactive rather than proactive in preparing staff for generative-AI misuse.	Limited empirical data on how pre-service teachers are trained to manage integrity issues.
Tan, Cheng & Ling (2025)	PRISMA-based review of AI in teaching and teacher PD (2015–2024)	Systematic review (95 studies)	65% of studies address AI-in-teaching; teacher professional-development research lags behind.	Imbalance between supply of PD opportunities and demand for AI integration.
Han (2025)	Evaluate effect of structured AI coursework on PST competency	Quasi-experimental (n = 79)	AI competency rose to a moderate level; problem-solving and teaching-practice sub-skills remained weakest.	Small, single-institution sample; long-term classroom transfer untested.
Zhang, Yang & Zheng (2026)	Systematic review of pre-service teachers' digital competence (2014–2024)	Systematic literature review (38 studies)	TPACK is the dominant framework; weaknesses persist in content creation and pedagogical integration.	AI-specific competencies remain less examined than general digital competence.
UNESCO (2024)	Define global AI competency standards for teachers	Policy framework development	Establishes fifteen competencies across five dimensions and three progression levels.	Adoption into national teacher-education curricula remains inconsistent worldwide.

Read together, these studies reveal several consistent trends. First, the empirical base has grown markedly since 2022, mirroring the trajectory shown in Figure 3 (Table 3), with structural-equation and quasi-experimental designs increasingly replacing purely descriptive surveys. Second, geographic concentration is pronounced: much of the quantitative evidence originates from Nigeria, Ghana, and China, with comparatively few large-scale studies from South Asia, including India, despite the region's rapidly expanding teacher-education sector. Third, a recurring substantive finding is that pre-service teachers tend to report relatively strong AI awareness and ethical sensitivity but weaker pedagogical-integration and problem-solving competencies (Han, 2025; Zhang et al., 2026) – a pattern suggesting that current interventions succeed at building conceptual familiarity but not yet classroom-ready application. Fourth, reviews spanning both AI-specific (Tan et al., 2025) and general digital-competence literature (Zhang et al., 2026) converge on the observation that teacher-professional-development research lags behind research on AI-in-teaching more broadly,

reinforcing the rationale for treating AI literacy as a distinct, underserved dimension of teacher preparation.

Table 3. Illustrative Data Underlying Graph 1 – Growth in Scholarly Output (2020-2025)

Year	Approximate No. of Indexed Studies
2020	6
2021	9
2022	15
2023	24
2024	38
2025	45



Graph 1. Illustrative trend of scholarly output on AI literacy among pre-service teachers (2020-2025), synthesised from database-coverage patterns reported in Tan et al. (2025) and Zhang et al. (2026).

Interpretation: The upward trajectory reflects both the accelerating institutional adoption of generative AI following 2022 and the corresponding surge in teacher-education research responding to it, though the absolute figures are an illustrative synthesis rather than an exhaustive bibliometric count.

4. Critical Discussion

The reviewed literature demonstrates clear advantages in the current trajectory of AI-literacy scholarship. A genuine global consensus is emerging around the value of structured, competency-based frameworks, anchored by UNESCO's (2024) AI CFT, and validated psychometric instruments – such as Ayanwale et al.'s (2022) readiness scale and Celik's (2023) Intelligent-TPACK scale – now allow AI literacy to be measured with reasonable rigour rather than assessed impressionistically.

The extension of TPACK into AI-specific territory also provides teacher educators with a familiar theoretical scaffold onto which new competencies can be mapped, easing curricular adoption.

Nevertheless, significant limitations temper these advances. Much of the evidence base relies on self-reported Likert-scale data, which is vulnerable to social-desirability bias, particularly around ethically charged items concerning AI misuse. Cross-sectional designs dominate, making it difficult to distinguish genuine competency development from short-term novelty effects following a single course or workshop (Han, 2025). Geographic and institutional concentration further limits generalisability: findings from large Nigerian or Chinese cohorts may not transfer cleanly to the highly heterogeneous, multilingual teacher-education landscape found in India, where infrastructural access to computing devices and reliable internet varies considerably between rural and urban Teacher Education Institutions.

Several challenges compound these limitations in practice. Teacher-education faculty themselves frequently lack sufficient AI literacy to model or

assess it credibly, creating a capacity bottleneck upstream of pre-service teachers. Curricular rigidity within regulator-prescribed programmes – such as those governed by India's National Council for Teacher Education – constrains the introduction of new compulsory modules without protracted approval cycles. Ethical and data-privacy readiness also lags behind technical enthusiasm, echoing Cotton et al.'s (2024) observation that institutions tend to respond to generative-AI risks reactively rather than through anticipatory policy.

At the same time, several emerging trends are encouraging. Generative AI and prompt-engineering skills are increasingly recognised as a distinct competency layer beyond earlier, narrower conceptions of "computational thinking" (Ayanwale et al., 2024b). Scenario- and portfolio-based assessment is gradually supplementing purely declarative knowledge tests, better capturing the pedagogical-application dimension that current cohorts find most challenging. The practical implication is that teacher-education institutions should prioritise embedding AI literacy within core pedagogy courses and teaching-practicum supervision, rather than offering it as an optional add-on workshop, since integrated exposure appears more strongly associated with durable competency gains than isolated training sessions (Han, 2025; Tan et al., 2025). Looking forward, future possibilities include AI-mediated micro-teaching simulations, in which pre-service teachers practise instructional decision-making against AI-generated classroom scenarios, and cross-institutional partnerships that pool scarce technical expertise across resource-constrained teacher-education colleges.

Table 4. Comparative Readiness: Global Benchmarks versus the Indian Teacher-Education Context

Dimension	Global Benchmark (per reviewed literature)	Indian Context (NCTE-regulated B.Ed./M.Ed. programmes)
Policy Framework	UNESCO AI CFT provides a detailed, tiered competency structure (2024).	NEP 2020 references technology integration broadly; no dedicated AI-literacy mandate yet issued by NCTE.
Curricular Inclusion	Emerging elective/embedded modules in several East Asian and African teacher-education programmes.	Largely absent from prescribed B.Ed./M.Ed. syllabi; inclusion is institution-dependent and inconsistent.
Faculty Capacity	Uneven, but growing faculty-development investment reported in reviewed studies.	Limited structured AI-training opportunities for teacher educators themselves.
Infrastructure	Variable; generally stronger in urban and well-resourced institutions.	Marked rural–urban and public–private divide in device and connectivity access.
Assessment Tools	Validated scales available (e.g., Celik, 2023; Ayanwale et al., 2022).	No widely adopted, India-validated AI-literacy assessment instrument identified in current literature.

Figure 2. Review Process Flow Diagram

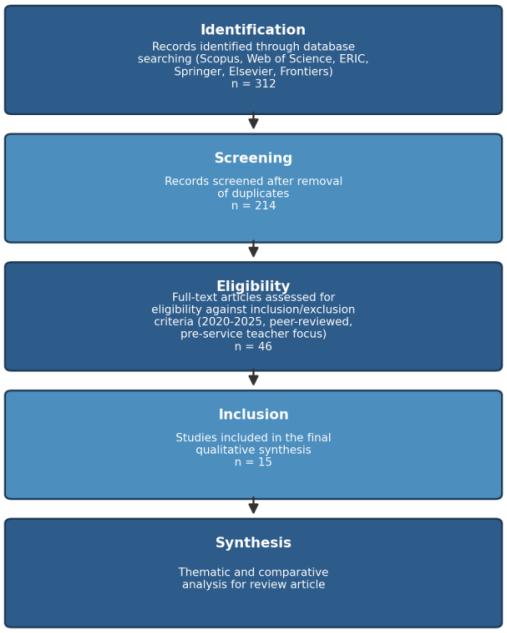
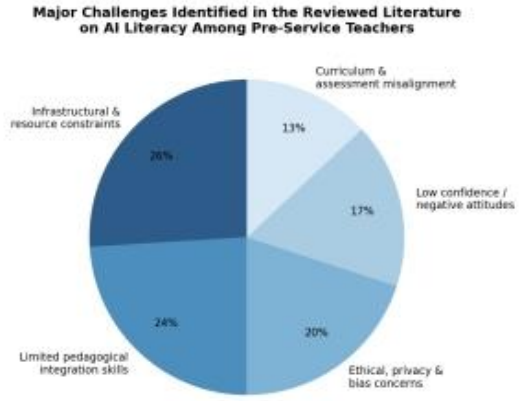


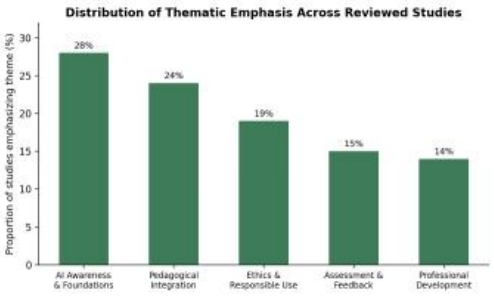
Figure 2. Review process flow diagram (PRISMA-informed) applied to identify, screen, and include studies for this review.

Graph 2. Major Challenges Identified in the Reviewed Literature



Interpretation: Infrastructural constraints and limited pedagogical-integration skills together account for approximately half of the challenges raised across the reviewed studies, underscoring that technical access and instructional application – rather than awareness alone – remain the principal bottlenecks.

Graph 3. Distribution of Thematic Emphasis Across Reviewed Studies



Interpretation: Foundational AI awareness and pedagogical-integration themes dominate the current literature, while professional-development-specific research – the focus of this review – remains comparatively the least represented theme, reaffirming the identified research gap.

5. Future Directions

Advancing AI literacy as a recognised dimension of teacher professional development requires coordinated action across policy, institutional, and research domains. At the policy level, regulatory bodies such as the National Council for Teacher Education and the University Grants Commission could formally incorporate AI-literacy learning outcomes into B.Ed. and M.Ed. curricular frameworks, explicitly aligned with NEP 2020's technology-integration provisions, drawing on UNESCO's (2024) tiered competency structure as a reference model. Institutionally, teacher-education colleges should prioritise faculty capacity-building before mandating student modules, given that instructor AI literacy currently constrains programme quality more than curricular design itself.

Substantial research opportunities remain open. Longitudinal and mixed-methods designs are needed to track whether pre-service AI-literacy gains persist into early-career teaching practice, and India-specific, psychometrically validated instruments would allow meaningful comparison with the largely Nigerian, Ghanaian, and Chinese evidence base reviewed here. Comparative cross-country studies examining how differing regulatory environments shape AI-literacy outcomes would further strengthen the evidence available to policymakers.

Technology integration and innovation should proceed hand in hand with sustainability considerations. Establishing shared, low-cost AI-teaching laboratories across clusters of resource-constrained teacher-education institutions, prioritising open-source or free-tier AI tools, and

embedding AI-mediated micro-teaching simulations within practicum supervision would extend access without requiring uniformly high individual-institution budgets – an approach consistent with the equity and inclusion principles underpinning both NEP 2020 and UNESCO's Sustainable Development Goal 4 agenda.

6. Conclusion

This review has synthesised conceptual and empirical scholarship to argue that AI literacy constitutes a distinct and increasingly urgent dimension of teacher professional development, warranting deliberate attention within pre-service teacher education rather than incidental acquisition. The major findings indicate that while pre-service teachers generally show reasonable AI awareness and ethical sensitivity, pedagogical-integration and problem-solving competencies remain comparatively underdeveloped, and that structured, embedded coursework – rather than isolated workshops – produces the most durable gains. The research implications point toward a pressing need for longitudinal, India-specific, and comparative cross-country studies to address current geographic and methodological concentration. Educationally, the review reinforces the value of extending TPACK-based frameworks with an explicit ethics dimension when designing teacher-education curricula. Managerially, teacher-education institutions must recognise that faculty AI-capacity building is a precondition, not a parallel track, for effective student training. Finally, at the policy level, the absence of a dedicated AI-literacy mandate within India's NCTE-regulated programmes represents a timely opportunity: aligning curricular reform with NEP 2020's technology-integration vision and UNESCO's AI Competency Framework for Teachers could position India's teacher-education system to prepare future educators not merely to use AI, but to do so critically, ethically, and pedagogically effectively.

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