

# Generative artificial intelligence in teacher training: a narrative scoping review

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**Abstract.** The emergence of generative artificial intelligence (GenAI) has transformed various sectors, including education. This narrative scoping review examines how GenAI is being integrated into teacher training programs, exploring its applications, benefits, challenges, and implementation frameworks. By synthesizing findings from recent literature (2022-2025), we identify key themes including the development of AI literacy among teachers, the impact on pedagogical content knowledge, and ethical considerations in implementation. Our analysis reveals significant benefits of GenAI in enhancing teaching performance and facilitating personalized learning, while also highlighting challenges such as technical limitations, ethical concerns, and resistance to change. We identify gaps in current research, particularly in non-STEM subjects and ethical framework development, and suggest directions for future research to advance the responsible integration of GenAI in teacher education.

**Keywords:** generative artificial intelligence, teacher training, teacher education, AI literacy, pedagogical content knowledge, instructional design, professional development, ethical implications, educational frameworks, pre-service teachers, in-service teachers, AI integration, large language models

## 1. Introduction

The educational landscape is rapidly transforming with the integration of artificial intelligence (AI), particularly generative AI (GenAI) technologies. Since the release of ChatGPT in late 2022, the educational community has witnessed unprecedented interest in how these technologies might reshape teaching and learning processes [8]. Teacher education stands at the forefront of this transformation, as preparing educators to effectively utilize and teach with GenAI becomes increasingly crucial for contemporary education systems.

Generative AI refers to artificial intelligence systems capable of creating original content – text, images, code, or other media – based on patterns learned from extensive datasets [11]. Tools like ChatGPT, DALL-E, and Midjourney represent the current generation of these technologies, characterized by their ability to generate human-like responses and creative outputs. As these tools become increasingly accessible, their potential applications in education have expanded dramatically, prompting both enthusiasm and concern among educators [3].

Teacher training programs worldwide are grappling with how to incorporate these emerging technologies into their curricula, ensuring that future educators are not only proficient in using GenAI tools but also capable of teaching their students to engage with these technologies critically and responsibly [36]. The rapid pace of technological advancement presents both opportunities and challenges for teacher education institutions, demanding thoughtful consideration of how best to prepare educators for an AI-augmented educational future.

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This narrative scoping review seeks to map the current landscape of GenAI integration in teacher training, exploring key applications, benefits, challenges, and implementation frameworks. By synthesizing findings from recent literature, we aim to provide a comprehensive overview of this evolving field and identify gaps that warrant further investigation. Our analysis is guided by the following research questions:

1. What are the current applications of GenAI tools in pre-service and in-service teacher training programs?
2. What benefits and challenges are associated with incorporating GenAI into teacher training?
3. What frameworks or models have been developed to guide the integration of GenAI in teacher education?
4. What gaps exist in current implementation and research?

## **2. Methodology**

This narrative scoping review follows a structured approach to identify, select, and synthesize relevant literature on generative AI in teacher training. Unlike systematic reviews with rigid inclusion criteria, narrative scoping reviews offer flexibility in exploring emerging topics while maintaining methodological rigor [39].

### **2.1. Search strategy and selection process**

We conducted a comprehensive search of the literature published between November 2022 (coinciding with the public release of ChatGPT) and March 2025. Primary databases searched included Scopus and Web of Science. Search terms included combinations of “generative AI”, “ChatGPT”, “large language models”, “teacher training”, “teacher education”, “professional development”, and related terms.

Articles were selected based on their relevance to the integration of generative AI in pre-service or in-service teacher education. We included empirical studies, theoretical papers, reviews, and case studies that substantially addressed how GenAI technologies are being or could be integrated into teacher education. While not following the strict PRISMA protocol, we documented our search process to ensure transparency and replicability.

### **2.2. Data extraction and synthesis**

From each included publication, we extracted information regarding:

- study characteristics (type, methodology, context);
- GenAI technologies examined;
- teacher education context (pre-service, in-service, subject areas);
- implementation approaches and frameworks;
- reported benefits and challenges;
- ethical considerations.

Data were analyzed thematically, identifying key patterns, trends, and gaps in the literature. The narrative synthesis focused on mapping the current landscape of GenAI in teacher education rather than evaluating the quality of individual studies or conducting meta-analyses of outcomes.

## **3. Current applications of GenAI in teacher training**

The integration of generative AI technologies in teacher training reflects diverse approaches across educational contexts. Our analysis reveals several key applications that are reshaping how teachers are prepared for increasingly AI-influenced educational environments.

### 3.1. Pre-Service teacher education

Pre-service teacher education programs are incorporating GenAI tools to enhance various aspects of teacher preparation. Blonder, Feldman-Maggor and Rap [6] found that GenAI tools are being used to evaluate and enhance pedagogical content knowledge (PCK) among pre-service science teachers. Through interactive dialogues with GenAI systems, pre-service teachers engage in lesson planning activities that reveal their understanding of content, pedagogy, and PCK while facilitating the practical application of theoretical knowledge.

The CONALI Ontology framework, examined by Lombardi et al. [20], demonstrates how structured ontological approaches combined with ChatGPT can support instructional design processes among pre-service teachers. In their study of 110 students enrolled in a Primary Education Sciences Laboratory, they found that this combination helped future educators articulate SMART objectives, resulting in clearer, more focused instructional design. The integration of ChatGPT significantly improved the efficiency and creativity of the design process, enabling students to quickly generate ideas and refine their projects.

Beyond specific applications, Moorhouse et al. [24] explored the development of professional GenAI competence among pre-service language teachers through an 11-week intervention course. Their findings revealed improvements in participants' pedagogical competence and critical awareness of GenAI tools deployment, though they noted less evidence of development in teachers' capacity to guide their future students in using these tools effectively and responsibly.

### 3.2. In-Service teacher professional development

For practicing educators, GenAI tools are being integrated into professional development initiatives that aim to enhance teaching practices and address evolving classroom needs. Mulyani et al. [26] demonstrated that GenAI significantly enhances teaching performance by improving ease of use, usefulness, and learning. Their study of 466 teachers found that teacher perceptions of AI's usability influence its integration into student-focused learning, learning material development, and teaching practice enhancement.

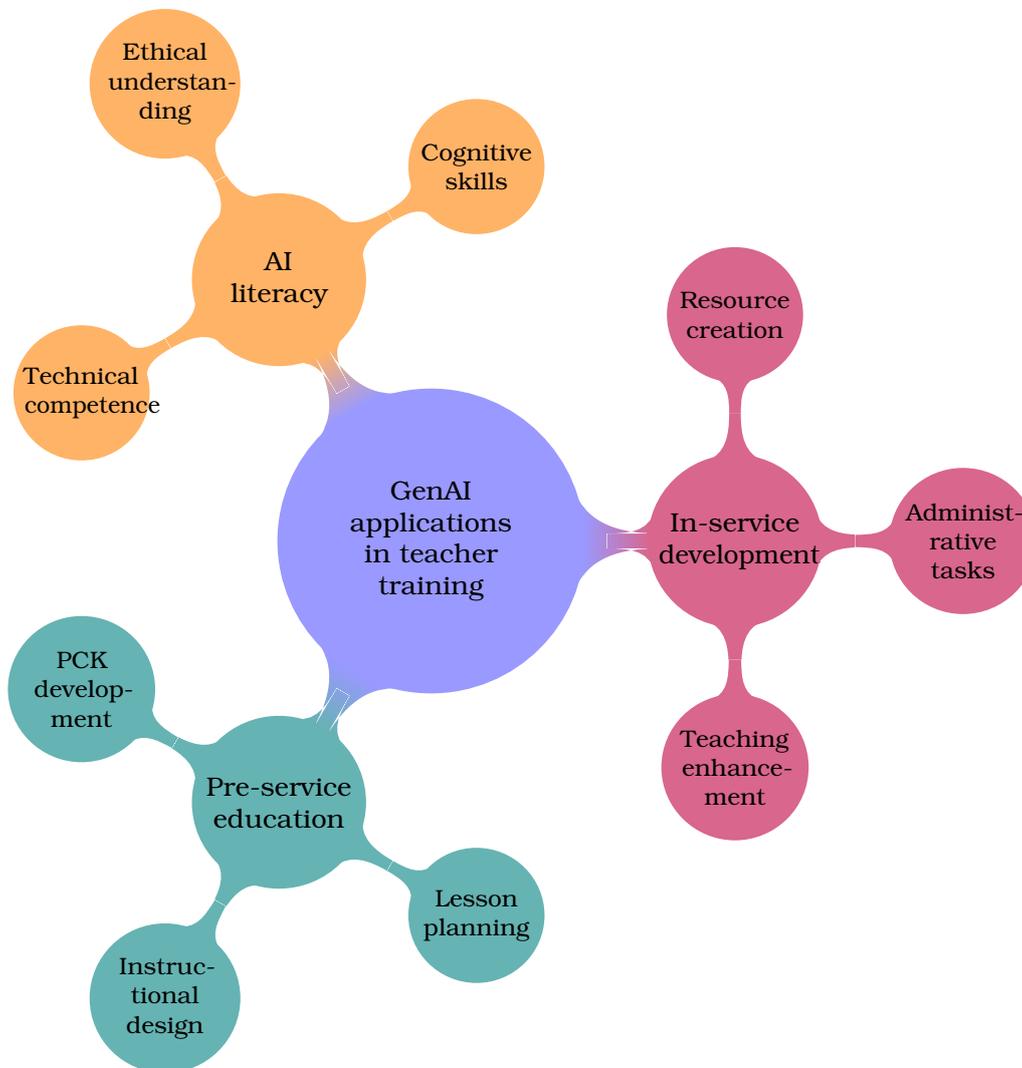
Project-based training models, such as those examined by Xie et al. [41], show promise in helping in-service teachers develop practical AI integration skills. Their design-based research on a project-based training model for primary and secondary school teachers found that GenAI-empowered approaches improved training performance and teachers' capabilities to implement AI-enhanced instruction.

Laak and Aru [19] conducted a nationwide survey among Estonian K-12 teachers, finding that 49% had already modified their teaching processes in response to GenAI by including tasks that encourage critical thinking, eliminating written homework, and allowing the use of GenAI to generate new ideas. Moreover, 74% reported using GenAI to make their work more efficient (e.g., answering emails from parents), highlighting the practical utility of these tools in teachers' professional lives.

### 3.3. AI literacy development

A common thread across both pre-service and in-service contexts is the focus on developing AI literacy among educators. Macdowell et al. [22] described a self-study approach to investigate professional practices related to GenAI, analyzing curriculum, instruction, and assessment in an upper-level undergraduate course in multimedia design and production. They developed the Student Artificial Intelligence Literacy (SAIL) framework to support equitable and inclusive access to the educational benefits offered by AI, facilitating student AI literacy through curriculum engagement and three distinct types of interactions: cognitive, socio-emotional, and instructor-guided.

Similarly, Siiman [34] designed a 45-minute training session for pre-service teachers to use Microsoft Copilot and identify ways AI can be used to assist with future teaching practices. Their results showed that teachers perceived AI tools as most beneficial for lesson planning, creating assessment questions and tasks, creating images, brainstorming and idea generation, creating educational games, and generating and rewriting text.



**Figure 1:** Major applications of generative AI in teacher training.

#### 4. Benefits of incorporating genai in teacher training

The integration of generative AI technologies in teacher training programs has yielded several notable benefits, as evidenced by the emerging literature in this field. These benefits span from enhanced teaching performance to the development of specialized AI competencies.

##### 4.1. Enhanced teaching performance and efficiency

Research consistently highlights improved teaching performance as a key benefit of GenAI integration in teacher education. Mulyani et al. [26] found that GenAI significantly enhances teaching effectiveness by improving ease of use, usefulness, and learning capabilities. Their study involving 466 teachers demonstrated that

perceptions of AI's usability positively influenced its integration into student-focused learning, learning material development, and teaching practice enhancement.

The efficiency gains are particularly notable. Laak and Aru [19] reported that 74% of surveyed teachers use GenAI to make their work more efficient, handling administrative tasks such as responding to parent emails and generating feedback for students. This efficiency allows teachers to dedicate more time to high-value instructional activities and personalized student interactions.

#### **4.2. Personalized learning and content creation**

GenAI tools support the development of personalized learning experiences, an increasingly important aspect of contemporary education. Fortino, Mangione and Pupo [11] analyzed case studies showcasing GenAI applications in education, highlighting tangible benefits such as increased student engagement, improved test scores, and accelerated skill development. The capacity of GenAI to generate diverse educational content tailored to individual student needs represents a significant advancement in teaching capabilities [14].

Kong and Yang [17] proposed a human-centered learning and teaching framework using GenAI for self-regulated learning development. Their case study involving Chinese language writing ability among primary students demonstrated that teachers equipped with GenAI tools and AI literacy could refine their teaching strategies to better equip students to meet future challenges. The 60-hour development program for teachers increased their perceived ability to design AI-integrated courses that enhanced students' attention, engagement, confidence, and satisfaction.

#### **4.3. AI literacy and professional competence development**

The development of AI literacy emerges as both a means and an end in teacher education. Macdowell et al. [22] documented how teachers engaged in experiential activities focused on developing AI literacy alongside collaborative assignments to co-author an open-access textbook on teaching with GenAI. Their Student Artificial Intelligence Literacy (SAIL) framework facilitates student AI literacy through curriculum engagement and three distinct types of interactions: cognitive, socio-emotional, and instructor-guided.

Moorhouse et al. [24] introduced the concept of professional GenAI competence (P-GenAI-C) and evaluated an 11-week intervention course aimed at enhancing this competence among pre-service language teachers. Their findings showed significant improvement in participants' pedagogical competence and critical awareness of GenAI tools, though development was less pronounced in their capacity to guide students in using these tools effectively and responsibly.

#### **4.4. Impact on pedagogical content knowledge and self-efficacy**

Research suggests that GenAI positively impacts teachers' pedagogical content knowledge (PCK) and self-efficacy. Blonder, Feldman-Maggor and Rap [6] proposed using GenAI tools to evaluate PCK among pre-service science teachers, finding that interactive dialogues with GenAI revealed teachers' understanding of content and pedagogy while facilitating the practical application of theoretical knowledge.

Lu et al. [21] conducted a study comparing traditional teaching methods with GenAI-assisted teaching skills training among 215 preservice mathematics, science, and computer teachers. They found that scores of teachers in the experimental group were considerably higher than those in the control group, both in teacher self-efficacy and higher-order thinking. This suggests that GenAI can effectively support teachers' professional development and enhance their confidence in implementing innovative teaching strategies.

**Table 1**

Key benefits of GenAI integration in teacher training.

<b>Benefit category</b>	<b>Description</b>	<b>Key studies</b>
Enhanced teaching performance	Improved teaching effectiveness, efficiency in planning and assessment, streamlined administrative tasks	Mulyani et al. [26], Laak and Aru [19]
Personalized learning	Creation of adaptive content, differentiated instruction materials, student-focused resources	Fortino, Mangione and Pupo [11], Kong and Yang [17]
AI literacy development	Building teacher competence in AI tools, frameworks for developing AI understanding	Macdowell et al. [22], Moorhouse et al. [24]
Pedagogical content knowledge	Integration of subject knowledge with teaching methodology, enhanced lesson design	Blonder, Feldman-Maggor and Rap [6], Lombardi et al. [20]
Teacher self-efficacy	Increased confidence in technology integration, higher professional self-assessment	Lu et al. [21], Kong, Yang and Hou [18]

## 5. Challenges and barriers in GenAI implementation

Despite the promising benefits, the integration of generative AI in teacher education presents significant challenges that must be addressed to ensure effective and ethical implementation. These challenges span technical, ethical, pedagogical, and equity dimensions.

### 5.1. Technical challenges

The technical infrastructure required to implement GenAI effectively represents a substantial challenge for many teacher education programs. Roy et al. [33] highlighted the need for significant infrastructure and faculty training to effectively implement GenAI in education. Their analysis of postgraduate education in pathology and microbiology revealed that barriers to implementation include technical limitations and the necessity for substantial faculty training.

Many educators lack the necessary AI competencies and familiarity with these technologies, which can hinder their integration. Ng, Chan and Lo [28] identified school readiness and teachers' AI competencies as major challenges in their study of educators in Canada. These findings align with those of Cheah and Kim [9], who found diverse levels of familiarity with GenAI among STEM teachers, with over half lacking user experience despite acknowledging the importance of equipping students with AI-related knowledge and skills.

Concerns about data quality and reliability persist as well. Blonder and Feldman-Maggor [5] and Wang and Li [38] documented educators' apprehension regarding the accuracy and reliability of AI-generated content, which can affect the quality of educational materials and assessments. The uncertainty about the trustworthiness of GenAI outputs creates hesitation among educators, particularly when considering high-stakes educational contexts.

### 5.2. Ethical concerns

Ethical considerations emerge as a significant challenge in implementing GenAI in teacher education. Yu et al. [42] explored ethical dimensions related to the use of GenAI in higher education, focusing on issues such as data privacy, algorithmic

bias, and intellectual property concerns. Similarly, Tang and Su [35] identified five main ethical implications of using AI models in the classroom: algorithmic bias and discrimination, data privacy leakage, lack of transparency, decreased autonomy, and academic misconduct.

The potential for GenAI to perpetuate existing biases is a particularly pressing concern. Gabriel [12] examined the complex relationship between GenAI and educational equity, noting that AI systems can perpetuate existing biases, leading to unfair educational outcomes and further marginalizing already disadvantaged groups.

Academic integrity concerns also feature prominently in the literature. Gallent-Torres, Zapata-González and Ortego-Hernando [13] analyzed the impact of GenAI in higher education with a focus on ethics and academic integrity, highlighting concerns about the potential for AI-generated plagiarism and the ethical implications of data accuracy. These issues become increasingly complex when considering how teachers should both use these tools themselves and guide their students in responsible use.

### **5.3. Pedagogical concerns**

The pedagogical implications of GenAI integration pose challenges for teacher education. Nadim and Di Fuccio [27] analyzed the potential negative impacts of GenAI on teaching and research, highlighting concerns about diminished critical thinking and negative effects on educational outcomes. Their analysis suggests that overreliance on AI tools could negatively affect students' critical thinking skills and their ability to engage deeply with material.

The evolving role of teachers in an AI-augmented educational environment creates uncertainty. Zhai [43] explored the transformative impact of GenAI on teachers' roles and agencies in education, noting that teachers may resist adopting AI due to fears of being replaced or concerns about the technology's impact on their professional roles. This resistance can be particularly pronounced among educators with established teaching approaches.

### **5.4. Equity and access concerns**

Digital divide issues represent a significant barrier to equitable GenAI implementation. Ramírez-Montoya, Oliva-Córdova and Patiño [32] identified challenges related to the digital divide and unequal access to technology in their survey of 115 educators working in higher education institutions in Ecuador, Guatemala, and Mexico. Similarly, Henadirage and Gunarathne [16] found that in Global South contexts like Sri Lanka, barriers to GenAI integration include the absence of comprehensive policies and guidelines at the university level and unequal access to technology.

Gabriel [12] specifically addressed GenAI and educational inequity, analyzing both opportunities and challenges presented by these emerging technologies in educational contexts. Their paper highlights concerns about digital divides, both in terms of access to technology and digital literacy skills, as well as the potential for AI systems to perpetuate existing biases.

## **6. Frameworks and models for GenAI integration**

Several frameworks and models have emerged to guide the integration of generative AI in teacher education, providing structured approaches for developing AI literacy and implementing GenAI tools in educational contexts.

### **6.1. AI literacy frameworks**

AI literacy frameworks focus on developing educators' understanding and competence in using AI technologies. Gómez-Rodríguez et al. [15] proposed a comprehensive AI literacy training program designed to develop necessary skills for university teachers

<p><b>Technical challenges</b></p> <ul style="list-style-type: none"> <li>• Infrastructure requirements</li> <li>• Faculty technological competence</li> <li>• Data quality and reliability</li> <li>• System integration issues</li> </ul>	<p><b>Ethical concerns</b></p> <ul style="list-style-type: none"> <li>• Data privacy and security</li> <li>• Algorithmic bias</li> <li>• Academic integrity</li> <li>• Intellectual property</li> </ul>
<p><b>Pedagogical concerns</b></p> <ul style="list-style-type: none"> <li>• Impact on critical thinking</li> <li>• Changing teacher roles</li> <li>• Resistance to new approaches</li> <li>• Assessment authenticity</li> </ul>	<p><b>Equity and access</b></p> <ul style="list-style-type: none"> <li>• Digital divide</li> <li>• Socioeconomic barriers</li> <li>• Language and cultural biases</li> <li>• Global implementation gaps</li> </ul>

**Figure 2:** Major challenges in GenAI implementation for teacher training.

to integrate AI into their curricula and research. Their program covers the foundations of AI to its specific application in teaching, highlighting ethical aspects, critical thinking, and pedagogical integration. Based on frameworks such as DigiComEdu, the program aims to empower teachers, ensuring their preparation to lead the responsible implementation of AI in the classroom and research.

The Student Artificial Intelligence Literacy (SAIL) framework, developed by Macdowell et al. [22], facilitates AI literacy through curriculum engagement and three distinct types of interactions: cognitive, socio-emotional, and instructor-guided. This framework emerged from analyzing the curriculum, instruction, and assessment in an upper-level undergraduate course in multimedia design and production, offering a structured approach to developing AI literacy among future educators.

Black et al. [4] articulated a framework of seven critical strategies for addressing the urgent need for Educator Preparation Programs (EPPs) to prepare preservice teachers to effectively integrate AI-powered instructional tools and teach this new area of content knowledge in PreK-12 classrooms. Their framework emphasizes the importance of preservice teachers’ critical examination and application of AI, including a focus on equity, ethics, and culturally responsive teaching.

**6.2. Pedagogical integration models**

Several models focus specifically on integrating GenAI into pedagogical practice. Kong and Yang [17] proposed a human-centered learning and teaching framework that uses GenAI tools for self-regulated learning development through domain knowledge learning. Their framework illustrates how GenAI tools can revolutionize educational practices and transform teaching and learning processes to become human-centered. It emphasizes the evolving roles of teachers as skillful facilitators and humanistic storytellers who craft differentiated instructions and develop students’ individualized learning.

The LAIK framework, developed by Al-Ali, Tili and Al-Ali [1], offers a practical approach to integrating GenAI in higher education classrooms. The framework identifies four practical stages: (1) laying the foundation, (2) assembling GenAI-friendly classes, (3) investigating and monitoring, and (4) keeping the teacher informed. It offers a variety of options for practical ways to integrate GenAI technology to support learning in the classroom.

McDermott and Stager [23] examined how GenAI could be integrated into the ELEVATE framework, which was originally developed for designing eXtended Reality (XR) training experiences. This adapted framework incorporates learning theories from

behaviorism, cognitivism, and constructivism into a cohesive approach based on the Dreyfus and Dreyfus skill acquisition model and Bloom's Revised Taxonomy, offering guidance for developing appropriate expectations and forms of instruction for students at different proficiency levels.

### **6.3. Ethical and policy frameworks**

Recognizing the ethical implications of GenAI, several frameworks focus on guiding responsible implementation. Paschal and Melly [30] conducted a critical analysis and synthesis of relevant literature on ethical guidelines for using AI in education, discussing approaches to ensure effective and efficient use of AI in education. Their work calls for institutions to establish clear policies and frameworks that align with ethical guidelines and incorporate them into decision-making processes.

The AI Ecological Education Policy Framework, described by Cacho [8], provides guidelines for incorporating GenAI into university-level teaching and learning processes at both the university-departmental level and within individual academic autonomy. This framework offers a suggestive reference for faculty and students to integrate GenAI into their coursework, with a focus on ethical, honest, responsible, and fair use of AI in course development, implementation, and student engagement.

Mouta, Pinto-Llorente and Torrecilla-Sánchez [25] explored the ethical dimensions surrounding the utilization of AI technologies in education, conducting a systematic literature review to analyze various applications and objectives, with a particular focus on pinpointing inherent shortcomings within the existing literature. Their work discusses how cultural differences, inclusion, and emotions have been addressed in AI education contexts and explores capacity-building efforts and guidelines for the ethical use of these systems.

### **6.4. Teacher role and agency frameworks**

Some frameworks focus specifically on how GenAI transforms teachers' roles and agencies. Zhai [43] proposed a comprehensive framework that addresses teachers' perceptions, knowledge, acceptance, and practices of GenAI. Their framework categorizes teachers into four roles – Observer, Adopter, Collaborator, and Innovator – each representing different levels of GenAI engagement and outlining teachers' agencies in GenAI classrooms. This approach highlights the need for quality teacher education programs, continuous professional development, and institutional support to help teachers evolve from basic GenAI users to co-creators of knowledge alongside GenAI systems.

Xie et al. [41] constructed a project-based training model for primary and secondary school teachers empowered by GenAI. Their model, developed through design-based research, aims to improve training performance and capability through a structured approach to GenAI integration. The model emphasizes practical application of GenAI tools in educational contexts, highlighting the importance of hands-on experience in developing teachers' AI competencies.

## **7. Gaps in current implementation and research**

Despite growing interest in generative AI applications for teacher education, our analysis reveals several notable gaps in current implementation and research that warrant further attention.

### **7.1. Underrepresented subject areas and teaching competencies**

Research on GenAI in education has predominantly focused on STEM fields, with less attention to humanities, social sciences, and other non-STEM disciplines. Wu and Zhang [40] noted this disparity, highlighting the need for more research on GenAI

**Table 2**

Frameworks for GenAI integration in teacher training.

Framework type	Key components	Representative models
AI Literacy frameworks	Developing understanding of AI technologies, ethical awareness, critical evaluation of AI outputs	SAIL Framework [22], AI Literacy Training Program [15]
Pedagogical integration models	Instructional design with AI, classroom implementation strategies, assessment approaches	Human-Centered Learning Framework [17], LAIK Framework [1], ELEVATE Framework [23]
Ethical and policy frameworks	Guidelines for responsible use, data privacy considerations, equity and access principles	AI Ecological Education Policy Framework [8], Ethical Guidelines [30]
Teacher Role and agency frameworks	Evolving teacher identities, professional development pathways, implementation stages	Teacher Roles Framework [43], Project-Based Training Model [41]

applications in non-STEM higher education contexts. This gap is significant because GenAI tools may offer unique possibilities and challenges when applied to subjects that emphasize interpretation, argumentation, and creative expression.

Ethical and moral implications of GenAI use in education represent another under-explored area. While several studies acknowledge ethical concerns [3, 5], fewer offer substantive frameworks or guidelines for addressing these issues in teacher education contexts. This gap is particularly concerning given the rapid adoption of GenAI tools and their potential to influence educational values and practices.

Teacher training specifically focused on effective GenAI integration also remains underdeveloped. Lombardi et al. [20] noted “a paucity of training courses for educators in the use of AI systems” despite the increasingly crucial role of AI in education. This gap between technological advancement and teacher preparation creates challenges for effective implementation.

## 7.2. Methodological limitations in current research

Current research on GenAI in teacher education exhibits several methodological limitations. Case studies represent the most common approach [10], providing valuable insights into specific implementations but limiting generalizability across contexts. While valuable for exploring emerging practices, case studies alone cannot provide comprehensive evidence of effectiveness or transferability.

Mixed-methods research combining qualitative and quantitative approaches offers promising insights [2, 7], but these studies often involve small samples or specific institutional contexts, limiting broader applicability. Moreover, few studies employ experimental or quasi-experimental designs that could establish causal relationships between GenAI integration and educational outcomes.

Pishtari et al. [31] conducted one of the few experimental studies, implementing an ABAB reversal design to investigate the impact of an AI-driven feedback system on teachers’ learning designs. Such methodologically rigorous approaches remain rare in the literature, highlighting the need for more robust research designs.

## 7.3. International and contextual variations

Research on GenAI in education exhibits significant geographical disparities, with studies predominantly originating from developed countries such as the United States, the United Kingdom, and Australia [37]. This imbalance creates gaps in understanding

how GenAI implementation might vary across different educational systems and cultural contexts.

Henadirage and Gunarathne [16] highlighted the scarcity of research on GenAI implementation in Global South contexts, particularly South Asian countries. Their study of barriers to GenAI adoption in Sri Lankan higher education revealed unique challenges, including the absence of comprehensive policies and guidelines, uncertainty about information reliability, and resistance to technological advancement.

Cultural and institutional readiness for GenAI varies significantly across contexts. Alammari [2] found that approximately half of surveyed educators in Saudi Arabia were at stages characterized by understanding and familiarity with GenAI integration, indicating tangible readiness for adoption. However, such readiness cannot be assumed across all educational contexts, particularly in regions with limited technological infrastructure or different educational priorities.

#### **7.4. Emerging research directions**

Several emerging areas warrant further investigation as the field of GenAI in teacher education evolves. The long-term impact of GenAI integration on teacher identity, autonomy, and professional development trajectories represents an important research direction. Nadim and Di Fuccio [27] raised concerns about GenAI's potential to diminish critical thinking and creativity, highlighting the need for longitudinal studies examining how teacher-AI relationships evolve over time.

The development of context-specific frameworks for GenAI integration in teacher education also represents a promising research direction. While existing frameworks offer valuable guidance [1, 17], they may not adequately address the unique characteristics and challenges of diverse educational systems and cultural contexts. Frameworks tailored to specific educational environments could enhance implementation effectiveness.

The intersection of GenAI literacy and specific subject pedagogies represents another underdeveloped area. While general AI literacy frameworks exist [22], research on how these frameworks interact with subject-specific pedagogical knowledge remains limited. Understanding how AI literacy development relates to subject teaching could enhance the relevance and effectiveness of teacher preparation.

### **8. Discussion and implications**

The integration of generative AI in teacher training represents a transformative shift in how educators are prepared for increasingly AI-influenced educational environments. Our review reveals several key insights and implications for teacher education policy, practice, and research.

#### **8.1. Balancing technological innovation and pedagogical foundations**

The effective integration of GenAI in teacher education requires a careful balance between technological innovation and sound pedagogical foundations. While GenAI tools offer significant potential to enhance teaching efficiency, content creation, and personalized learning [17, 26], they must complement rather than replace core pedagogical principles. Teacher education programs must avoid what Nadim and Di Fuccio [27] term “unquestioning adoption”, which risks diminishing critical thinking and creativity.

The frameworks reviewed in this paper, particularly the human-centered learning framework [17] and the LAIK framework [1], demonstrate promising approaches to achieving this balance. These frameworks prioritize human agency and pedagogical purpose while leveraging GenAI capabilities to enhance teaching and learning. Future teacher education initiatives should similarly emphasize how GenAI tools can serve



**Figure 3:** Key gaps in current GenAI research and implementation.

pedagogical goals rather than allowing technological capabilities to dictate educational practices.

### 8.2. Developing comprehensive AI literacy

AI literacy emerges as a crucial component of teacher preparation in the GenAI era. Beyond technical competence, comprehensive AI literacy encompasses critical evaluation, ethical understanding, and pedagogical application of AI technologies. The SAIL framework [22] and the AI literacy training program described by Gómez-Rodríguez et al. [15] offer valuable approaches to developing these multifaceted competencies.

Teacher education programs should consider AI literacy not as a standalone skill but as an integrated aspect of pedagogical content knowledge. Ning et al. [29] explored the relationship between various knowledge elements in teachers' AI-TPACK (Artificial Intelligence – Technological Pedagogical Content Knowledge), finding that AI-Technological Knowledge interacts with other knowledge domains to influence teachers' overall competence. This suggests that AI literacy development should be integrated across the teacher education curriculum rather than isolated in specialized courses.

### 8.3. Addressing ethical implications proactively

The ethical implications of GenAI in education require proactive attention in teacher preparation programs. Tang and Su [35] identified five main ethical implications of

AI in education: algorithmic bias and discrimination, data privacy leakage, lack of transparency, decreased autonomy, and academic misconduct. Similarly, Blonder and Feldman-Maggor [5] emphasized the need for comprehensive teacher training to effectively and ethically employ GenAI in educational practices.

Teacher education programs should incorporate explicit ethical frameworks and guidelines for responsible GenAI use, similar to those proposed by Paschal and Melly [30]. These frameworks should address not only technical ethical issues like data privacy and algorithmic bias but also broader educational ethics concerns such as academic integrity, student autonomy, and equitable access. Moreover, teacher candidates should be prepared to guide their future students in navigating these ethical considerations when using GenAI tools.

#### **8.4. Ensuring equitable implementation**

Addressing equity concerns in GenAI implementation represents a significant challenge for teacher education. The digital divide, both in terms of access to technology and digital literacy, poses barriers to equitable GenAI integration [12, 32]. Teacher education programs must prepare future educators to recognize and address these disparities, ensuring that GenAI implementation does not exacerbate existing educational inequities.

Ng, Chan and Lo [28] suggested several strategies to motivate GenAI integration in education, including professional development, clear guidelines, and access to AI software and technical support. These strategies should be adapted to address equity concerns specifically, with teacher education programs emphasizing approaches to GenAI implementation that can bridge rather than widen opportunity gaps. This might include preparing teachers to implement GenAI in low-resource environments, addressing language and cultural biases in AI systems, and developing alternative approaches for contexts with limited technological infrastructure.

#### **8.5. Implications for research**

Our review highlights several implications for future research on GenAI in teacher education. First, more research is needed on GenAI applications in non-STEM subjects, exploring how these tools can enhance teaching and learning in humanities, social sciences, arts, and language education. Second, methodologically rigorous studies, including experimental and longitudinal designs, are necessary to establish causal relationships between GenAI integration and educational outcomes. Third, research should explore GenAI implementation across diverse educational contexts, particularly in Global South regions and low-resource environments.

Additionally, research should investigate the long-term impacts of GenAI on teacher identity, autonomy, and professional development. As Zhai [43] suggested, teachers may evolve through various roles in relation to GenAI – from Observer to Innovator – with implications for how teacher education programs prepare educators for these evolving relationships with AI technologies.

### **9. Conclusion**

This narrative scoping review has examined the landscape of generative AI integration in teacher training, exploring applications, benefits, challenges, and implementation frameworks. Our analysis reveals a field in rapid development, with promising approaches emerging alongside significant gaps and challenges.

Generative AI offers substantial benefits for teacher education, including enhanced teaching performance, personalized learning capabilities, AI literacy development, and positive impacts on pedagogical content knowledge and self-efficacy. However, these benefits are accompanied by technical, ethical, pedagogical, and equity challenges

that must be thoughtfully addressed. Various frameworks have been developed to guide GenAI integration, focusing on AI literacy, pedagogical implementation, ethical considerations, and teacher roles.

Despite growing interest in this area, significant gaps remain in current research and implementation. These include underrepresented subject areas, methodological limitations, contextual variations, and emerging research needs related to teacher identity and long-term impacts. Addressing these gaps will require collaborative efforts among researchers, teacher educators, policymakers, and technology developers.

As generative AI technologies continue to evolve, teacher education must adapt to prepare educators who can leverage these tools effectively, critically, and ethically. This preparation should balance technological innovation with sound pedagogical foundations, develop comprehensive AI literacy, address ethical implications proactively, and ensure equitable implementation. By addressing these considerations, teacher education can help shape an educational future where generative AI enhances rather than diminishes human teaching and learning.

**Declaration on generative AI:** During the preparation of this work, the authors used Claude 3.7 Sonnet to improve writing style. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

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