International Journal of Evaluation and Research in Education (IJERE)
Vol. 15, No. 2, April 2026, pp. 966~975
ISSN: 2252-8822, DOI: 10.11591/ijere.v15i2.37225

Generative AI in teacher education: a systematic review

Longfa Yuan[1], Rafiza Abdul Razak[2], Amirrudin Kamsin[3], Siti-Soraya Abdul-Rahman[4]
[1]Institute for Advanced Studies, Universiti Malaya, Kuala Lumpur, Malaysia
[2]Department of Curriculum and Instructional Technology, Faculty of Education, Universiti Malaya, Kuala Lumpur, Malaysia
[3]Department of Computer System and Technology, Faculty of Computer Science and Information Technology, Universiti Malaya, Kuala Lumpur, Malaysia
[4]Department of Artificial Intelligence, Faculty of Computer Science and Information Technology, Universiti Malaya, Kuala Lumpur, Malaysia

Article Info

Article history:

Received Oct 7, 2025
Revised Dec 27, 2025
Accepted Feb 1, 2026

Keywords:

Educational technology
Generative AI
Systematic review
Teacher education
Teacher training

ABSTRACT

This study addresses a critical gap in the literature by conducting one of the earliest systematic reviews (2021-2025) on generative artificial intelligence (GenAI) in teacher education. Using a structured screening and coding process, 35 peer-reviewed articles from Scopus and Web of Science (WoS) were analyzed to examine methodological trends, geographical disparities, and cross-cultural adaptability. The review identifies four major application areas, including stakeholder perception analysis, instructional resource generation, curriculum design, and student-AI collaborative learning, and synthesizes their underlying pedagogical mechanisms. Key findings reveal pronounced geographical imbalance (with no studies from Africa or Latin America), heavy reliance on short-term qualitative designs, and limited empirical or longitudinal validation. Based on these insights, the study proposes a conceptual framework linking GenAI applications, challenges, and future research pathways. This work contributes a structured evidence base and offers guidance for advancing GenAI-integrated teacher education through more rigorous, inclusive, and context-sensitive research.

Corresponding Author:

Rafiza Abdul Razak
Department of Curriculum and Instructional Technology, Faculty of Education, Universiti Malaya
University Road, 50603 Kuala Lumpur, Federal Territory of Kuala Lumpur, Malaysia
Email: rafiza@um.edu.my

1. INTRODUCTION

Teacher education is undergoing rapid transformation driven by digital innovation and the emergence of generative artificial intelligence (GenAI) [1], [2]. GenAI systems, such as ChatGPT, Claude, Copilot, Gemini, and DeepSeek, produce human-like text, images, and multimodal content [3], [4] are increasingly integrated into educational practice [5], [6]. In teacher education, GenAI supports lesson planning [7], formative assessment [8], professional reflection [9], and AI literacy development [10], [11]. Its use can also be interpreted through established frameworks such as technological pedagogical content knowledge (TPACK) and substitution, augmentation, modification, redefinition (SAMR), which explain how technological, pedagogical, and content knowledge intersect in AI-mediated teaching.

Recent studies emphasize that AI-supported environments can enhance inclusivity and accessibility, and promote developmentally appropriate learning [12]–[14]. These findings highlight the need to prepare teachers to adopt GenAI in equitable and pedagogically meaningful ways. Despite these opportunities, empirical evidence on GenAI in teacher education remains limited, particularly in underrepresented regions such as Africa and Latin America [15], [16]. Existing studies are also constrained by small sample sizes, short-term designs, and limited cross-cultural applicability.

To address these gaps, this study conducts the first preferred reporting items for systematic reviews and meta-analyses (PRISMA)-based systematic review (2021-2025) focusing specifically on GenAI in teacher education. The review aims to: i) examine current GenAI applications; ii) analyze reported benefits and challenges; and iii) identify research gaps and implications for future practice. By synthesizing findings from recent studies, this review provides a timely overview of how GenAI is being conceptualized and implemented in teacher education.

The novelty of this review lies in three dimensions. First, it provides the earliest systematic synthesis of empirical GenAI studies in teacher education from 2021 to 2025, with explicit attention to geographical distribution, methodological patterns, and cross-cultural adaptability, which are areas underrepresented in existing reviews. Second, by analyzing 35 peer-reviewed studies, it proposes an integrative conceptual framework linking applications, pedagogical mechanisms, and future research pathways. Third, it highlights critical methodological limitations, particularly the dominance of qualitative designs (60%) and absence of longitudinal validation, offering directions for more robust empirical approaches.

Current literature shows pronounced geographical imbalance (26% of studies from China and 14% from the US), scarcity of longitudinal research, and a lack of culturally responsive frameworks for GenAI integration. These issues limit understanding of GenAI's long-term impact and contextual appropriateness. Accordingly, this review is guided by the following research questions (RQ):

- What are the current applications of GenAI in teacher education? (RQ1)
- What benefits and challenges are identified in the literature? (RQ2)
- What research gaps remain, and what are their implications for future research and practice? (RQ3)

2. METHOD

This study adhered to the PRISMA guidelines, a widely accepted standard for conducting systematic reviews across various disciplines. PRISMA provides a structured framework that includes the following key steps: i) establishing clear inclusion and exclusion criteria; ii) formulating and executing a comprehensive search strategy; iii) screening and selecting eligible studies; iv) systematically describing and evaluating the included studies; and v) synthesizing and analyzing the results [17]. Applying these steps ensures transparency, consistency, and rigor throughout the review process, as shown in Figure 1.

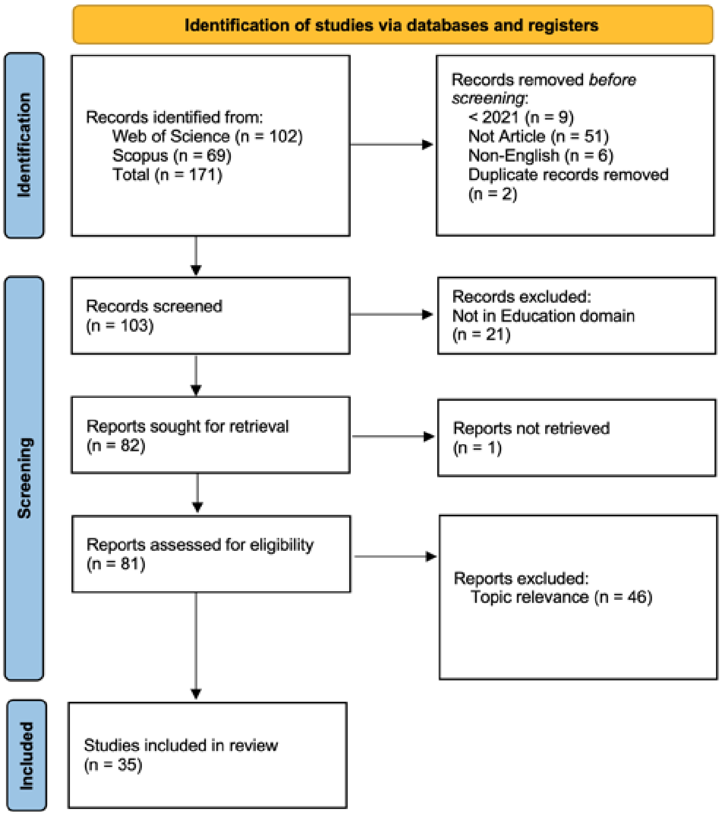

Figure 1. Procedure of the search approach

2.1. Inclusion and exclusion criteria

This study employed clearly defined inclusion and exclusion criteria to ensure the selection of relevant literature aligned with the research questions. Specifically, only studies related to GenAI in education, written in English, and published between January 1st, 2021 and July 31st, 2025 in the Web of Science (WoS) and Scopus databases were included. Articles had to explicitly focus on GenAI and be related to teacher education or teacher professional development. Studies were excluded if they were not related to education or GenAI, not written in English, not peer-reviewed, or conducted within K-12 educational settings. These criteria ensured the relevance and quality of the selected studies.

2.2. Literature search

WoS and Scopus were chosen as primary data sources for their broad coverage and reputation. Using Boolean logic with keywords such as "GenAI" and "teacher education", 171 articles were initially identified. After excluding outdated, non-English, non-article, and duplicate records, 103 remained. Scope screening removed 89 unrelated or duplicate items, leaving 82. Further screening excluded 46 irrelevant or non-retrieved articles, as seen in Figure 1. Two researchers independently screened the studies (Cohen's kappa=0.85), resulting in 35 articles for final review. The full list of reviewed articles can be made available upon reasonable request.

3. RESULTS AND DISCUSSION

The analysis of publication years shows a clear upward trend from 2021 to 2024, followed by a slight decline in 2025. This increase, particularly in 2023 and 2024, coincides with the emergence of multimodal GenAI models such as ChatGPT-4 (released in March 2023) and Gemini (released in December 2023), suggesting that technological advancements may have stimulated research interest in teacher education. The slight drop in 2025 may partly relate to the submission deadline. This trend suggests that technological advancements may have contributed to a shift in research focus from text-based tool applications [18] to multimodal content generation [19]. Note that the submission deadline (July 2025) may have resulted in underreporting.

Figure 2 presents the geographical distribution of the publications analyzed in the study. The data indicates that China (26%) tends to focus on curriculum design and policy integration, as seen in research on AI curriculum development for primary schools [20] and policy adaptability analysis [7]. This emphasis is closely linked to the national promotion of AI education pilot programs in recent years. In contrast, studies from the United States (14%) are more oriented toward human-AI collaborative learning and ethical reflection, such as analyses of human-machine interaction in writing contexts [21] and discussions on the evolving role of teachers [22]. However, regions such as Africa and Latin America are notably absent, indicating a critical gap in understanding GenAI's applicability in diverse and resource-constrained educational settings. This reflects a strong emphasis on developing critical AI literacy.

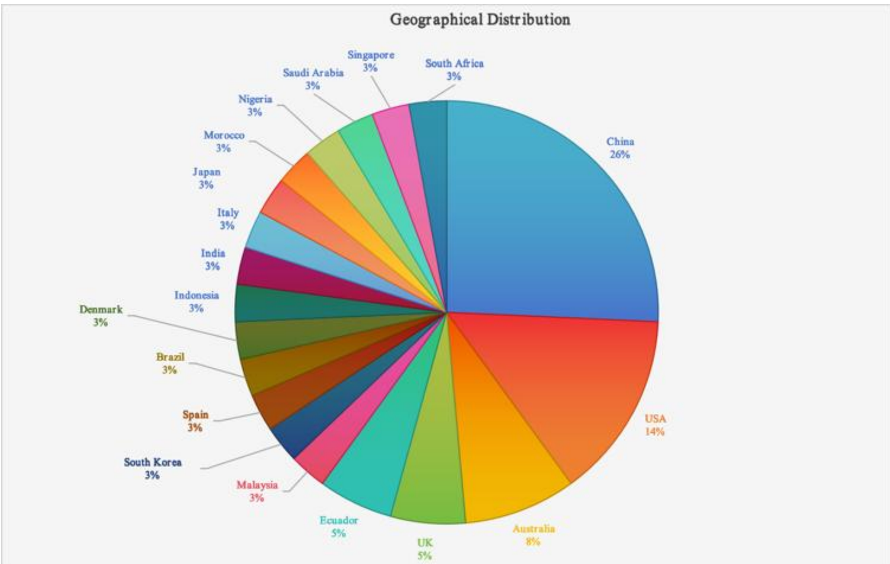

Figure 2. Geographical distribution

The analysis of methodological approaches shows that qualitative studies account for the majority (60%), most of them focus on stakeholder perceptions and needs analysis, such as attitude surveys involving teachers and students [21] and teacher interviews [22]. This indicates that the field is still primarily oriented toward descriptive research. Mixed-method studies (11%) are mostly applied in contexts related to instructional resource support [23], aiming to balance subjective experiences with objective data. Quantitative studies (29%) tend to concentrate on the development of competency assessment tools, such as an AI literacy scale for teachers, but typically involve relatively small sample sizes [24]. The high proportion of qualitative research reflects the absence of a standardized quantitative assessment framework for evaluating GenAI use in teacher education.

3.1. What are the current applications of GenAI in teacher education?

GenAI has shown diverse applications in teacher education, as demonstrated by recent empirical studies across multiple contexts. These applications encompass understanding the perceptions and needs of key stakeholders, supporting instructional resources and content generation, informing curriculum design and development, fostering student-AI collaborative learning, guiding educational practice and policy development, and providing tools for research and evaluation. Together, these findings reflect the growing integration of GenAI into pedagogical practices and teacher preparation programs.

3.1.1. Understanding the perceptions and needs of stakeholders

In the context of rapidly advancing educational technology, understanding the perceptions and needs of key stakeholders, particularly teachers and students, is crucial for the effective integration of GenAI into writing instruction [22], [25]. Barrett and Pack [21] focus on the acceptance of GenAI by both teachers and students across various writing scenarios, offering empirical evidence to support its pedagogical integration. Their findings highlight the need for clear usage guidelines and teacher preparation. Meanwhile, Yau *et al*. [26] investigate faculty and student perceptions across eight Hong Kong universities, noting potential self-reporting biases and the absence of longitudinal evidence. Their study offers insight into actual GenAI usage patterns, which is essential for informing instructional design. Additionally, Chan and Tsi [27] explore the perspectives of two secondary English teachers on early AI adoption. Although the sample is small, the study provides useful implications for tailoring teacher education programs to support GenAI integration. Collectively, these studies underscore the importance of understanding real-world perceptions and support needs to facilitate responsible and effective GenAI adoption in education.

3.1.2. Instructional resources and content support

Hwang and Chen [23] highlight the multifaceted roles that GenAI can play in education, including acting as a teacher, tutor, or learner. The study demonstrates the potential of GenAI in supporting tasks such as academic proofreading and test item generation, thereby enriching instructional resources. In contrast, recent European AI-in-education research indicates that AI tools, ranging from intelligent tutoring systems to virtual reality (VR)/augmented reality (AR)-based learning environments, are enriching instructional resources and expanding the diversity of content available to learners. Such tools support personalized learning, creative production, and interactive knowledge exploration, thereby strengthening the instructional resource ecosystem [28]. GenAI tools like ChatGPT also enhance learner motivation: a study with Japanese university students found that GenAI-supported writing classes significantly strengthened their ideal L2 self and learning engagement [29].

3.1.3. Curriculum design and development

Dai *et al*. [10] emphasize that incorporating external resources, including GenAI-generated materials, can help align AI curricula for primary education with local needs. Kim [30] identifies limited exploration of GenAI across science disciplines in pre-service teacher education, particularly in experimental contexts, suggesting underused opportunities for enhancing science curriculum design [31] and fostering innovative instructional approaches [32]. Houssaini *et al*. [33] integrate design thinking, constructive alignment, and GenAI into the DRIIPT model for developing a medical curriculum in Morocco, illustrating GenAI's role in curriculum innovation.

3.1.4. Promoting student-AI collaborative learning

Kim [30] examines learning models supporting student-AI collaboration (SAC), while recent work demonstrates that GPT can sustain knowledge-building discourse through pedagogy-aligned interaction designs, such as mediating discussions to scaffold collective idea development [34]. Although not always framed explicitly as GenAI, such frameworks provide a valuable foundation for incorporating GenAI into collaborative learning scenarios [18]. Fassbender [35] highlights teacher educators' perspectives on integrating critical AI literacy and notes GenAI's potential to enhance student learning experiences, while also emphasizing the need to understand long-term motivational and pedagogical impacts, making it relevant to SAC discussions [36].

3.1.5. Informing educational practice and policy development

Holmes and Tuomi [37] provide a comprehensive review of AI in education, offering educators a broad foundation for considering GenAI adoption. Thompson *et al*. [38] highlight the lack of higher-education-specific guidelines and call for more empirical evidence to support policy development. Additionally, Liu *et al*. [1] demonstrate how TPACK and SAMR can guide GenAI integration, offering useful insights for both educators and policymakers.

3.1.6. Research and evaluation tools

O'Dea [5] discusses developing tools to measure teachers' GenAI integration capacity, suggesting that GenAI itself can serve as a research and assessment instrument. Similarly, Cooper *et al*. [39] present an AI competency framework based on literature review, model analysis, and expert validation, demonstrating how GenAI-related research informs teacher education curriculum design and assessment standards. This addresses RQ1 by showing how GenAI is being adopted across instructional design, content generation, collaborative learning, and curriculum innovation, thereby mapping the breadth of its applications in teacher education.

3.2. What benefits and challenges are identified in the literature?

GenAI has demonstrated potential benefits in education. Understanding teachers' and students' attitudes toward its use provides valuable empirical evidence to inform integration into instructional practices [25], [40]. Barrett and Pack [21] compare university students' and teachers' acceptance of GenAI across writing scenarios and reveal slight discrepancies in perceived appropriate use, supporting the need for clear usage guidelines and enhanced teacher training. Recent studies also provide systematic reviews and case analyses of GenAI applications in education [21]. Holmes and Tuomi [37] offer an overview of AI practices in educational settings, while Hwang and Chen [23] explore GenAI use cases, offering practical insights for educators. GenAI expands functional roles in teaching through academic proofreading, sentiment analysis, and test-item generation. Dai *et al*. [10] show that primary school computer science teachers can leverage external GenAI resources to align curricula with local needs, supporting inclusive science, technology, engineering, and mathematics (STEM) learning [41] and enhancing conceptual understanding [19].

Despite increasing interest in GenAI, several challenges remain [42]. Many studies suffer from limited sample representativeness, with participants drawn from narrow contexts. For example, Barrett and Pack [21] focus on a single university and mostly English teachers; Yau *et al*. [26] survey eight Hong Kong universities concentrated in engineering and science; and Chan and Tsi [27] examine only two secondary English teachers. Methodological limitations are common: several studies rely heavily on self-reported perceptions without triangulation through classroom observations or behavioral data, creating a gap between reported attitudes and actual practices [26]. Long-term effects remain unclear due to the lack of longitudinal research. Technological relevance is also an issue, as some studies rely on outdated AI models, reducing applicability to current GenAI capabilities [21]. Additionally, simplified or hypothetical scenarios often fail to reflect real-world instructional complexity [27]. Ethical concerns are frequently noted, yet specific actionable guidelines are scarce [26]. A study of 56 Ecuadorian EFL undergraduates found that ChatGPT-generated text was viewed as dishonest, though less so than machine translation, revealing region-specific ethical nuances requiring tailored guidance [43]. Cross-cultural applicability also remains limited, as many studies are situated within specific national contexts, restricting generalizability [23], [30]. The survey findings show that Brazilian K-12 science teachers perceive ChatGPT as offering potential benefits but raising notable challenges for assessment and academic integrity [44].

The reviewed literature presents divergent findings regarding the benefits and challenges of GenAI in teacher education. Barrett and Pack document strong acceptance among students and teachers in writing courses [21], whereas Yau *et al*. [26] identify skepticism in high-stakes assessment contexts due to academic integrity concerns. These inconsistencies suggest that GenAI perceptions are highly context-dependent, shaped by institutional policy, disciplinary culture, and national norms. While many studies note efficiency and creativity gains, few examine potential trade-offs such as overreliance on automated content, weakened critical thinking, or increased cognitive load for teachers evaluating AI-generated outputs. Given that most studies rely on short-term trials or hypothetical scenarios, it remains uncertain whether the reported benefits translate into sustainable pedagogical improvements, underscoring the need for cautious interpretation and further empirical validation.

In line with these findings, recent work highlights GenAI's potential to support inclusivity and accessibility. Jaime-Vargas [13] shows that GenAI-enhanced tools can reduce learning barriers and facilitate equitable participation for diverse learners, suggesting that teacher education programs should prepare pre-service teachers to apply GenAI for inclusive instruction. Similarly, Roldan-Cardona *et al*. [12] demonstrate that AI-supported early childhood environments can promote inclusive and sustainable learning, underscoring a broader need for GenAI-mediated pedagogies that address learner diversity, an aspect still underrepresented in teacher education research. Taken together, these findings respond to RQ2 by identifying both the pedagogical benefits and the methodological, ethical, and contextual challenges associated with GenAI, highlighting areas where teacher training requires targeted support.

3.3. What research gaps remain, and what are their implications for future research and practice?

3.3.1. Gaps in current research

Despite growing interest in GenAI in education, several challenges persist. Many studies have limited sample diversity. For example, Barrett and Pack [21] focus on a single university with mainly English teachers; Yau *et al*. [26] draw samples from eight Hong Kong universities with disciplinary imbalance; Chan and Tsi [27], and Fassbender [35] rely on only two secondary English teachers, reducing generalizability. A lack of large-scale empirical evidence is also common, as noted, where most findings remain conceptual without experimental or survey-based validation [20], [38], [45]. Long-term effects are underexplored because most studies rely on short-term or cross-sectional data, missing sustained impact patterns [21], [26], [45]. Technological limitations persist, as several studies use outdated tools or focus narrowly on text-based AI, overlooking emerging multimodal developments [21]. Ethical guidelines are frequently mentioned but remain vague and lack actionable standards [20], [23], [28], [38]. Cross-cultural and interdisciplinary adaptability is also underexamined, with most research rooted in specific national contexts, limiting insights into GenAI's applicability across diverse educational systems [20], [30]. A cross-cultural survey involving 1,217 participants from 76 countries highlights correlations between cultural dimensions and GenAI perceptions, including academic dishonesty concerns, and underscores the need for culturally responsive ethical policies [46].

3.3.2. Implications for future research and practice

Future research should improve the generalizability of findings by expanding sample sizes and including teachers and students from diverse regions, school types, and academic disciplines [3], [47]. Longitudinal and empirical studies are needed to evaluate the long-term effects of educational models, curriculum designs, and AI applications, addressing the absence of sustained follow-up in prior work. Greater attention is required to AI tool design and technical limitations, with a focus on practical integration that reduces technological obsolescence. Multimodal and emerging GenAI technologies warrant exploration to broaden the technological scope of research. The development of clear, actionable ethical guidelines and evaluation standards is essential for responsible AI use in education [3], [5], [16]. In-depth analyses of regional education policies are needed to understand how they shape AI adoption and inform more effective policy design [11], [48]. Research should also incorporate more complex and authentic teaching scenarios to increase ecological validity [3], [24]. Finally, cross-cultural and interdisciplinary studies are necessary to explore how educational policies, cultural contexts, and subject-specific characteristics influence the implementation of AI-enhanced learning across global settings [49].

The importance of inclusive GenAI-supported learning environments has also been emphasized in recent work. Al-Barakat *et al*. [14] show that digital storytelling environments, when supported by AI, enhance young children's science process skills, illustrating how AI-mediated pedagogies can strengthen developmentally appropriate learning. When considered alongside the findings of Roldan-Cardona *et al*. [12] and Jaime-Vargas [13], these studies collectively highlight the need for teacher education research to examine how GenAI can support accessibility, inclusiveness, and culturally responsive teaching. This reveals a clear research gap. Although GenAI holds promise, teacher education studies rarely explore inclusive design principles or equity-oriented instructional frameworks, indicating a critical direction for future inquiry.

Current research in this field also exhibits underlying assumptions and biases [50], [51]. Many studies presume that teachers are willing and able to integrate GenAI, overlooking barriers such as technostress, job insecurity, and institutional constraints. The literature often highlights benefits while giving limited attention to possible downsides, including ethical dilemmas, intellectual property disputes, and reduced teacher autonomy. Some work extrapolates from early-generation AI models without acknowledging limitations of current technologies or uncertainties about future developments. Cross-cultural variations are frequently overlooked, as existing frameworks are largely drawn from Western or technologically advanced contexts and may not apply to under-resourced educational settings. Future research should adopt a more critical and context-sensitive approach, evaluating the real educational value of GenAI and developing culturally responsive and ethically grounded frameworks for teacher education.

3.4. Limitations of this study

The limitations of the study include: i) the literature search was limited to publications up to July 2025, potentially omitting recent developments; ii) the exclusion of non-English publications may have overlooked innovative practices from non-Anglophone contexts; and iii) no formal quality assessment was conducted to evaluate potential bias in the included studies. To synthesize the relationships between GenAI applications, their pedagogical mechanisms, existing challenges, and improvement pathways, a conceptual framework is developed as shown in Figure 3. This framework provides an integrated structure that helps clarify how different aspects of GenAI research interact and where further investigation is required.

The findings reveal two underexplored issues in current GenAI research. First, the field is dominated by qualitative descriptive studies that lack large-scale or longitudinal validation, limiting the strength of existing conclusions. Second, the research landscape is marked by severe geographical imbalance, which reduces the cross-cultural applicability of many findings. By identifying these gaps, the study directly answers RQ3 and underscores the need for empirical validation, cross-cultural frameworks, and inclusive GenAI design in future teacher education research.

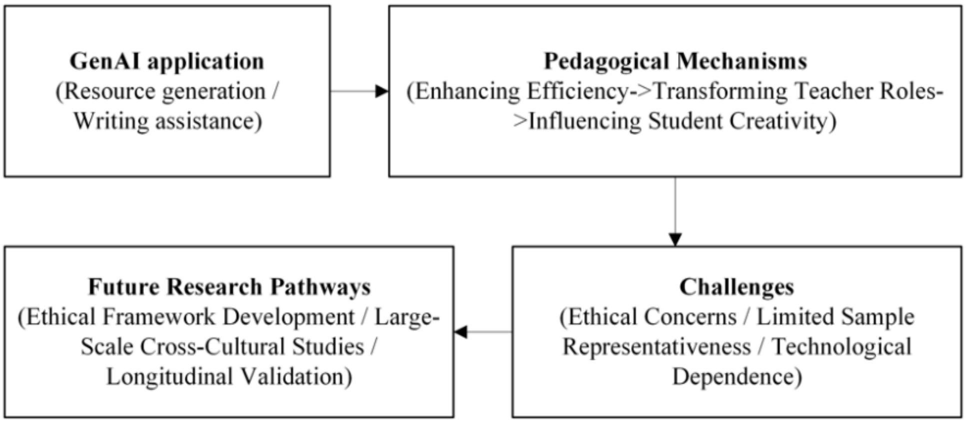

Figure 3. Conceptual framework of GenAI in teacher education

4. CONCLUSION

This study examines GenAI's applications in teacher education, analyzing its benefits, challenges, and research gaps, while identifying three critical tensions between research and practice. First, the gap between technological capabilities and educational implementation. While GenAI supports tasks such as lesson planning, many teachers still lack the skills needed to evaluate the pedagogical quality of AI-generated content. This gap suggests a need for clearer pedagogical integration strategies and targeted professional development that prioritizes educational value over technical features. Second, the gap between research ecology and global diversity. Current research remains fragmented, with studies disproportionately concentrated in China and the United States. This limits the cross-cultural applicability of GenAI integration and leaves the needs of teachers in resource-constrained regions insufficiently represented. Third, the gap between research stage and practical demands. Exploratory, short-term studies dominate, offering little actionable guidance. Future work should move beyond describing possibilities to developing practical, context-sensitive frameworks, focusing on human-AI collaboration while reaffirming teachers' central role. Current conclusions about GenAI's effectiveness are tentative, constrained by methodological limitations and rapid technological evolution.

FUNDING INFORMATION

Authors state no funding involved. This article is derived from the first author's doctoral dissertation.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Longfa Yuan	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Rafiza Abdul Razak	✓	✓			✓	✓			✓	✓		✓	✓	
Amirrudin Kamsin	✓		✓		✓					✓		✓		
Siti-Soraya Abdul-Rahman		✓			✓			✓		✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] J. Liu *et al.*, "A bibliometric analysis of generative AI in education: current status and development," *Asia Pacific Journal of Education*, vol. 44, no. 1, pp. 156–175, Jan. 2024, doi: 10.1080/02188791.2024.2305170.

[2] M. Akour and M. Alenezi, "Higher education future in the era of digital transformation," *Education Sciences*, vol. 12, no. 11, p. 784, Nov. 2022, doi: 10.3390/educsci12110784.

[3] A. D. Samala *et al.*, "Unveiling the landscape of generative artificial intelligence in education: a comprehensive taxonomy of applications, challenges, and future prospects," *Education and Information Technologies*, vol. 30, no. 3, pp. 3239–3278, Feb. 2025, doi: 10.1007/s10639-024-12936-0.

[4] V. Mavrych, E. M. Yousef, A. Yaqinuddin, and O. Bolgova, "Large language models in medical education: a comparative cross-platform evaluation in answering histological questions," *Medical Education Online*, vol. 30, no. 1, p. 2534065, Dec. 2025, doi: 10.1080/10872981.2025.2534065.

[5] X. O'Dea, "Generative AI: is it a paradigm shift for higher education?" *Studies in Higher Education*, vol. 49, no. 5, pp. 811–816, May 2024, doi: 10.1080/03075079.2024.2332944.

[6] K.-E. K. Bilstrup, M. H. Kaspersen, N. O. Bouvin, and M. G. Petersen, "ml-machine.org: Infrastructuring a research product to disseminate AI literacy in education," in *Proceedings of the CHI Conference on Human Factors in Computing Systems*, May 2024, pp. 1–16, doi: 10.1145/3613904.3642539.

[7] A. Brandão, L. Pedro, and N. Zagalo, "Teacher professional development for a future with generative artificial intelligence – an integrative literature review," *Digital Education Review*, no. 45, pp. 151–157, Jul. 2024, doi: 10.1344/der.2024.45.151-157.

[8] G.-G. Lee and X. Zhai, "Using ChatGPT for science learning: a study on pre-service teachers' lesson planning," *IEEE Transactions on Learning Technologies*, vol. 17, pp. 1643–1660, 2024, doi: 10.1109/TLT.2024.3401457.

[9] S. Lee, J. Jeon, and H. Choe, "Generative AI (GenAI) and pre-service teacher agency in ELT," *ELT Journal*, vol. 79, no. 2, pp. 287–296, Jun. 2025, doi: 10.1093/elt/ccaf005.

[10] Y. Dai *et al.*, "Collaborative construction of artificial intelligence curriculum in primary schools," *Journal of Engineering Education*, vol. 112, no. 1, pp. 23–42, Jan. 2023, doi: 10.1002/jee.20503.

[11] B. L. Moorhouse and L. Kohnke, "The effects of generative AI on initial language teacher education: the perceptions of teacher educators," *System*, vol. 122, p. 103290, Jun. 2024, doi: 10.1016/j.system.2024.103290.

[12] M. Roldan-Cardona, M. Chacón-Castro, J. Jadán-Guerrero, L. Salvador-Ullauri, and P. Acosta-Vargas, "Music education with artificial intelligence for inclusive and sustainable early childhood learning," *Emerging Science Journal*, vol. 9, pp. 201–218, Oct. 2025, doi: 10.28991/ESJ-2025-SIED1-012.

[13] J. A. Jaime-Vargas, "Generative AI for enhancing accessibility and inclusion in higher education: a systematic review," *HighTech and Innovation Journal*, vol. 6, no. 2, pp. 723–734, Jun. 2025, doi: 10.28991/HIJ-2025-06-02-022.

[14] A. A. Al-Barakat, O. M. Al-Hassan, R. M. AlAli, and N. A. Ibrahim, "The impact of digital storytelling-based learning environment on young children's science process skills," *Emerging Science Journal*, vol. 9, pp. 19–38, May 2025, doi: 10.28991/ESJ-2025-SIED1-02.

[15] Y. K. Dwivedi, "Generative artificial intelligence (GenAI) in entrepreneurial education and practice: emerging insights, the GAIN framework, and research agenda," *International Entrepreneurship and Management Journal*, vol. 21, no. 1, p. 82, Dec. 2025, doi: 10.1007/s11365-025-01089-2.

[16] L. Kohnke and D. Zou, "Artificial intelligence integration in TESOL teacher education: promoting a critical lens guided by TPACK and SAMR," *TESOL Quarterly*, vol. 59, no. S3, pp. S267–S278, Dec. 2025, doi: 10.1002/tesq.3396.

[17] M. L. Rethlefsen and M. J. Page, "PRISMA 2020 and PRISMA-S: common questions on tracking records and the flow diagram," *Journal of the Medical Library Association: JMLA*, vol. 110, no. 2, pp. 253–257, Nov. 2022, doi: 10.5195/jmla.2022.1449.

[18] J. Kim, H. Lee, and Y. H. Cho, "Learning design to support student-AI collaboration: perspectives of leading teachers for AI in education," *Education and Information Technologies*, vol. 27, no. 5, pp. 6069–6104, 2022, doi: 10.1007/s10639-021-10831-6.

[19] H. Liu, X. Zhang, J. Zhou, Y. Shou, Y. Yin, and C. Chai, "Cognitive styles and design performances in conceptual design collaboration with GenAI," *International Journal of Technology and Design Education*, vol. 35, no. 3, pp. 1169–1202, Jul. 2025, doi: 10.1007/s10798-024-09937-y.

[20] J. M. Lodge, K. Thompson, and L. Corrin, "Mapping out a research agenda for generative artificial intelligence in tertiary education," *Australasian Journal of Educational Technology*, vol. 39, no. 1, pp. 1–8, May 2023, doi: 10.14742/ajet.8695.

[21] A. Barrett and A. Pack, "Not quite eye to A.I.: student and teacher perspectives on the use of generative artificial intelligence in the writing process," *International Journal of Educational Technology in Higher Education*, vol. 20, no. 1, p. 59, Nov. 2023, doi: 10.1186/s41239-023-00427-0.

[22] C. K. Y. Chan and K. K. W. Lee, "The AI generation gap: are Gen Z students more interested in adopting generative AI such as ChatGPT in teaching and learning than their Gen X and millennial generation teachers?" *Smart Learning Environments*, vol. 10, no. 1, p. 60, Nov. 2023, doi: 10.1186/s40561-023-00269-3.

[23] G. J. Hwang and N. S. Chen, "Editorial position paper: exploring the potential of generative artificial intelligence in education: applications, challenges, and future research directions," *Educational Technology and Society*, vol. 26, no. 2, pp. 1–16, 2023, doi: 10.30191/ETS.202304_26(2).0014.

[24] L. Shi, "Assessing teachers' generative artificial intelligence competencies: instrument development and validation," *Education and Information Technologies*, vol. 30, no. 16, pp. 23365–23384, Nov. 2025, doi: 10.1007/s10639-025-13684-5.

[25] C. K. Y. Chan and W. Hu, "Students' voices on generative AI: perceptions, benefits, and challenges in higher education," *International Journal of Educational Technology in Higher Education*, vol. 20, no. 1, p. 43, Jul. 2023, doi: 10.1186/s41239-023-00411-8.

[26] K. W. Yau, C. S. Chai, T. K. F. Chiu, H. Meng, I. King, and Y. Yam, "A phenomenographic approach on teacher conceptions of teaching Artificial Intelligence (AI) in K-12 schools," *Education and Information Technologies*, vol. 28, no. 1, pp. 1041–1064, Jan. 2023, doi: 10.1007/s10639-022-11161-x.

[27] C. K. Y. Chan and L. H. Y. Tsi, "Will generative AI replace teachers in higher education? A study of teacher and student perceptions," *Studies in Educational Evaluation*, vol. 83, p. 101395, Dec. 2024, doi: 10.1016/j.stueduc.2024.101395.

[28] J. F. M. Sánchez-Jara, S. G. Gutiérrez, J. C. Rodríguez, and B. S. Syroyid, "Artificial intelligence-assisted music education: a critical synthesis of challenges and opportunities," *Education Sciences*, vol. 14, no. 11, p. 1171, Oct. 2024, doi: 10.3390/educsci14111171.

[29] J. Huang and A. Mizumoto, "The effects of generative AI usage in EFL classrooms on the L2 motivational self system," *Education and Information Technologies*, vol. 30, no. 5, pp. 6435–6454, Apr. 2025, doi: 10.1007/s10639-024-13071-6.

[30] J. Kim, "Leading teachers' perspective on teacher-AI collaboration in education," *Education and Information Technologies*, vol. 29, no. 7, pp. 8693–8724, May 2024, doi: 10.1007/s10639-023-12109-5.

[31] W. Li, X. Zhang, J. Li, X. Yang, D. Li, and Y. Liu, "An explanatory study of factors influencing engagement in AI education at the K-12 level: an extension of the classic TAM model," *Scientific Reports*, vol. 14, no. 1, p. 13922, Jun. 2024, doi: 10.1038/s41598-024-64363-3.

[32] J. Cordero, J. Torres-Zambrano, and A. Cordero-Castillo, "Integration of generative artificial intelligence in higher education: best practices," *Education Sciences*, vol. 15, no. 1, p. 32, Dec. 2024, doi: 10.3390/educsci15010032.

[33] M. S. Houssaini, A. Aboutajeddine, I. Toughrai, and A. Ibrahimi, "Development of a design course for medical curriculum: Using design thinking as an instructional design method empowered by constructive alignment and generative AI," *Thinking Skills and Creativity*, vol. 52, p. 101491, Jun. 2024, doi: 10.1016/j.tsc.2024.101491.

[34] A. V. Y. Lee, S. C. Tan, and C. L. Teo, "Designs and practices using generative AI for sustainable student discourse and knowledge creation," *Smart Learning Environments*, vol. 10, no. 1, p. 59, Nov. 2023, doi: 10.1186/s40561-023-00279-1.

[35] W. J. Fassbender, "'I can almost recognize its voice': AI and its impact on ethical teacher-centaur labor," *English Teaching: Practice & Critique*, vol. 23, no. 1, pp. 104–117, Apr. 2024, doi: 10.1108/ETPC-08-2023-0101.

[36] G. van den Berg and E. du Plessis, "ChatGPT and generative AI: possibilities for its contribution to lesson planning, critical thinking and openness in teacher education," *Education Sciences*, vol. 13, no. 10, p. 998, Sep. 2023, doi: 10.3390/educsci13100998.

[37] W. Holmes and I. Tuomi, "State of the art and practice in AI in education," *European Journal of Education*, vol. 57, no. 4, pp. 542–570, Dec. 2022, doi: 10.1111/ejed.12533.

[38] K. Thompson, L. Corrin, and J. M. Lodge, "AI in tertiary education: progress on research and practice," *Australasian Journal of Educational Technology*, vol. 39, no. 5, pp. 1–7, Dec. 2023, doi: 10.14742/ajet.9251.

[39] G. Cooper, K.-S. Tang, and A. Fitzgerald, "Intersections of mind and machine: navigating the nexus of artificial intelligence, science education, and the preparation of pre-service teachers," *Journal of Science Education and Technology*, vol. 34, no. 6, pp. 1255–1259, Dec. 2025, doi: 10.1007/s10956-025-10200-9.

[40] Y.-C. Hsu and Y.-H. Ching, "Generative artificial intelligence in education, part one: the dynamic frontier," *TechTrends*, vol. 67, no. 4, pp. 603–607, Jul. 2023, doi: 10.1007/s11528-023-00863-9.

[41] M. L. Bernardi, R. Capone, E. Faggiano, and H. Rocha, "Generative AI in mathematics education: pre-service teachers' knowledge and implications for their professional development," *International Journal of Mathematical Education in Science and Technology*, vol. 56, no. 8, pp. 1513–1530, Aug. 2025, doi: 10.1080/0020739X.2025.2490104.

[42] L. Yan, R. Martinez-Maldonado, and D. Gasevic, "Generative artificial intelligence in learning analytics: contextualising opportunities and challenges through the learning analytics cycle," in *Proceedings of the 14th Learning Analytics and Knowledge Conference*, Mar. 2024, pp. 101–111, doi: 10.1145/3636555.3636856.

[43] A. S. Nelson, P. V. Santamaría, J. S. Javens, and M. Ricaurte, "Students' perceptions of generative artificial intelligence (GenAI) use in academic writing in English as a foreign language," *Education Sciences*, vol. 15, no. 5, p. 611, May 2025, doi: 10.3390/educsci15050611.

[44] F. F. Monteiro, P. V. S. Souza, M. C. da Silva, J. R. Maia, W. F. da Silva, and D. Girardi, "ChatGPT in Brazilian K-12 science education," *Frontiers in Education*, vol. 9, p. 1321547, Feb. 2024, doi: 10.3389/feduc.2024.1321547.

[45] W. M. Lim, A. Gunasekara, J. L. Pallant, J. I. Pallant, and E. Pechenkina, "Generative AI and the future of education: Ragnarök or reformation? A paradoxical perspective from management educators," *The International Journal of Management Education*, vol. 21, no. 2, p. 100790, Jul. 2023, doi: 10.1016/j.ijme.2023.100790.

[46] A. Yusuf, N. Pervin, and M. Román-González, "Generative AI and the future of higher education: a threat to academic integrity or reformation? Evidence from multicultural perspectives," *International Journal of Educational Technology in Higher Education*, vol. 21, no. 1, p. 21, Mar. 2024, doi: 10.1186/s41239-024-00453-6.

[47] J. Lu, R. Zheng, Z. Gong, and H. Xu, "Supporting teachers' professional development with generative AI: the effects on higher order thinking and self-efficacy," *IEEE Transactions on Learning Technologies*, vol. 17, pp. 1267–1277, 2024, doi: 10.1109/TLT.2024.3369690.

[48] D. Zou, H. Xie, and L. Kohnke, "Navigating the future: establishing a framework for educators' pedagogic artificial intelligence competence," *European Journal of Education*, vol. 60, no. 2, p. e7011, Jun. 2025, doi: 10.1111/ejed.70117.

[49] F. Jin, L. Sun, Y. Pan, and C.-H. Lin, "High heels, compass, spider-man, or drug? Metaphor analysis of generative artificial intelligence in academic writing," *Computers & Education*, vol. 228, p. 105248, Apr. 2025, doi: 10.1016/j.compedu.2025.105248.
[50] M. Rice, N. DePascal, J. T. A. de Jesús, H. McFeely, A. Traylor, and L. Heaviland, "What is the machine? Teachers' professional learning about generative artificial intelligence as tutors for children," *Professional Development in Education*, vol. 51, no. 3, pp. 418–433, May 2025, doi: 10.1080/19415257.2024.2407413.
[51] A. Bozkurt, "GenAI et al.: cocreation, authorship, ownership, academic ethics and integrity in a time of generative AI," *Open Praxis*, vol. 16, no. 1, pp. 1–10, Feb. 2024, doi: 10.55982/openpraxis.16.1.654.

BIOGRAPHIES OF AUTHORS

Longfa Yuan is a Ph.D. student at the Institute for Advanced Studies, Universiti Malaya (UM). He holds a Bachelor's Degree in E-Commerce and has an academic background in Computer Science, and a Master's Degree in Modern Educational Technology. His academic background and research focus lie at the intersection of artificial intelligence and education. He has a strong interest in the application of AI in educational contexts and has published several papers in this area, offering unique insights and perspectives. His research interests include educational science, artificial intelligence in education, and e-commerce. He can be contacted at email: 22104099@siswa.um.edu.my.

Rafiza Abdul Razak is the former Head of the Department of Curriculum and Instructional Technology, Faculty of Education, Universiti Malaya. She holds a Ph.D. in Instructional Technology from the International Islamic University Malaysia. Committed to educational innovation, she led the establishment of facilities such as the InTechPro Studio and collaborated with Microsoft to enhance teacher training. She has led multiple international research projects, registered 81 innovations (including patents and copyrights), published in WoS and Scopus journals, and received recognitions such as the Microsoft Master Trainer award. She was featured in successful people in Malaysia. She can be contacted at email: rafiza@um.edu.my.

Amirrudin Kamsin is an associate professor and the Head of the Department of Computer System and Technology, Faculty of Computer Science and Information Technology, Universiti Malaya. He holds a Ph.D. in Human-Computer Interaction from University College London. He has published over 120 research papers in SCI- and Scopus-indexed journals, with more than 10 of his articles cited over 100 times. His research interests include human-computer interaction, virtual reality, multimedia, personal task management, and personal time management. He can be contacted at email: amir@um.edu.my.

Siti-Soraya Abdul-Rahman is a senior lecturer in the Department of Artificial Intelligence, Faculty of Computer Science and Information Technology, Universiti Malaya. She received her Ph.D. in Cognitive Science from the University of Sussex, United Kingdom, in 2012. Her current research interests lie in the areas of machine learning and deep learning, large language models, knowledge representation and reasoning, and data science, including predictive analytics, data analytics, text analytics, and sentiment analysis. She is also actively involved in research in cognitive science (particularly cognition and programming, and physics problem-solving), artificial intelligence in education, e-learning, and expert systems. She can be contacted at email: siti_soraya@um.edu.my.