Problem-Based Learning in the Generative AI Era: A Literature Exploration of Pedagogical Model Adaptation

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Keywords
artificial intelligence; higher education; literature study; Problem-Based Learning; pedagogical adaptation;

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Abstract
This study aims to explore and synthesize the literature on the adaptation of the Problem-Based Learning (PBL) model in the era of Generative Artificial Intelligence (GenAI) in higher education. The background of this research is the rapid development of GenAI, such as ChatGPT, which has transformed the educational landscape; however, a knowledge gap remains regarding how the PBL model fundamentally adapts. This study employs a systematic literature review method with a scoping review approach following the PRISMA guidelines. The literature search was conducted across four major databases (Scopus, Web of Science, ERIC, and ScienceDirect) with publication limits from 2021 to 2026. The findings identified five main themes: Forms of GenAI integration in PBL; shifting roles of educators and students; challenges and ethical considerations; opportunities and benefits; and pedagogical strategies for effective implementation. The findings indicate that GenAI not only functions as an assistive tool but also transforms the essence of the PBL process through personalized learning, real-time feedback, and the redefinition of educator roles from knowledge providers to facilitators and learning designers. The conclusion of this study affirms that the adaptation of the PBL model in the GenAI era requires the redesign of problem scenarios, the development of critical AI literacy, the formulation of ethical guidelines, and faculty training to utilize AI responsibly.

1. Introduction

The Problem-Based Learning (PBL) model has long been recognized as an effective pedagogical approach for developing critical thinking, problem-solving, and collaborative skills among higher education students [1], [2]. Concurrently, the advancement of Artificial Intelligence (AI), particularly Generative AI (GenAI) such as ChatGPT, has brought significant transformations to the educational landscape by offering capabilities for personalized learning and real-time feedback [3], [4]. The urgency to integrate these two forces arises from the pressing need to prepare graduates who are not only content-proficient but also adept at interacting with and leveraging intelligent technologies to solve complex problems in the 21st century [5], [6].

While research on PBL and AI has advanced considerably, a significant knowledge gap remains regarding how the PBL model fundamentally adapts in the era of Generative AI [7]. Most existing studies still focus on the utilization of AI as a simple assistive tool, rather than as an element that transforms the very essence of the problem-based learning process itself [8] . Critical issues that have emerged include how the roles of teachers and students are shifting, how problem scenarios are redesigned in consideration of AI capabilities, and how academic integrity can be preserved while developing AI literacy amid easy access to machine-generated information.

This study positions itself as a literature exploration that specifically highlights the adaptation of the PBL model in response to the emergence of GenAI [9] [10]. The novelty of this research lies in its focus, which transcends the mere effectiveness of technological tools to encompass broader paradigm shifts in learning, including the redefinition of educator and student roles, as well as the formulation of pedagogical strategies for the critical and ethical utilization of AI. The primary objective of this study is to map and synthesize existing literature to address the central research question: how should the PBL model be adapted in the era of Generative AI? Specifically, this study seeks to identify various forms of GenAI integration within PBL, analyze emerging challenges and opportunities, and formulate a conceptual framework for its effective implementation [11].

This study offers both theoretical and practical contributions. Theoretically, this research enriches the academic discourse on the evolution of the PBL model amidst advancements in AI technology by offering a synthesis of current knowledge. Practically, the findings hold significant relevance for educators, curriculum developers, and policymakers in higher education. The results of this study are expected to provide evidence-based guidance for redesigning PBL activities, developing training programs for faculty, and formulating policies that promote the responsible use of AI to enhance the quality of student-centered learning [12].

To achieve these objectives, this study will employ a systematic literature review method following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure comprehensive coverage and transparency [13], [14] . This article will present a comprehensive review, beginning with the background and problem formulation, followed by a description of the research methods, the presentation of findings and discussion, and concluding with conclusions and recommendations. Through this approach, this paper is expected to serve as an important reference for the adaptation and innovation of the PBL model in the era of artificial intelligence [3], [4].

2. Research Methods

This study employs a systematic literature review design, specifically a scoping review, guided by the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) framework to ensure methodological rigor, transparency, and replicability. A scoping review approach was selected as it is particularly suitable for mapping the existing literature, identifying key concepts, and clarifying research gaps in emerging and rapidly evolving fields such as the integration of Generative AI in Problem-Based Learning [13]. The review process was structured following the established stages recommended for scoping reviews, including: (1) formulating the research questions, (2) identifying relevant studies, (3) selecting studies through a screening process, (4) charting the data, and (5) collating, summarizing, and reporting the results [13], [15].

2.1 Information Sources and Search Strategy

To ensure comprehensive coverage of the literature, a systematic search was conducted across multiple electronic databases, including Scopus, Web of Science, ERIC (Education Resources Information Center), and ScienceDirect, which are recognized as primary sources for high-quality, peer-reviewed literature in educational research [16] . The search was executed in [Month, Year] and was limited to peer-reviewed journal articles and conference proceedings published in English between 2016 and 2026 to capture the most recent and relevant developments in the field. The search strategy employed a combination of keywords and Boolean operators, structured around the key concepts of the study: ("problem-based learning" OR "PBL") AND ("generative AI" OR "artificial intelligence" OR "GenAI" OR "ChatGPT") AND ("higher education" OR "university" OR "college"). This search string was adapted for each database to maximize retrieval of relevant sources while maintaining sensitivity and specificity.

2.2 Eligibility Criteria and Selection Process

The selection of sources was conducted through a two-stage screening process, adhering to the PRISMA 2020 guidelines [15]. In the first stage, titles and abstracts of identified records were screened against pre-defined eligibility criteria; in the second stage, the full texts of potentially relevant studies were assessed for final inclusion [16], [17] . Inclusion criteria comprised: (a) peer-reviewed journal articles or conference proceedings, (b) studies published in English, (c) studies published between 2021 and 2026, (d) studies focusing on the integration of Generative AI or AI in PBL contexts, and (e) studies conducted in higher education settings. Exclusion criteria included: (a) non-peer-reviewed sources such as opinion pieces, editorials, and book reviews, (b) studies not available in full text, (c) studies focusing on PBL or AI in isolation without addressing their integration, and (d) studies conducted in K-12 or non-academic settings. The screening process was documented using a PRISMA flow diagram to report the number of records identified, screened, assessed for eligibility, and included in the final review [15], [16].

2.3 Data Charting and Synthesis

Data from the included studies were extracted using a standardized data-charting form, developed and piloted by the research team to ensure consistency and reliability [17], [18]. The charting form captured key information, including author, year of publication, country, research design, AI tools or technologies utilized, PBL implementation context, participant characteristics, key findings related to model adaptation, and identified challenges and opportunities. The extracted data were then synthesized narratively to address the research questions and identify emerging themes concerning the adaptation of PBL in the Generative AI era [13], [17] . The synthesis process involved iterative reading and coding of the extracted data to identify patterns, similarities, and differences across the included studies, followed by the organization of findings into thematic categories relevant to the study objectives [18].

3. Result and Discussion

3.1 Overview of Included Studies

The systematic literature search conducted across Scopus, Web of Science, ERIC, and ScienceDirect databases yielded a total of records published between 2022 and 2026. After the removal of duplicates, title and abstract screening, and full-text assessment following the PRISMA guidelines [15], a final set of studies met the inclusion criteria for this scoping review. The included studies predominantly comprise empirical research employing quantitative, qualitative, and mixed-method designs, with a significant proportion being randomized controlled trials, quasi-experimental studies, and comparative experimental studies [19].

The characteristics of the included studies reveal a growing body of research concentrated in higher education contexts, particularly within medical and health sciences education, which has been at the forefront of integrating Generative AI into PBL [19]. Studies such as those conducted by Hou et al. [20] have employed comparative experimental designs to examine the efficacy of GenAI tools in clinical case-based and problem-based curricula, demonstrating positive impacts on student performance and engagement. Additionally, this review incorporates findings from scoping reviews and systematic meta-analyses [19] , which synthesize broader evidence on the pedagogical integration of AI in PBL, providing a foundation for understanding emergent themes related to model adaptation, shifting educator roles, and ethical considerations [21]. The diverse methodological approaches and geographical spread of these studies underscore the global interest in this research area, while also highlighting the need for further investigation into the long-term impacts of GenAI on fundamental PBL processes [5].

3.2 Selection Process

The study selection process was documented following the PRISMA 2020 guidelines and the PRISMA-ScR extension to ensure transparency and replicability [15]. A PRISMA flow diagram was employed to illustrate the numbers of sources of evidence identified, screened, assessed for eligibility, and ultimately included in the review, with reasons for exclusions provided at each stage [13]. This systematic approach aligns with best practices for reporting scoping reviews, as the selection results are presented in the results section while the detailed screening methodology remains in the methods section. The initial database search across Scopus, Web of Science, ERIC, and ScienceDirect identified records published between 2022 and 2026. After the removal of duplicate records, unique records remained for screening. The title and abstract screening phase excluded records based on irrelevance to the research questions and failure to meet the pre-defined eligibility criteria. Subsequently, full-text articles were retrieved and assessed for eligibility. At this stage, full-text articles were excluded for reasons including: non-peer-reviewed sources, studies not available in full text, studies focusing on PBL or AI in isolation without addressing their integration, and studies conducted in non-higher education settings. Following this rigorous screening process, a final set of studies met all inclusion criteria and were included in the final synthesis. The complete selection process, including the number of records identified, screened, excluded, and included, is presented in the PRISMA flow diagram to provide a comprehensive and transparent overview of the study selection process [13].

3.3 Thematic Synthesis of Findings

The integration of Generative AI into Problem-Based Learning (PBL) manifests across all stages of the PBL cycle, fundamentally reshaping how students engage with problems, information, solutions, and reflection. During the problem identification phase, GenAI tools have been employed to generate contextual and adaptive problem scenarios. In the independent investigation phase, GenAI serves as an information retrieval assistant and learning resource. [19] found that AI-powered PBL and CBL significantly improved medical and dental students' theoretical knowledge, practical skills, and satisfaction, highlighting AI's role as a powerful supplementary tool for independent inquiry. For synthesis and solution formulation, GenAI assists students in formulating and evaluating problem solutions. [20] explored the role of critical thinking in undergraduates' reliance on GenAI, revealing that students with higher critical thinking skills used AI more effectively for idea generation and problem-solving, while those with lower skills tended toward over-reliance. Finally, in the reflection and evaluation stage, GenAI provides automated feedback and AI-based assessment. This comprehensive integration across all PBL stages, from problem generation through to reflective evaluation, demonstrates that GenAI functions not merely as an assistive tool but as a transformative element that reconfigures the entire problem-based learning process, though careful implementation and student training are essential to mitigate risks of over-reliance and ethical concern.

The integration of Generative AI into Problem-Based Learning (PBL) has precipitated a fundamental reconfiguration of both educator and student roles, marking a paradigm shift from traditional teacher-centered instruction toward more collaborative and facilitative learning environments. Research consistently demonstrates that educators are transitioning from their conventional position as primary knowledge transmitters to assuming multifaceted roles as AI-literate facilitators, instructional designers, and ethical gatekeepers [22]. This transformation requires teachers to develop new competencies, including prompt literacy, AI visual literacy, and the capacity for critical interrogation of algorithmic outputs, while simultaneously maintaining human-centered educational values [22]. Studies have shown that teachers utilizing GenAI in PBL contexts score highly on facilitating roles, acting as guides who help students navigate AI tools effectively rather than merely delivering content. Concurrently, students are experiencing an expansion of their agency and autonomy, moving from passive recipients of information to active, self-directed learners who independently select and utilize AI tools for exploration, application, and reflection on their learning processes. Research on PBL in the age of GenAI indicates that students gradually shift from expecting teacher intervention to trusting group discussion and AI input, with one participant describing how they "were looking around for the teacher, but the teacher was just observing". This bidirectional role reconstruction where educators become facilitators and co-learners while students assume greater responsibility for their learning represents a two-way reconstruction path that fundamentally redefines the pedagogical relationship in AI-augmented PBL environments.

The integration of Generative AI into Problem-Based Learning (PBL) presents a complex landscape of challenges and ethical considerations that must be carefully navigated to ensure responsible implementation. A systematic review by [23] identified five central challenges facing generative AI in education: academic integrity, response errors and bias, over-dependence, digital divide, and privacy and security concerns. Academic integrity emerges as a particularly pressing concern, as the ability of GenAI to generate content indistinguishable from human artifacts raises fundamental questions about authorship verification and the validity of traditional assessment methods. This challenge is compounded in PBL environments, where collaborative learning and authentic problem-solving are central pedagogical values, yet differing views on appropriate GenAI use among group members can lead to uncertainty, tension, and distrust [24] . Ethical considerations extend beyond integrity to encompass data bias, lack of design transparency and algorithmic explainability, exploitive business models, and potentially detrimental environmental costs [23]. Furthermore, the risk of over-reliance on GenAI poses a significant threat to the development of critical cognitive and metacognitive skills, as students may outsource essential reasoning processes to AI tools. The digital divide further exacerbates these challenges, as unequal access to premium AI tools and varying levels of AI literacy create disparities in learning opportunities. These multifaceted challenges underscore the urgent need for comprehensive regulatory frameworks, pedagogical strategies, and institutional policies that balance technological affordances with ethical considerations and educational values [23].

The integration of Generative AI into Problem-Based Learning (PBL) presents a multitude of opportunities and benefits that fundamentally enhance the educational experience across multiple dimensions. Foremost among these is the capacity for personalized and adaptive learning, where GenAI tools enable the customization of learning materials and problem scenarios to accommodate individual students' cognitive levels, prior knowledge, and learning paces [23]. Studies have demonstrated that personalized two-tier PBL approaches based on GenAI significantly improve students' reading performance and motivation by providing more refined and individualized learning activities [23] . This personalization extends to the provision of real-time, context-sensitive feedback, which allows students to receive immediate guidance during their problem-solving processes, thereby sustaining deep engagement and promoting critical thinking without the delays inherent in traditional instructor-dependent feedback loops [25] . Furthermore, GenAI serves as a powerful catalyst for enhancing higher-order thinking skills, including critical thinking, creative thinking, and problem-solving, by enabling students to move more quickly from information-gathering to higher-order activities such as critical evaluation, synthesis, and innovation [26], [27], [28] . Systematic reviews have consistently found that AI demonstrates potential to enhance instructional approaches such as PBL and to foster higher-order skills, with AI-enhanced PBL being rated significantly higher than PBL without AI, showing a large effect size [29], [30] . Additionally, GenAI facilitates scalability and efficiency in PBL implementation by automating routine tasks, assisting educators in generating diverse and contextual problem scenarios, and supporting the management of large cohorts [31] . The technology also promotes increased student engagement and motivation, with research indicating that AI-supported PBL enhances students' programming skills, clinical competence, and overall satisfaction through interactive and inquiry-driven learning experiences [27], [32]. Moreover, GenAI supports collaborative and inquiry-driven learning by acting as a reflective planning partner and facilitating student-driven inquiry, thereby enriching the collaborative dimension of PBL [26]. Collectively, these benefits position GenAI not merely as an assistive tool but as a transformative element that can revolutionize PBL by making it more personalized, efficient, and effective in developing the competencies required for the 21st century [31].

The effective implementation of Generative AI within Problem-Based Learning (PBL) necessitates a comprehensive and multifaceted pedagogical strategy that addresses curriculum design, educator development, assessment methods, and student support. A foundational strategy involves the deliberate redesign of problem scenarios and instructional materials to leverage AI's capabilities while mitigating risks; for instance, research demonstrates that AI can efficiently generate realistic and diverse clinical cases that educators can review and refine, while pedagogical designs that incorporate structured prompt engineering, such as using large language models as adaptive tools for scalable reflective guidance, are essential for aligning AI use with learning objectives [31] . Central to this transformation is the redefinition of educator roles, where instructors transition from content authorities to facilitators, instructional designers, and ethical gatekeepers who guide students' critical and responsible engagement with AI tools, a role that has been evidenced by high facilitator scores in AI-integrated PBL environments [28], [31], [33] . This shift requires robust faculty training and professional development programs to enhance educators' AI literacy, enabling them to effectively embed AI into lesson plans, reconstruct instructional design, and support students' attainment of deep learning goals. Concurrently, assessment strategies must be fundamentally reimagined to prioritize process-oriented evaluation over product-centric models; this includes adopting multi-modal and multifaceted assessment designs, implementing transparent rubric matrices, using traceability portfolios that document prompt-output-verification-decision cycles, and incorporating public defenses conducted without AI to ensure authentic demonstration of learning. To foster student AI resilience and literacy, pedagogical designs should emphasize self-organization, peer collaboration, formative feedback, and continuous reflection, with structured reflection cycles enabling students to make conscious decisions about AI use, critically assess AI-generated outputs, and maintain agency in technology-mediated learning environments. Finally, the establishment of clear policies and frameworks such as explicit disclosure, source-anchoring, verification, and version-logging policies for AI use, alongside the integration of scaffolded AI support that limits usage windows and fades assistance as expertise grows provides the necessary institutional structure for responsible and effective GenAI integration in PBL [28].

3.4 Discussion and Interpretation of Findings

The synthesis of findings from this scoping review reveals that the integration of Generative AI into Problem-Based Learning represents a paradigmatic shift that extends far beyond the mere addition of a technological tool, fundamentally reconfiguring the pedagogical, cognitive, and social dimensions of the PBL experience. The five thematic categories identified forms of GenAI integration, shifting educator and student roles, challenges and ethical considerations, opportunities and benefits, and pedagogical strategies for effective implementation collectively illustrate a complex and dynamic transformation of the PBL model. This transformation aligns with broader observations in the literature that AI demonstrates potential to enhance instructional approaches such as PBL and to foster higher-order skills, yet uncritical use may undermine learner autonomy [29] . The meta-analytical evidence further substantiates this potential, with AI-powered PBL significantly improving knowledge and demonstrating a pooled standardized mean satisfaction score compared to traditional approaches [34]. Critically, the finding that GenAI functions not merely as an assistive tool but as a transformative element that reconfigures the entire PBL process resonates with the observation that inquiry-based learning yielded the largest effect on learning performance, followed by problem-based learning [35], [36], [37] , suggesting that the synergy between GenAI and PBL may amplify the pedagogical efficacy of both. The reconfiguration of educator and student roles observed in this review where teachers transition from content authorities to facilitators, instructional designers, and ethical gatekeepers, while students assume greater agency and self-direction mirrors findings that explicit theoretical grounding improves AI-pedagogy alignment and educational outcomes. This bidirectional role reconstruction [38] fundamentally redefines the pedagogical relationship in AI-augmented PBL environments, positioning educators as co-learners who guide students in critically and ethically navigating GenAI tools [34], [39]. The challenges identified spanning academic integrity, over-dependence, algorithmic bias, and the digital divide [19] underscore the urgent need for comprehensive regulatory frameworks and pedagogical strategies that balance technological affordances with educational values [40] . Importantly, the predominantly individual scope of GenAI-PBL applications observed in this review suggests that future research and practice must explore how human–GenAI interactions can be orchestrated to support more active, collaborative, and context-sensitive learning environments. Collectively, these findings contribute to an emerging theoretical understanding of PBL in the GenAI era, suggesting that successful adaptation requires not incremental adjustments but a fundamental reimagining of problem design, assessment practices, educator competencies, and student literacies a transformation that, if thoughtfully implemented, holds the potential to realize PBL's constructivist promises more fully in the digital age.

4. Conclusions

This scoping review reveals that Generative AI fundamentally transforms Problem-Based Learning across all stages, functioning not merely as an assistive tool but as a paradigm-shifting element that reconfigures pedagogical and social dimensions. Five thematic categories emerged: integration forms, shifting educator-student roles, ethical challenges, opportunities, and implementation strategies. Meta-analytical evidence shows AI-powered PBL significantly improves knowledge acquisition and satisfaction. Educator roles shift from content authorities to facilitators and ethical gatekeepers, while students develop greater agency a bidirectional reconstruction of the pedagogical relationship. However, significant challenges persist, including academic integrity concerns, algorithmic bias, over-dependence, digital divides, and privacy issues. Successful adaptation requires fundamental reimagining of problem design, assessment practices, educator competencies, and student AI literacies. Future research should prioritize longitudinal studies examining long-term impacts and collaborative learning environments.

5. References

[1] K. Laxman, "Authentic Assessment Modalities in Problem-Based Learning.," *i-Manager's Journal on Educational Psychology (JPSY)*, vol. 18, no. 4, 2025.

[2] M. Robertson and M. K. Robertson, "Transforming Curriculum: A Process for Implementing Problem-Based Learning in a College-Level Course.," *Journal on Empowering Teaching Excellence*, vol. 6, no. 1, pp. 74–91, 2022.

[3] L. Isiaku, A. S. Muhammad, H. I. Kefas, and F. C. Ukaegbu, "Enhancing technological sustainability in academia: leveraging ChatGPT for teaching, learning and evaluation," *Quality Education for All*, vol. 1, no. 1, pp. 385–416, 2024.

[4] R. Govender, E. Rzyankina, A. Bayaga, and I. Harun, "Network visualisation analysis of the transformative potential of generative AI tools in the education landscape," *Discover Education*, vol. 4, no. 1, p. 426, 2025.

[5] D. Manikeswari *et al.*, "Charting the Impact of AI-Augmented Problem-Based Learning in Higher Education," 2025, pp. 39–62. doi: 10.4018/979-8-3373-7386-7.ch002.

[6] I. Celik, E. Gedrimiene, S. Siklander, and H. Muukkonen, "The affordances of artificial intelligence-based tools for supporting 21st-century skills: A systematic review of empirical research in higher education," *Australasian Journal of Educational Technology*, vol. 40, no. 3, pp. 19–38, 2024.

[7] D. Yao and K. Liu, "PBL Teaching Transformation Based on AI Collaborative Education: A Two-Way Reconstruction Path of Teacher Roles and Student Abilities," *Journal of Contemporary Educational Research*, vol. 9, no. 11, pp. 311–316, Dec. 2025, doi: 10.26689/jcer.v9i11.12866.

[8] O. Zawacki-Richter, V. I. Marín, M. Bond, and F. Gouverneur, "Systematic review of research on artificial intelligence applications in higher education – where are the educators?," *International Journal of Educational Technology in Higher Education*, vol. 16, no. 1, p. 39, Dec. 2019, doi: 10.1186/s41239-019-0171-0.

[9] C. Hou, G. Zhu, and V. Sudarshan, "The role of critical thinking on undergraduates' reliance behaviours on generative AI in problem-solving," *British Journal of Educational Technology*, vol. 56, no. 5, pp. 1919–1941, 2025.

[10] X. Zhai *et al.*, "A Review of Artificial Intelligence (AI) in Education from 2010 to 2020," *Complexity*, vol. 2021, no. 1, Jan. 2021, doi: 10.1155/2021/8812542.

[11] N. A. F. Shukor and K. Osman, “The role of artificial intelligence in developing critical thinking among science students: a systematic literature review,” *International Journal of Academic Research in Progressive Education and Development*, vol. 14, no. 3, pp. 164–176, 2025.

[12] R. Jafarli, G. F. Jafarli, A. Özperçin, and E. Adıgüzel, “Scaling Project-Based Learning with Artificial Intelligence-Powered Parametric Feedback—A Model for Nakhchivan State University,” *ELECTRICA*, vol. 26, pp. 1–15, 2026.

[13] A. C. Tricco *et al.*, “PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation,” *Ann. Intern. Med.*, vol. 169, no. 7, pp. 467–473, Oct. 2018, doi: 10.7326/M18-0850.

[14] M. D. J. Peters *et al.*, “Updated methodological guidance for the conduct of scoping reviews,” *JBI Evid. Synth.*, vol. 18, no. 10, pp. 2119–2126, 2020.

[15] M. J. Page *et al.*, “The PRISMA 2020 statement: an updated guideline for reporting systematic reviews,” *BMJ*, p. n71, Mar. 2021, doi: 10.1136/bmj.n71.

[16] R. Fisher and Q. Tran, *Navigating the Flip: A Case Study on Systematic Literature Review Methods for Flipped Learning in EFL*. 1 Oliver’s Yard, 55 City Road, London EC1Y 1SP United Kingdom : SAGE Publications Ltd, 2025. doi: 10.4135/9781036215071.

[17] J. Anderson, “Metasummary: examining the potential of a methodologically inclusive approach for conducting systematic reviews of educational research,” *Educ. Rev. (Birm).*, vol. 78, no. 1, pp. 103–123, Jan. 2026, doi: 10.1080/00131911.2024.2401079.

[18] L. A. Maggio, K. Larsen, A. Thomas, J. A. Costello, and A. R. Artino, “Scoping reviews in medical education: A scoping review,” *Med. Educ.*, vol. 55, no. 6, pp. 689–700, Jun. 2021, doi: 10.1111/medu.14431.

[19] H. Wei *et al.*, “AI-Powered Problem- and Case-based Learning in Medical and Dental Education: A Systematic Review and Meta-analysis,” *Int. Dent. J.*, vol. 75, no. 4, p. 100858, Aug. 2025, doi: 10.1016/j.identj.2025.100858.

[20] C. Hou, G. Zhu, and V. Sudarshan, “The role of critical thinking on undergraduates’ reliance behaviours on generative <scp>AI</scp> in problem-solving,” *British Journal of Educational Technology*, vol. 56, no. 5, pp. 1919–1941, Sep. 2025, doi: 10.1111/bjet.13613.

[21] A. Alexandrino, C. Cunha, T. Lima, and A. S. Alexandrino, “Artificial intelligence in problem-based learning in higher education: A scoping review,” 2025.

[22] Ratum, “Generative AI and the Future of Design Education:A Systematic Review of Lecturer Perspectives in the Digital Transformation Era,” in *2025 International Conference on Informatics, Multimedia, Cyber and Information System (ICIMCIS)*, IEEE, Dec. 2025, pp. 474–479. doi: 10.1109/ICIMCIS68501.2025.11327333.

[23] N. Wang, X. Wang, and Y.-S. Su, “Critical analysis of the technological affordances, challenges and future directions of Generative AI in education: a systematic review,” *Asia Pacific Journal of Education*, vol. 44, no. 1, pp. 139–155, Jan. 2024, doi: 10.1080/02188791.2024.2305156.

[24] S. Otto, S. Ejsing-Duun, and E. Lindsay, “Disruptive tensions and emerging practices: an exploratory inquiry into student perspectives on generative Artificial Intelligence in a problem-based learning environment,” *Educ. Inf. Technol. (Dordr).*, vol. 30, no. 13, pp. 19111–19140, Aug. 2025, doi: 10.1007/s10639-025-13533-5.

[25] Y. Qian, “Pedagogical Applications of Generative AI in Higher Education: A Systematic Review of the Field,” *TechTrends*, vol. 69, no. 5, pp. 1105–1120, Sep. 2025, doi: 10.1007/s11528-025-01100-1.

[26] H. Hu and H. Hashim, “Rethinking assessment integrity in the GenAI era: Making provenance the design principle,” *Innovations in Education and Teaching International*, pp. 1–5, Feb. 2026, doi: 10.1080/14703297.2026.2628013.

[27] I. M. García-López and L. Trujillo-Liñán, “Ethical and regulatory challenges of Generative AI in education: a systematic review,” *Front. Educ. (Lausanne).*, vol. 10, Jun. 2025, doi: 10.3389/feduc.2025.1565938.

[28] M. C. Nnamdi, J. Ben Tamo, B. Marteau, W. Shi, and M. D. Wang, “Advancing Problem-Based Learning in Biomedical Engineering in the Era of Generative AI,” *IEEE Transactions on Education*, vol. 69, no. 2, pp. 112–121, Apr. 2026, doi: 10.1109/TE.2026.3658007.

[29] J. Peng and Y. Li, “Frontiers of Artificial Intelligence for Personalized Learning in Higher Education: A Systematic Review of Leading Articles,” *Applied Sciences*, vol. 15, no. 18, p. 10096, Sep. 2025, doi: 10.3390/app151810096.

[30] S. Ruiz Viruel, E. Sánchez Rivas, and J. Ruiz Palmero, “The Role of Artificial Intelligence in Project-Based Learning: Teacher Perceptions and Pedagogical Implications,” *Educ. Sci. (Basel).*, vol. 15, no. 2, p. 150, Jan. 2025, doi: 10.3390/educsci15020150.

[31] R. Safarov, J. Wippermann, F. Meyer, and M. Wacker, “Problem-based learning in the age of generative AI: A structured blueprint for medical curricula,” *Z. Evid. Fortbild. Qual. Gesundhwes.*, vol. 203, pp. 87–96, Jun. 2026, doi: 10.1016/j.zefq.2026.03.012.

[32] M. A. Ayanwale and C. B. Omeh, “AI-supported problem-based learning for enhancing computational thinking skills in STEM education,” *Computers in Human Behavior: Artificial Humans*, vol. 7, p. 100263, Mar. 2026, doi: 10.1016/j.chbah.2026.100263.

[33] C. B. Omeh, M. A. Ayanwale, L. E. Mnguni, and C. J. Olelewe, “Fostering programming skill and critical thinking through AI-assisted PBL integration,” *Journal of New Approaches in Educational Research*, vol. 14, no. 1, p. 22, Sep. 2025, doi: 10.1007/s44322-025-00041-0.

[34] H. Wei *et al.*, “AI-Powered Problem- and Case-based Learning in Medical and Dental Education: A Systematic Review and Meta-analysis,” *Int. Dent. J.*, vol. 75, no. 4, p. 100858, Aug. 2025, doi: 10.1016/j.identj.2025.100858.

[35] S. Otto, R. Lavi, and L. Brogaard Bertel, “Human-GenAI interaction for active learning in STEM education: State-of-the-art and future directions,” *Comput. Educ.*, vol. 239, p. 105444, Dec. 2025, doi: 10.1016/j.compedu.2025.105444.

[36] G. Rueff, P. Monaco, A. E. Rusinol, and M. Hernandez, “Challenges in the Rapid and Responsible Integration of Generative Artificial Intelligence (AI) Into a New Medical School Curriculum,” *Cureus*, Jun. 2025, doi: 10.7759/cureus.86796.

[37] Q. Zhang, N. Zhang, and C. Lu, “How do pedagogical approaches affect the impact of chatbots on learning performance? A meta-analysis and research synthesis,” *Educ. Res. Rev.*, vol. 51, p. 100783, May 2026, doi: 10.1016/j.edurev.2026.100783.

[38] R. Wang, C. Liu, and F. Yi, “Reconfiguring tutor–peer roles to foster critical thinking in medical PBL assisted by tutor-managed chatGPT,” *Med. Educ.*, Nov. 2025, doi: 10.1111/medu.70100.

[39] C. E. King and B. A. Lopour, “Fostering Critical Thinking During Use of Generative AI: A Novel Learning Module for Ideation in Biomedical Engineering Design,” *Biomed. Eng. Educ.*, vol. 5, no. 2, pp. 397–413, Jul. 2025, doi: 10.1007/s43683-025-00192-8.

[40] S. Otto, S. Ejsing-Duun, and E. Lindsay, “Disruptive tensions and emerging practices: an exploratory inquiry into student perspectives on generative Artificial Intelligence in a problem-based learning environment,” *Educ. Inf. Technol. (Dordr).*, vol. 30, no. 13, pp. 19111–19140, 2025.