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# Systematic Review on Teacher Education and the Integration of Artificial Intelligence

Nirumala Rothinam[1*], Ramachandran Vengrasalam[2], Samikannu Jabamoney[3], Sivabala Naidu[4], Ranjit Singh Gill[5], Andrew L. S. Foong[6]

[1,2,3,4,5,6] *Quest International University, Perak, Malaysia, nirumala.rothinam@qiu.edu.my, rama.vengra@qiu.edu.my, samikkanu.jabamoney@qiu.edu.my, sivabala.naidu@qiu.edu.my, ranjit.gill@qiu.edu.my, andrew.foong@qiu.edu.my*

*Corresponding Author: nirumala.rothinam@qiu.edu.my

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## ABSTRACT

The rapid expansion of Generative Artificial Intelligence (GenAI), AIGC tools, and digital simulations is reshaping teacher education. However, research on how these technologies is integrated into pre-service and in-service teacher training remains fragmented, with limited synthesis across pedagogical, psychological, and institutional dimensions. This systematic review synthesizes empirical evidence (2025) on the integration of GenAI and digital simulations in teacher training programmes, examining their effects on pedagogical competencies, digital readiness, and professional identity formation. The bibliographic coupling results show that the included studies cluster into four main intellectual groups. The strongest cluster focuses on teaching and learning foundations, reflecting shared pedagogical references. A second cluster centres on teacher education and professional development, linked through TPACK, readiness, and adoption models. A third cluster connects curriculum and subject-specific research, while a fourth highlights technology-driven studies on AI, VR/AR, and digital learning environments. Together, these clusters illustrate both a common theoretical base and growing diversification in AI-related teacher education research. GenAI emerged as a pedagogical partner that enhances lesson planning, differentiation, feedback, and teacher self-directed professional development. Digital simulations, including VR, avatar-based environments, and 3D modelling, supported communication skills, design thinking, and scenario-based decision-making. Across studies, teachers displayed curiosity and optimism but lacked comprehensive AI literacy, with readiness shaped by TPACK profiles, digital-competence frameworks, TAM and TPB constructs, and evolving professional identities. Key barriers included infrastructure inequality, insufficient training, overreliance on self-report outcomes, and concerns about creativity, authenticity, and ethical use. Teacher education programmes must embed structured AI-literacy curricula, model AI-rich instruction, ensure equitable access to technological infrastructure, and strengthen institutional support systems. Policy frameworks should incorporate ethical guidelines, assessment standards, and mechanisms for sustained professional development. AI-enabled teacher training holds substantial potential to enhance pedagogical competence and reshape professional identity. Yet its effectiveness depends on long-term integration, rigorous evaluation, and equitable implementation. Coordinated curricular, institutional, and policy reforms are essential for translating AI innovation into meaningful and sustainable teacher development.

**Keywords:** Generative AI, Teacher Education, Digital Simulations, AI Literacy, Technology Acceptance

## INTRODUCTION

The integration of emerging technologies into education has become an essential component of contemporary teacher preparation. Recent empirical work demonstrates that Generative AI (GenAI) and digital simulations create powerful opportunities to personalise teacher training, support instructional decision-making, and model complex

classroom interactions without exposing real students to risk. Yet, despite their rapid uptake across educational systems, the development of robust, evidence-based pedagogical frameworks has not kept pace with technological advancements. This gap underscores the need for a systematic synthesis of current research to understand how these tools are being implemented and to what extent they influence teacher readiness and professional growth. The purpose of this systematic review is to search for, assess, and summarize the determinants of effective technology integration in teacher training. Specifically, this review seeks to explore the contextual factors (e.g., curriculum design, mentorship models) influencing the adoption of GenAI and simulations.

## Background

The VOSviewer bibliometric map (Figure 1) provides a visual representation of the dominant research themes, relationships, and structural dynamics within contemporary teacher education literature. Each node represents a frequently occurring keyword, and the spatial arrangement, clustering, and link strength illustrate how closely related these terms are within published research. The map is divided into several dense clusters, each reflecting a conceptual domain within teacher education. At the centre of the map, large nodes such as teaching, teacher training, teacher education, curriculum, and professional development dominate the visual field. The size and central positioning of these nodes indicate their high frequency and foundational role in shaping the broader research landscape. The dense interconnections between them suggest that traditional pedagogical concepts still anchor the field, reinforcing that research continues to prioritise core questions about instructional practices, teacher preparation models, and curricular planning.

Surrounding this core are clusters associated with educational technology, ICT, e-learning, and curriculum development. These clusters appear closely linked to the central pedagogical terms, signalling a clear integrative shift toward technology-enhanced learning. Their proximity to the central nodes reflects how digitalisation is no longer treated as an external add-on but has become an embedded component of teaching, assessment, and instructional design. This alignment echoes recent arguments that AI-supported learning environments and personalised systems are progressively reshaping educational ecosystems (Shoukat et al., 2025). The map also contains bridging nodes, such as professional identity, inclusion, environmental education, engineering education, and health education—that serve as connectors between core pedagogical clusters and specialised subfields. These bridging terms indicate diversification within teacher education research, where scholars examine how teaching practices intersect with broader social, cultural, and disciplinary contexts. Their presence highlights expanding research interest in the multidimensional roles teachers are expected to fulfil.

However, what is most noteworthy in the VOSviewer map is the comparatively weak representation of keywords directly associated with artificial intelligence, generative AI, digital simulations, virtual reality, and AI-mediated pedagogy. These terms appear on the periphery of the map, often forming small or isolated clusters with fewer linkages to the dominant pedagogical structures. This underrepresentation suggests that although AI is gaining prominence globally, its pedagogical and identity-related implications are still emerging as research topics. This visual pattern aligns with current discussions emphasising both the promise and the uncertainty surrounding AI's role in shaping future educational models (Cascu, 2025; Yang et al., 2025). The map therefore reveals a critical opportunity for synthesis: while traditional pedagogical themes remain firmly established, and technological terms are expanding, AI-related research has not yet integrated deeply into the mainstream teacher education discourse. Instead, generative AI, immersive simulations, and adaptive learning systems remain fragmented lines of inquiry, signalling an early-stage research field that is ripe for consolidation. Interpreting the VOSviewer map in this way demonstrates why a systematic review is timely and necessary. The visual structure provides concrete evidence of a developing but insufficiently connected knowledge base at the intersection of teacher training and advanced digital technologies, precisely the area that this review aims to clarify and synthesise.

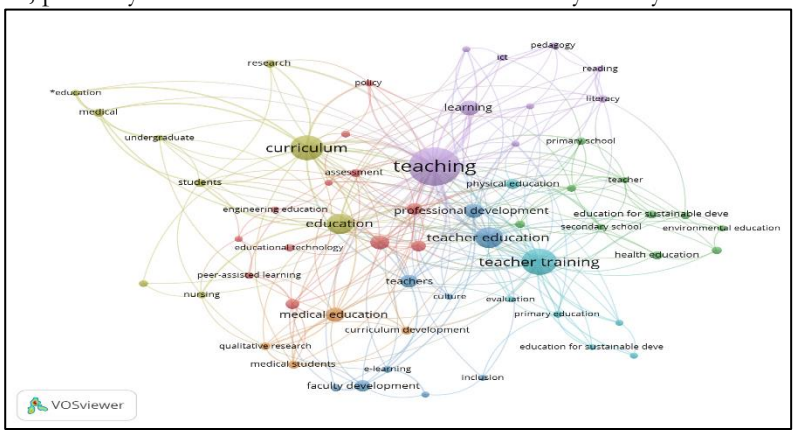


**Figure 1:** VOSviewer bibliometric map

 

## METHODS

### Eligibility Criteria

The review applied clearly defined eligibility criteria to ensure that only studies directly relevant to the integration of Generative AI and digital simulations in teacher education were included. To capture the rapid evolution of AI technologies, the timeframe was restricted to publications between 2024 and 2026, a period that reflects the emergence and widespread adoption of advanced models such as ChatGPT-4, Gemini, and AIGC platforms. Only empirical studies were eligible, as the review aimed to synthesise evidence based on actual implementation, teacher behaviour, and measurable educational outcomes rather than theoretical propositions or opinion-based discussions. Studies were required to be written in English and must have focused explicitly on pre-service or in-service teacher training, including professional development programmes, teacher preparation courses, or internship-based pedagogical interventions. Research that examined AI solely from a learner perspective, addressed policy-level issues without reporting teacher-level data, or explored educational technologies unrelated to AI or simulation-based systems was excluded to maintain conceptual clarity and relevance.

### Information Sources

To ensure comprehensive coverage, systematic searches were conducted using three major academic databases: Scopus, Web of Science, and ERIC. These databases were selected due to their extensive indexing of education, technology, and interdisciplinary research, which is crucial for a topic situated at the intersection of AI and teacher training. Scopus and Web of Science provided broad access to peer-reviewed journals in educational technology, computer science, and teacher education, while ERIC contributed high-quality educational research and practitioner-focused studies. Together, these sources ensured that the review captured both methodological diversity and geographical breadth across different teacher education contexts.

### Search Strategy

The search strategy was designed to identify studies that not only used AI tools but integrated them meaningfully into teaching and learning processes within teacher-training environments. A combination of keywords and Boolean operators was employed, drawing from terms associated with AI, pedagogy, and teacher development. Search expressions included variations of "Generative AI," "AI in teacher education," "teacher training," "virtual or digital simulations," "AIGC," "pedagogical competence," and "professional identity." The search strategy emphasised studies that examined how teachers engaged with AI tools within structured training experiences rather than those that merely surveyed attitudes or speculated on potential future uses. This approach ensured that the resulting dataset reflected concrete empirical evidence of AI-mediated pedagogical change.

### Selection Process

Study selection as shown in Figure 2 followed a structured, multi-phase procedure aligned with PRISMA recommendations. The initial search results were screened at the title and abstract level to remove studies that clearly did not meet the eligibility criteria. Common reasons for exclusion at this stage included a primary focus on student learning outcomes, insufficient connection to teacher training, absence of AI-related interventions, or the lack of empirical methodology. Full texts of potentially relevant studies were then retrieved and examined in detail to determine their suitability for inclusion. During this stage, studies were excluded if they described AI conceptually without presenting empirical findings, if they involved technologies unrelated to AI or digital simulations, or if they provided insufficient methodological detail to allow meaningful analysis. Only studies demonstrating explicit empirical engagement with AI or simulation-based interventions in teacher-training contexts were retained for synthesis.

 

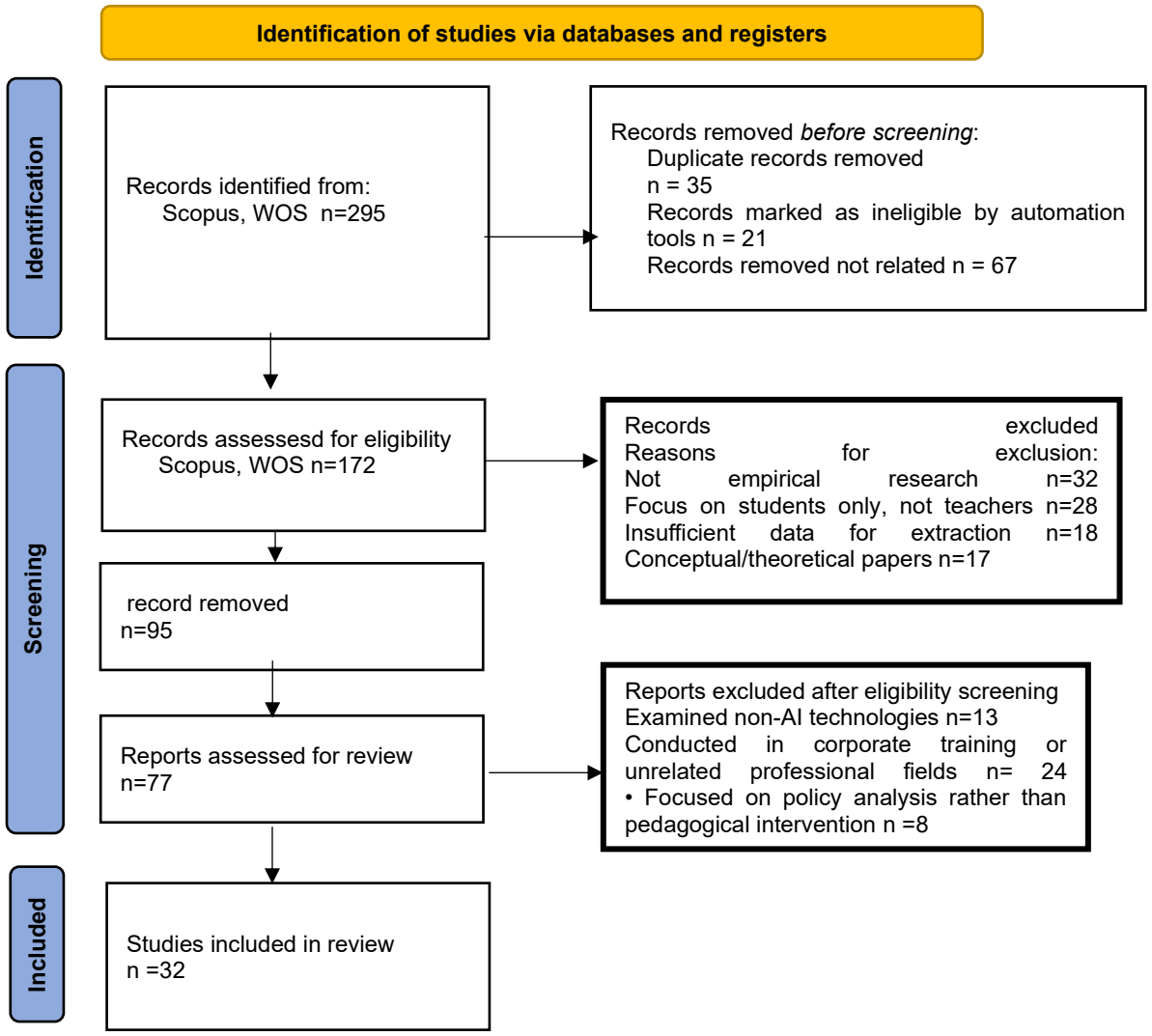


**Figure 2:** PRISMA diagram

### Data Collection Process

The final set of studies was subjected to a detailed data extraction process using a structured template designed to support consistency and comparability. For each study, information was collected on publication details, country or region, research setting, characteristics of participants (including teacher status, sample size, and demographic features where available), and methodological design. Additional attention was given to identifying the specific AI tools or simulation systems utilised, the nature of the pedagogical or professional-development intervention, and the theoretical frameworks underpinning the study. Extracted outcomes included changes in pedagogical competence, professional identity, perceived usefulness of AI, digital readiness, self-efficacy, and other indicators of teacher development. This systematic approach not only ensured rigour but also facilitated a coherent synthesis of findings across studies that varied widely in design, population, and instructional context. A standardized data extraction form was developed by the research team to ensure consistency in coding and interpretation. Although the form was not formally piloted, it was collaboratively refined during the initial phase of data extraction. The final version is displayed in Figure 2. Thematic analysis was conducted using an inductive coding approach, without the use of qualitative analysis software. The authors independently coded the extracted data manually using Microsoft Excel. The themes were identified through iterative comparison, and disagreements were resolved in consultation.

### Risk of Bias Assessment

In accordance with PRISMA 2020 guidelines, the methodological quality of the 32 included studies was assessed with attention to potential risks of bias arising from study design, sampling procedures, measurement practices, and reporting completeness. Sampling bias was evident in several studies, particularly those using small, convenience-based, or single-institution samples. Examples include pre-service teacher cohorts with fewer than 50 participants (e.g., Cai et al., 2025; Fecke et al., 2025; Setiyawan et al., 2025) and qualitative studies with highly

 

limited participant numbers (e.g., Mnguni, 2025; Isma'il & Ibrahim, 2025). Such sampling approaches restrict external validity and limit the generalisability of findings across broader teacher populations. Large-scale surveys (e.g., Lucas et al., 2025; Tomczyk & Majkut, 2025; Aimicheva et al., 2025) help address this issue but still rely on voluntary participation, which may introduce self-selection bias. Measurement bias emerged due to the widespread reliance on self-reported outcomes, including perceived readiness, digital competence, attitudes, anxiety, and behavioural intention (e.g., Lucas et al., 2025; Tomczyk & Majkut, 2025; Hazzan-Bishara et al., 2025). Self-report instruments are vulnerable to recall inaccuracies and social desirability effects, thereby limiting the accuracy of assessments related to actual teaching performance or long-term behavioural change.

Moreover, instrument validity and reliability varied across studies. Although some utilised validated frameworks such as TPACK, TAM/EETAM, DigCompEdu, or established digital competence scales, others relied on researcher-developed instruments with limited psychometric reporting (e.g., Dalyanci et al., 2025; Jaksic et al., 2025). Inadequate reporting of scale development, factor structure, or reliability coefficients affects internal validity and increases the risk of measurement bias.For qualitative and mixed-methods studies, several did not describe inter-coder agreement or triangulation procedures (e.g., Żammit, 2025; Mnguni, 2025), raising concerns about subjective interpretation bias and analytic reliability.In intervention and experimental studies, such as AI-supported teaching internships or simulation-based training (e.g., Zheng, 2025; Rogers & Maccormac, 2025; Dogan & Gogus, 2025), instructor-evaluators were sometimes the same individuals delivering the intervention, introducing potential expectancy bias and compromising the objectivity of outcome assessments. Finally, reporting bias was observed where studies did not fully disclose methodological procedures, sampling strategies, or limitations, making it difficult to fully determine the robustness of findings. Overall, consistent with PRISMA expectations, the included studies provide valuable evidence on AI and simulation integration in teacher education; however, risks of bias related to sampling, measurement, and reporting suggest that conclusions should be interpreted with caution, and future research should incorporate more rigorous and transparent methodological practices.

## RESULTS

### Study Selection

The database search initially identified 295 records from Scopus and Web of Science. After removing 35 duplicates and 88 records flagged through automation or preliminary screening, 172 records proceeded to title and abstract review. A further 95 records were removed at this stage, mainly because they did not report empirical data on teacher training or focused exclusively on student outcomes. Full-text screening of 77 articles led to the exclusion of studies that examined non-AI technologies, those situated in corporate or non-educational training settings, and papers that discussed AI only at the level of policy without a pedagogical intervention component. The final sample comprised 32 empirical studies that directly investigated the integration of Generative AI, AIGC tools, or digital simulations in pre-service or in-service teacher education.

### Study Characteristics

The 32 studies span a wide geographical range, including Europe (Portugal, Spain, Malta, Poland, Turkey, Kazakhstan), Asia (China, Vietnam, Thailand, Indonesia), Africa (South Africa, Nigeria), and North America, with a small number of cross-regional or international samples. This diversity demonstrates that experimentation with AI-enhanced teacher training is a genuinely global phenomenon, but coverage remains uneven, with most work clustered in European and East Asian contexts. In terms of participants, the studies include pre-service teachers enrolled in initial teacher education programmes (for example, Cai et al., 2025; Lucas et al., 2025; Momdjian et al., 2025), early-career or beginning teachers and experienced in-service teachers in school or university settings (Aimicheva et al., 2025; Chen et al., 2025; Tomczyk & Majkut, 2025). Several studies extend the lens to teacher educators and university professors responsible for designing training programmes, particularly in relation to sustainability and SDGs (Espejo-Antúnez et al., 2025) or design education (Huang et al., 2025).

Methodologically, quantitative survey designs are most common, often using established frameworks such as TPACK, TAM or extended technology-acceptance models (Lucas et al., 2025; Wang et al., 2023; Hazzan-Bishara et al., 2025; Tomczyk & Majkut, 2025). Mixed-methods approaches combine surveys with interviews, observations or artefact analysis (Li et al., 2025; Chen et al., 2025; Somabut et al., 2025), while in-depth qualitative studies rely on phenomenology or thematic analysis to capture identity and belief structures (Isma'il & Ibrahim, 2025; Mnguni, 2025; Żammit, 2025). Experimental and quasi-experimental designs are less frequent but provide stronger causal evidence where they appear, for example in AI-supported internships (Zheng, 2025), AI co-teacher experiments (Niloy et al., 2025), and scenario-based simulation courses (Rogers & Maccormac, 2025).Overall, the dataset reveals a research field that is methodologically diverse but still dominated by self-report measures of readiness, attitude

 

and perceived competence, with comparatively fewer studies using objective performance indicators or long-term follow-up.

## Thematic Findings

### Generative AI as a Pedagogical Partner

A first major theme concerns the role of Generative AI as a pedagogical partner in teacher training. Several studies treat GenAI not merely as a productivity tool but as an active participant in the learning process. Niloy et al. (2025) demonstrate that a GenAI "co-teacher" in blended courses enables human teachers to cover approximately a quarter more content while simultaneously improving student satisfaction and achievement, suggesting that AI can assume part of the routine explanation and feedback workload. Similarly, Chang and Sun (2025) show that bilingual teachers use multimodal GenAI to design adaptive tasks, differentiate materials, and personalise instruction for diverse learners, although they also emphasise the need for explicit AI-literacy support for teachers.

At the level of teacher professional development, Li et al. (2025) illustrate how teachers appropriate ChatGPT as a self-directed PD partner. Teachers use the system to brainstorm ideas, rehearse explanations, and monitor their own professional goals, reporting high "self-management" in organising their learning. Jaksic et al. (2025) document similar patterns in AI-focused workshops: after short, intensive exposure to AI concepts and tools, high-school teachers show increased confidence and intention to integrate AI topics into their teaching.

At the same time, several studies underline the ambivalence of this partnership. Dalyanci et al. (2025) report that teachers appreciate GenAI's time-saving and personalisation potential but also express sustained concerns about plagiarism, reliability, and the possible erosion of students' critical thinking. Tomczyk and Majkut (2025) find that among Polish teachers, perceived usefulness and digital competence strongly predict AI use, whereas AI-related anxiety exerts only a minor negative effect; nevertheless, advanced pedagogical uses of GenAI remain rare, with most teachers limiting their use to information search and translation. Taken together, these studies suggest that GenAI is beginning to function as a "just-in-time mentor" for both teachers and students, but the depth of pedagogical integration is uneven and closely tied to levels of AI-specific competence and institutional support.

### Digital Simulations and VR for Competency Development

A second cluster of findings highlights the role of simulations, VR, and 3D environments in bridging the gap between theory and practice. Fecke et al. (2025) compare avatar-based and video-based digital simulations for communication training with pre-service teachers; avatar environments significantly reduce social inhibition and yield higher communication-skill ratings, suggesting that immersive, low-risk settings can support practice of challenging interpersonal skills. In nursing education, Rogers and Maccormac (2025) show that scenario-based blended learning combining virtual simulations with in-person debriefings improves students' perceived understanding and self-efficacy, while participants explicitly request a balanced mix of online and face-to-face elements. In vocational and technical education, simulations support domain-specific design thinking. Setiyawan et al. (2025) report that 3D modelling and printing for automotive prototyping helps pre-service vocational teachers develop deeper conceptual understanding of components and fosters positive attitudes toward integrating similar tools in their future classrooms. Wahelo et al. (2025) demonstrate that teachers with stronger "environmental identity" are more likely to adopt problem-based and simulation-rich pedagogies in climate-change education, indicating that values and identity intersect with simulation uptake.

At a broader institutional level, Chen (2025) shows that VR and AR technologies can modernise educational management by improving access to teaching resources and increasing operational efficiency. Although this study sits slightly outside traditional teacher training, it underscores how virtual environments can reshape the wider infrastructure within which teacher professional learning occurs.Across these studies, simulations function as protected spaces where trainees rehearse decision-making, communication and design without real-world consequences. However, they also demand substantial technological infrastructure and pedagogical design expertise, which not all institutions currently possess.

### Teacher Readiness, Digital Competence and AI Literacy

A third theme concerns the varying levels of teacher readiness and digital competence required for meaningful AI integration. Several large-scale surveys document substantial gaps in AI-related skills and knowledge. Aimicheva et al. (2025) find that Kazakhstani in-service teachers report high enthusiasm and perceived contextual maturity in applying digital technologies, yet the study still highlights the importance of targeted competence frameworks (TPACK and DigCompEdu) to guide professional growth. Cross-national comparisons reveal that initial teacher education programmes have not yet systematically embedded AI literacy. Lucas et al. (2025) show that pre-service teachers in Portugal and Spain feel unprepared to integrate AI into future teaching, citing limited opportunities for hands-on practice during their studies. Momdjian et al. (2025) demonstrate that among pre-service teachers, digital

 

competence develops most effectively when teacher educators model technology-rich teaching, rather than relying solely on direct instruction about tools.

Other studies explicitly conceptualise AI readiness as a multidimensional construct. Somabut et al. (2025) and Chen et al. (2025) both emphasise that teachers recognise the importance of GenAI but require structured professional development and clear policy guidance to move beyond cautious experimentation. Overall, the evidence points to a readiness gap: teachers are curious and often optimistic about AI, but systemic shortcomings in training, curriculum and infrastructure hinder sustained, pedagogically meaningful use.

**Professional Identity, Beliefs and Affective Responses**

A fourth theme addresses how AI integration intersects with teachers' professional identity and belief systems. Isma'il and Ibrahim (2025) show that science teachers initially fear that AI will erode their professional role, but through experience they come to view AI as a partner that supports rather than replaces them, shifting identity from "knowledge transmitter" to "facilitator of AI-mediated learning." Zheng (2025) reports that pre-service teachers undertaking AI-supported internships exhibit higher professional value, stronger sense of authority and reduced anxiety related to teaching identity, suggesting that carefully designed AI interventions can stabilise emerging professional selves.

Belief structures grounded in the Theory of Planned Behaviour are foregrounded in Mnguni's (2025) study of South African life-sciences pre-service teachers. Here, behavioural intentions to integrate AI are shaped by attitudes (perceived pedagogical benefits and philosophical concerns), behavioural beliefs (advantages and disadvantages), and subjective norms (inter-generational expectations, institutional authority, parental worries, and funding constraints). These nuanced findings illustrate why simply providing access to AI tools is insufficient; teachers' values, perceived control and social context strongly condition adoption. Studies on technology acceptance further show that psychological variables mediate between contextual factors and behaviour. Hazzan-Bishara et al. (2025) integrate external determinants such as institutional support with internal determinants like intrinsic motivation and self-efficacy, demonstrating that exposure to credible AI information and supportive environments enhances perceived usefulness and intention to use AI. Tomczyk and Majkut (2025) likewise find that attitudes and perceived competence, rather than anxiety, are the key predictors of actual AI use among Polish teachers. Together, these studies displayed in Table 1 reveal that AI adoption in teacher training is as much a matter of identity, beliefs and emotions as it is of technical skill.

**Table 1:** AI adoption in teacher

| AUTHORS | PARTICIPANTS | DESIGN | RESULT |
|---|---|---|---|
| Aimicheva, G., Shaikhanova, A., Iklassova, K., Tazabekova, P., Nazyrova, A., & Kadyr, Y. (2025). Fostering Teachers' Digital Competence in AI-Supported Learning Environments: Implications for Interactive Teaching and Student Achievement. *Applied Sciences*. | 916 in-service teachers from Kazakhstani secondary | survey | demonstrate high levels of interest and engagement: 96% of participants expressed readiness for further learning, 86% reported satisfaction with the course content, and 84% showed contextual maturity in applying newly acquired technologies in their instructional processes. |
| Alwaqdani, M. (2025). Investigating teachers' perceptions of artificial intelligence tools in education: potential and difficulties. *Education and Information Technologies*, *30*(3), 2737-2755. | 1101 Saudi teachers | questionnaire | The findings showed many teachers acknowledge AIED's potential to save time, assist in designing enriching activities, and personalize learning experiences, however, concerns exist regarding the effort required for training, potential |
| Cai, H., Han, B., Sun, J., Li, X., & Wong, L. H. (2025). Harnessing AI for teacher education to promote inclusive education: Investigating the effects of ChatGPT-supported lesson plan critiques on the development of pre-service teachers' lesson planning skills. *The Internet and Higher Education*, 101022. | 48 (Pre-service Teachers) | Lesson plan analysis, Epistemic Network Analysis | ChatGPT improved cognitive and affective critiques of lesson plans but was less effective for metacognitive feedback. |
| Carroll Steward, K., Gosselin, D., Bhattacharya, D., Chandler, M., & Forbes, C. T. (2025). Teachers' use and adaptation of a model-based climate curriculum: A three-year longitudinal study. *Journal of Geoscience Education*, *73*(1), 46-58. | 2 (Longitudinal Case) Longitudinal Case Study (3 yrs) | Interviews, Observations | Teachers struggled to fully implement model-based inquiry (simulations) without sustained support; curriculum adaptation required high fidelity. |
| Castro, A., Díaz, B., Aguilera, C., Prat, M., & Chávez-Herting, D. (2025). Identifying rural elementary teachers' perception challenges and opportunities in integrating artificial intelligence in teaching practices. *Sustainability*, *17*(6), 2748. | 45 (Rural Teachers) | TPACK Survey, Interviews | Teachers view AI as a supportive tool rather than a threat; limited infrastructure and professional development are major barriers. |
| Chang, W. L., & Sun, J. C. Y. (2025). Empowering Bilingual Teachers with Dynamic GenAI: Adaptive Design and Implementation of Multimodal Instructional Strategies. *Computers & Education*, 105490. | ~30 (Bilingual Teachers) | Retrospective interviews, Lesson plans | GenAI enables personalized learning environments; teachers value design support but need AI literacy training. |

 

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| Chen, R., Lee, V. R., & G Lee, M. (2025). A cross-sectional look at teacher reactions, worries, and professional development needs related to generative AI in an urban school district. *Education and Information Technologies*, 1-38. | 1,454 teachers | Surveys Interviews, Observations | Teachers in secondary school settings were less willing to allow AI chatbot usage, relative to those in elementary settings. While elementary and middle school teachers prioritized basic AI literacy as a professional development need, high school teachers emphasized strategies for guiding students to use AI and detecting AI-generated work. |
| Chen, X. (2025). Research on the modern method of educational management based on virtual augmented reality interaction technology. *GeoJournal*, *90*(3), 1-16. | 3000 Teachers / 200 Admins | Satisfaction Ratings, Data Analysis | AR improved management efficiency by 30%; 90% of teachers reported better access to teaching resources via VR/AR. |
| Cohn, C., Snyder, C., Fonteles, J. H., TS, A., Montenegro, J., & Biswas, G. (2025). A multimodal approach to support teacher, researcher and AI collaboration in STEM+ C learning environments. *British Journal of Educational Technology*, *56*(2), 595-620. | 1 Teacher (Case) | AI-generated multimodal timeline | AI visualization of classroom data helped the teacher reflect on feedback timing; demonstrated "human-AI collaboration" model. |
| Dalyanci, A. A., Mast, L., Krushinskaia, K., & Raes, A. (2025). Detecting Innovators in the Field: Teachers' Perceptions and Adoption of Generative AI in Education. *The Open/Technology in Education, Society, and Scholarship Association Journal*, *5*(1), 1-50. | 20 in-service teachers | Survey/Interview | as participants express enthusiasm about its potential for time-saving and personalized learning benefits, while also voicing significant concerns about plagiarism, GenAI's trustworthiness, and its possible negative impact on students' cognitive abilities. The study also highlights the current lack of sufficient training and support for teachers integrating GenAI. |
| Dogan, B., & Gogus, A. (2025). The Effect of the 'Instructional Technologies' Course on the Competencies of Teacher Candidates in Using Web 2.0 Tools: The Case of Early Childhood Education Program. *Technology, Knowledge and Learning*, *30*(2), 883-910. | 30 volunteer teacher candidates, the faculty, and the researcher from a foundation university in a metropolitan city | the semi-structured interview form | Course improved skills in creating digital materials; 2-hour duration was insufficient for long-term retention. findings suggest that the practice hours and functioning of the Instructional Technologies course in the Teacher Training Programs should be revised to support pre-service teachers' competencies in Türkiye. |
| Fecke, J., Lohberger, K., & Braun, E. (2025). The relationship between social inhibitions and various measures of communication skills in two types of digital simulations. *Computers & Education*, 105361. | 61 (Pre-service Teachers) | Observations, Self-reports | Avatar-based simulations significantly reduced social inhibitions and improved communication skills compared to video-based training. |
| Guan, L., Zhang, Y., & Gu, M. M. (2025). Pre-service teachers preparedness for AI-integrated education: An investigation from perceptions, capabilities, and teachers' identity changes. *Computers and Education: Artificial Intelligence*, *8*, 100341. | 24 pre-service teachers | survey | The findings indicate a need for more awareness of the possible changes in teachers' functions and roles in collaborative AI-integrated education, leading to specific teacher-training demands that aid them in success in AI-integrated education. |
| Hazzan-Bishara, A., Kol, O., & Levy, S. (2025). The factors affecting teachers' adoption of AI technologies: A unified model of external and internal determinants. *Education and Information Technologies*, 1-27. | 400 teachers | Survey | credible AI exposure and institutional support shape perceived usefulness and intention to use AI. The model highlights psychological and contextual determinants essential for effective AI adoption in education. |
| Heine, S., & König, J. (2025). Applying artificial intelligence in teacher education: Preservice teachers' attitudes and reflections in using ChatGPT for teaching and learning. *European Journal of Teacher Education*, *48*(5), 934-963. | 2023, we surveyed 1,687 preservice teachers | survey | Preservice teachers with positive attitudes towards ChatGPT reported higher digital self-efficacy; those with negative attitudes reported lower self-efficacy. While self-reported data limits interpretation, our findings provide an initial overview and suggest implications for AI's role in teacher education and evolving professional expectations. |
| Isma'il, A., & Ibrahim, H. B. (2025). Teachers' professional identity in the era of artificial intelligence: A phenomenological study. *International Journal of Professional Development, Learners and Learning*, *7*(2), e2517. | 30 (Science Teachers) | Semi-structured interviews | Teachers initially feared role erosion but evolved to view AI as a partner; identity shifted from "instructor" to "facilitator". |
| Jaksic, N., Ansaf, B., & Massey, M. (2025). Engaging High School Teachers with Artificial Intelligence Concepts, Applications, and Developments. *ASEE Computers in Education*, *14*(3). | ~20 (High School Teachers) | Surveys Pre/Post-Training Evaluation | Short-term intensive workshops significantly increased teachers' AI knowledge and confidence to integrate AI concepts. |
| Li, M., & Li, Y. (2025). Investigating the interrelationships of technological pedagogical readiness using PLS-SEM: A study of primary mathematics teachers in China. *Journal of Mathematics Teacher Education*, 1-23. | 554 primary mathematics teachers | survey | The findings underscore the pivotal roles of PD, CF, PCI, and STL in shaping mathematics teachers' readiness to integrate digital technologies. PD was notably influential, strengthening TPACK-related knowledge and indirectly enhancing teachers' technology-related attitudes. CF directly impacted readiness, while PCI significantly influenced perceived usefulness |

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| Li, Z., Wang, C., & Bonk, C. J. (2025). Generative AI for Teachers' Self-Directed Professional Development: A Mixed-Methods Study. *TechTrends*, 1-16. | 298 completed responses from K-12 schoolteachers | Surveys, Usage Logs Mixed Methods | Teachers successfully used ChatGPT for self-monitoring and goal-setting in PD; high "self-management" capabilities reported. |
| Liu, N. (2025). Exploring the factors influencing the adoption of artificial intelligence technology by university teachers: the mediating role of confidence and AI readiness. *BMC psychology*, *13*(1), 311. | 504 university teachers | survey | Confidence and AI readiness played a chain-mediating role in the relationship between subjective norms and behavioral intention |
| Martín-Gómez, S., & Ruiz, C. J. G. (2025). AI in Higher Education. Initial teacher training in the critical and didactic use of Artificial Intelligence. *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*. | 103 teacher candidates | Questionnaire (23 items) | 88% of trainees believe AI should be part of the curriculum; training improved "critical digital literacy" and prompt engineering skills. |
| Mnguni, L. (2025). A qualitative analysis of South African pre-service life sciences teachers' behavioral intentions for integrating AI in teaching. *Journal for STEM Education Research*, *8*(2), 230-256. | 10 purposively selected pre-service life sciences teachers in South Africa. | qualitative approach involving semi-structured interviews | The findings reveal that behavioral intentions are shaped by multiple factors within the framework of the Theory of Planned Behavior. Attitudes toward AI integration in life sciences education included themes such as pedagogical benefits, practical limitations, and philosophical concerns |
| Momdjian, L., Manegre, M., & Gutiérrez-Colón, M. (2025). A study of preservice teachers' digital competence development: Exploring the role of direct instruction, integrated practice, and modeling. *Evaluation and Program Planning*, *109*, 102538. | 399 PSTs / 84 Educators | DigCompEdu Survey | Modeling" by teacher educators was more effective than direct instruction for developing digital competence in trainees. |
| Niloy, A. C., Akter, S., Sultana, J., Rahman, M. A., Sultana, N., Prome, T. I., ... & Sen, A. (2025). Can generative AI Be an effective Co-Teacher? An experiment. *Computers and Education: Artificial Intelligence*, *8*, 100418. | 400 (Students/Teachers) | Pre/Post-tests, Reviews | AI co-teachers allowed physical teachers to cover 25% more content and increased student satisfaction and grades. |
| Oved, O., & Alt, D. (2025). Teachers' technological pedagogical content knowledge (TPACK) as a precursor to their perceived adopting of educational AI tools for teaching purposes. *Education and Information Technologies*, 1-27. | 514 teachers | Self-Efficacy Survey | It informs professional development, guiding targeted interventions to enhance teachers' technological and pedagogical skills for effective AI integration in classrooms. |
| Setiyawan, A., Soeharto, S., Maričić, M., & Lavicza, Z. (2025). Integrating 3D Modeling and Printing in Automotive Component Prototyping: Perceptions of Pre-service Vocational Teachers. *Technology, Knowledge and Learning*, 1-24. | 32 (Vocational PSTs) | Surveys, Reflections | 3D modeling simulations enhanced design thinking and prototyping skills; highly positive perception of utility for vocational training. |
| Somabut, A., Tuamsuk, K., Lowatcharin, G., Traiyarach, S., & Kwangmuang, P. (2025). Preparing for the AI era: Science teachers' readiness and professional development needs for generative AI integration in secondary education. *Social Sciences & Humanities Open*, *12*, 102259. | 30 science teachers | surveys, interviews, and document analysis. | While high teacher interest in AI integration (87 %) suggests promising potential, the study highlights the need for targeted interventions to address resource disparities and develop formal AI policies, particularly in smaller schools. |
| Tomczyk, Ł., & Majkut, A. (2025). Integrating AI in education: an analysis of factors influencing the acceptance, concerns, attitudes, competencies and use of generative artificial intelligence among Polish teachers. *Human Behavior and Emerging Technologies*, *2025*(1), 5599169. | 289 teachers | survey | Perceived usefulness and digital competence strongly predicted intention and actual use, while anxiety had minimal impact. Findings highlight limited advanced AI use and the need to strengthen teacher training and positive attitudes toward AI integration. |
| Tram, N. H. M. (2025). Unveiling the drivers of AI integration among language teachers: Integrating UTAUT and AI-TPACK. *Computers in the Schools*, *42*(2), 100-120. | 276 language teachers in Vietnam | survey | AI-TPACK emerges as a crucial factor, strongly influencing AI self-efficacy, performance expectancy, and effort expectancy. Facilitation is found to be a significant predictor of AI-TPACK. |
| Wahelo, T. T., Mengistu, D. A., & Merawi, T. M. (2025). Curbing environmental problems related to deforestation and climate change: The level of secondary school students' knowledge, attitudes and determinants in Metekel Zone, Northwest Ethiopia. *Geo: Geography and Environment*, *12*(1), e70004. | 134 Geography Teachers | Observations, Regression | Teachers with higher "environmental identity" were more likely to adopt problem-based/simulation methods. |
| Żammit, J. (2025). Secondary School Teachers' Experiences with Generative AI in Maltese Language Teaching. *Technology, Knowledge and Learning*, 1-19. | 47 (Secondary Teachers) | Semi-structured interviews | AI tools facilitated differentiated instruction and assessment; teachers reported increased student engagement but noted a lack of training. |
| Zheng, Z. (2025). The Impact of Artificial Intelligence on Pre-Service Teachers' Professional Identity: A Quasi-Experimental Study during Teaching Internships. In *SHS Web of Conferences* (Vol. 222, p. 01029). EDP Sciences. | 100 (Pre-service Teachers) | Pre/Post-tests (Identity/Anxiety scales) | AI-assisted internships improved "professional value" and "authority" while significantly reducing identity-related anxiety. |

## THEORETICAL FRAMEWORKS AND CONCEPTUAL CONTRIBUTIONS

Across the included studies (Figure 3), several theoretical frameworks shape how AI and digital simulations are conceptualised in teacher education. TPACK and related digital-competence models are especially prominent. Aimicheva et al. use a combined TPACK/DigCompEdu lens to show how contextual digital skills in AI-supported environments relate to interactive teaching and improved instructional design among in-service teachers in Kazakhstan. Momdjian et al. likewise draw on DigCompEdu to examine how direct instruction, integrated practice, and modelling influence preservice teachers' digital competence, concluding that modelling by teacher educators is the most powerful driver of meaningful technology integration. Oved and Alt focus directly on TPACK as a precursor to educational AI adoption and demonstrate that teachers' intention to use AI tools is linked to their overall TPACK profile, while actual use is most strongly driven by Technological Pedagogical Knowledge. Huang et al. extend this conversation by integrating TPACK with TAM in AIGC-based design education, showing that technological knowledge significantly supports the integration of content knowledge, whereas pedagogical knowledge is underutilised in guiding AIGC use. Together, these studies move TPACK beyond a generic technology-integration framework toward one that accommodates AI-specific affordances and constraints.

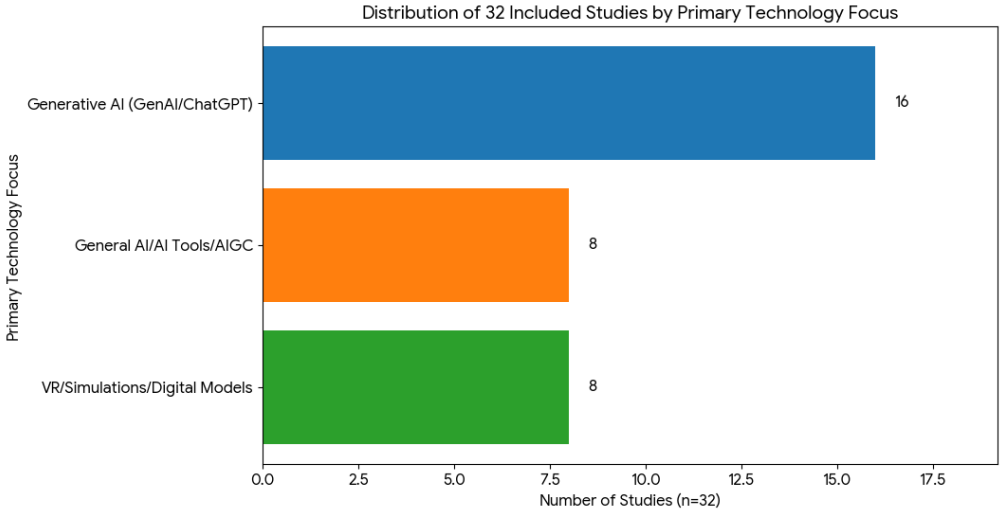


**Figure 3:** Distribution of studies

Technology acceptance models form a second conceptual backbone. Liu shows that subjective norms influence university teachers' intention to adopt AI, with confidence and AI readiness acting as key mediators, while Hazzan-Bishara et al. propose a unified model that integrates external determinants such as AI information exposure and institutional support with internal determinants such as intrinsic motivation and self-efficacy. Tomczyk and Majkut apply an Extended Educational Technology Acceptance Model to Polish teachers and demonstrate that perceived usefulness and digital competence are the strongest predictors of both intention and actual AI use, whereas anxiety plays a minimal role. Their cluster analysis, which distinguishes intensive users, occasional users, and non-users, refines our understanding of why some teachers move toward advanced AI use while others remain cautious.

The Theory of Planned Behaviour is explicitly mobilised in Mnguni's qualitative analysis of South African preservice life-sciences teachers, where attitudes, behavioural beliefs, subjective norms, and normative influences jointly shape intentions to integrate AI. This framework helps explain how perceived pedagogical benefits, philosophical worries, stakeholder expectations, and resource constraints interact in teacher decision-making. Identity-focused studies, such as those by Isma'il and Ibrahim, Zheng, and Żammit, add a further layer by showing how AI integration can shift teachers' self-perceptions from instructor to facilitator, enhance professional value and authority, and raise new questions about authenticity and creativity in AI-mediated classrooms. Taken together, these frameworks reveal that successful AI integration in teacher education is not solely a matter of technical competence. It requires the alignment of technological, pedagogical, and content knowledge with supportive attitudes, strong self-efficacy, coherent subjective norms, and institutional environments that legitimise AI use in both training and practice.

### Challenges and Limitations in Current Practice

Despite the promise highlighted in the reviewed studies, several consistent challenges emerge. One prominent issue is the short-term nature of many interventions. Dogan and Gogus show that an instructional technologies course significantly improves early-childhood teacher candidates' Web 2.0 and digital-material design skills, yet the

 

gains are difficult to sustain because the course is restricted to a brief two-hour weekly schedule. Jaksic et al. report similar patterns: high-school teachers' AI knowledge and confidence increase after intensive workshops, but the design offers limited opportunities for long-term practice or follow-up support. Even when interventions are more substantial, such as the 40-hour virtual SDG training for university professors in Espejo-Antúnez et al., questions remain about how far new knowledge becomes embedded in everyday teaching and curriculum design. The distribution of studies by technology focus as shown figure 4 is:

- Generative AI (GenAI/ChatGPT): This was the dominant focus, with 16 studies dedicated to its integration and impact on teacher training.
- Virtual Reality (VR) / Simulations / Digital Models: 8 studies examined these immersive technologies.
- General AI / AI Tools / AIGC (Acceptance, Adoption): 8 studies covered broader themes of AI acceptance, readiness, and general tool adoption.

The visualization below illustrates Figure 4:

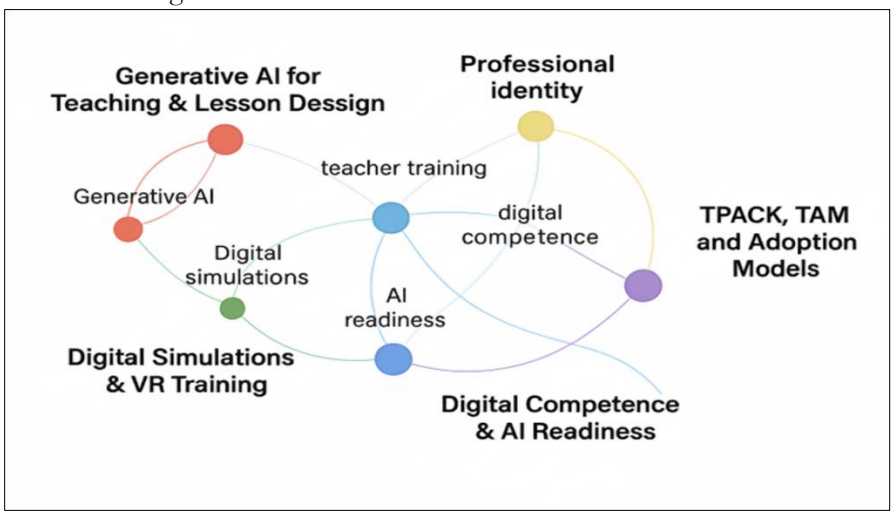


**Figure 4:** Distribution of studies by technology

Infrastructure and equity concern also surface repeatedly. Castro et al. document how rural teachers recognise AI as a supportive tool but face serious obstacles due to limited connectivity, device shortages, and insufficient technical support. Somabut et al. find that science teachers in smaller schools share high interest in generative AI but are constrained by resource disparities and the absence of clear institutional policies. Lucas et al. show that preservice teachers in Portugal and Spain often graduate with only superficial exposure to AI tools, largely because their programmes do not yet provide structured, hands-on AI training. These findings suggest that systemic and infrastructural issues remain major barriers to deep AI integration.

Another limitation is the heavy reliance on self-reported data. Many studies, including those by Liu, Lucas, Li, Somabut, Hazzan-Bishara et al., and Tomczyk and Majkut, measure constructs such as readiness, confidence, perceived usefulness, and intention via questionnaires. While these measures are valuable for understanding perceptions, they do not always demonstrate whether AI-enhanced training leads to observable changes in classroom practice or student outcomes. Only a minority of studies, such as Fecke et al., Rogers and Maccormac, Setiyawan et al., Cai et al., and Niloy et al., incorporate performance measures, lesson artefacts, or pre-post-tests that capture behavioural change.

Ethical, emotional, and identity-related dimensions are comparatively under-operationalised in quantitative work, even though qualitative studies provide rich insight into them. Isma'il and Ibrahim show that teachers initially fear role erosion before re-framing AI as a partner, while Mnguni documents concerns about philosophical implications and stakeholder expectations, and Żammit reports tensions around creativity, authenticity, and assessment in Maltese language teaching. These nuanced accounts highlight that emotional and ethical considerations can strongly shape long-term adoption, yet they are often reduced to single items or omitted entirely in survey models.

Finally, high-fidelity simulations and advanced AI tools are most visible in relatively well-resourced institutions. Fecke et al. demonstrate that avatar-based simulations reduce social inhibitions and improve communication skills among preservice teachers. Rogers and Maccormac show that scenario-based virtual learning enhances nursing students' self-efficacy, though students still request a balanced blend of virtual and face-to-face teaching. Chen's work on VR/AR in educational management, Setiyawan's study on 3D modelling and printing, and Cohn et al.'s multimodal analytics for STEM+C classrooms collectively illustrate substantial potential, but they also raise implicit questions about scalability, cost, and technical capacity in less advantaged settings.

 

The clusters align closely with the thematic structures visualised in the VOSviewer map. The purple cluster, anchored by the dominant keyword teaching, captures research emphasising pedagogical processes and learning improvement. The blue cluster corresponds to the dense network surrounding teacher education and teacher training, reflecting studies on competency-building and professional development. The green cluster mirrors VOSviewer's subject-linked nodes, including curriculum, secondary school, and discipline-specific education. Finally, the yellow–orange cluster aligns with technology-centric keywords (ICT, e-learning, educational technology), representing research on AI tools, simulations, and digital learning ecosystems. Together, these clusters illustrate how the SLR evidence maps onto the broader conceptual structure of teacher education scholarship.

**Table 2:** The bibliographic coupling results

| **Cluster no. (color)** | **Cluster label (based on VOS keywords)-publications** |
|---|---|
| 1 (purple) (VOS keywords: teaching, learning, pedagogy, literacy, reading, physical education) | n-10 Core pedagogical foundations in teaching and learning |
| 2 (blue) (VOS keywords: teacher training, teacher education, professional development, faculty development, inclusion) | n-9 Teacher education, training, and professional development |
| | |
| 3 (green) (VOS keywords: curriculum, assessment, secondary school, physical/health/environmental education, education for sustainable development) | n-6 Curriculum and subject-specific education |
| 4 (yellow–orange) (VOS keywords: ICT, educational technology, e-learning, medical education, engineering education, digital simulations) | n-7 Educational technology, AI tools, and digital learning environments |

**Implications for Policy and Practice**

The synthesis of 2025 studies point to several important implications for policy makers, teacher-education institutions, and schools. First, AI literacy should be treated as a core dimension of teacher professionalism. Lucas, Chen, Somabut, Castro, and Martín-Gómez and Ruiz consistently show that teachers across different contexts view AI as relevant and even necessary, yet they often lack conceptual understanding, ethical awareness, and practical strategies for classroom use. Initial teacher education and in-service programmes therefore need structured modules on AI concepts, generative AI capabilities and limitations, prompt design, bias, and responsible use, integrated into curriculum rather than offered as standalone enrichment.

Second, curricula can leverage AI both as an object of study and as a pedagogical partner. Cai demonstrates that ChatGPT-assisted lesson-plan critiques can enhance pre-service teachers' cognitive and affective evaluation of inclusive lesson plans. Niloy et al. show that generative AI co-teachers allow human instructors to cover more content and improve student satisfaction and performance. Chang and Sun illustrate how bilingual teachers use multimodal generative AI to design adaptive instructional strategies, while Li shows that teachers employ ChatGPT for self-directed professional development, goal setting, and reflection. These studies collectively suggest that AI can support feedback, differentiation, and planning, freeing teacher educators to focus on higher-order reflection, emotional support, and context-sensitive judgement.

Third, professional development should be continuous, contextualised, and participatory. Momdjian et al. show that when teacher educators model digital and AI-rich instruction, preservice teachers develop stronger competence than when they only receive direct instruction about tools. Espejo-Antúnez et al. demonstrate that a structured virtual course can significantly improve professors' SDG-related teaching, indicating the value of sustained online training. Jaksic et al. and Dogan and Gogus highlight the potential of AI-related workshops and courses while also revealing the limitations of short, isolated interventions. Martín-Gómez and Ruiz further underline the importance of training that explicitly cultivates critical and didactic AI use, including prompt literacy and reflective engagement.

Fourth, equity considerations must guide AI policy. Studies by Castro, Somabut, and Lucas show that without targeted investment in infrastructure, support, and clear policies, AI-enhanced teacher training could deepen existing divides between rural and urban schools, small and large institutions, and well- and under-resourced programmes. Policy makers therefore need to prioritise connectivity, device access, and local technical support, while institutions should develop clear guidelines on appropriate classroom use. Finally, assessment and quality assurance systems should be updated to include AI-related competencies. Frameworks such as those used by Aimicheva et al., Momdjian et al., Huang et al., Oved and Alt, Hazzan-Bishara et al., Liu, and Tomczyk and Majkut can be adapted to monitor teachers' AI readiness and digital competence over time and to inform accreditation, curriculum review, and resource allocation.

 

**Future Research Directions**

The review highlights several avenues for future work. Longitudinal studies are needed to examine whether gains in AI literacy, confidence and professional identity observed in short-term interventions (for example, Zheng, 2025; Jaksic et al., 2025; Li et al., 2025) translate into sustained changes in classroom practice and student outcomes. Multi-site comparative studies could explore how institutional cultures and policy frameworks mediate AI integration, building on cross-national insights from Lucas et al. (2025), and Wang et al. (2023) There is also a need for more robust mixed-methods designs that combine validated self-report scales with observational data, artefact analysis, learning analytics and, where appropriate, performance-based assessments. Such triangulation would help address current concerns about self-report bias and provide a richer picture of how AI and simulations reshape teaching and learning.

Conceptually, further work could deepen the integration between TPACK, technology-acceptance models and identity-based theories. Studies such as Hazzan-Bishara et al. (2025), Oved and Alt (2025), and Mnguni (2025) already point toward multi-layered models that encompass competence, beliefs, norms and emotions. Future research might develop and test comprehensive frameworks that explicitly model how AI literacy, ethical reasoning and professional identity co-evolve over the course of teacher preparation. Finally, more research from under-represented regions and marginalised communities is essential to ensure that the emerging evidence base does not simply reflect the conditions of well-resourced institutions. Investigations into low-cost, locally appropriate AI tools, as well as community-driven approaches to AI education, would contribute to a more equitable and globally relevant understanding of AI-enabled teacher training.

## CONCLUSION

The integration of Generative AI and digital simulations into teacher training represents a transformative leap in pedagogical preparation. By providing safe spaces for practice and instant, personalized feedback, these technologies are enhancing teacher confidence and competence. However, realizing their full potential requires a curriculum that balances technological proficiency with a strong ethical foundation and a clear professional identity.


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| **Prof. Dr. Sivabala Naidu** | Contributed to searches and thematic synthesis; provided methodological guidance and critical revisions; approved final manuscript; accountable for accuracy and integrity. |
| **Prof. Dr. Andrew L. S. Foong** | Assisted in data interpretation and synthesis; critically revised analytical sections; approved final manuscript; accountable for scholarly content. |
| **Prof. Dr. Ranjit Singh Gill** | Supported searches and appraisal; contributed to interpretation and revisions; approved final manuscript; accountable for content reliability. |
| **Assoc. Prof. Dr. Ramachandran Vengrasalam** | Participated in searches and theme validation; revised manuscript for clarity; approved final version; accountable for content integrity. |
| **Assoc. Prof. Dr. Samikannu Jabamoney** | Contributed to searches, data verification, and synthesis; revised methods/results sections; approved final manuscript; accountable for accuracy. |


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