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Generative AI-enhanced adaptive learning for improving student learning outcomes: a systematic literature review

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ABSTRACT

This study systematically reviews the use of generative artificial intelligence (GenAI) in adaptive learning to support measurable student learning outcomes. The revised focus responds to methodological concerns by operationalizing the outcome variable as learning outcomes, including conceptual understanding, critical thinking, digital literacy, problem-solving, communication, and self-regulated learning. The study employed a systematic literature review supported by qualitative thematic synthesis. Searches were conducted in Scopus-indexed sources, ERIC, ScienceDirect, SpringerLink, MDPI, DOAJ, and Google Scholar using combinations of the terms "generative AI", "ChatGPT", "large language models", "adaptive learning", "personalized learning", "student learning outcomes", "digital literacy", and "AI ethics". Literature published between 2019 and 2025 was prioritized. Inclusion criteria covered peer-reviewed journal articles, systematic reviews, conference papers, and authoritative institutional reports directly related to GenAI, AI in education, adaptive or personalized learning, and student competency development. The final synthesis corpus consisted of 24 relevant sources after screening by title, abstract, full-text relevance, publication credibility, and methodological clarity. The findings show that GenAI supports adaptive learning through content personalization, immediate feedback, differentiated tasks, formative assessment support, learning reflection, and independent study assistance. However, its educational value depends on teacher supervision, clear AI-use policy, source verification, data protection, equitable access, and assessment designs that measure learning processes rather than AI-generated products. This review concludes that GenAI should be positioned as a pedagogical support system, not a replacement for teachers or students' cognitive effort.

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Introduction

The rapid development of digital technology has changed how educational institutions design learning, assessment, and student support. Artificial intelligence (AI), learning analytics, and intelligent tutoring systems have expanded the possibility of personalized and adaptive learning by enabling learning environments to respond to student needs, performance patterns, and interaction data. Earlier reviews of AI in education demonstrate that AI has been used for profiling and prediction, intelligent tutoring, adaptive systems, automated assessment, and learning resource recommendation (Zawacki-Richter et al., 2019; Chen et al., 2020; Hwang et al., 2020; Zhang & Aslan, 2021). However, the emergence of generative artificial

intelligence (GenAI), including large language models such as ChatGPT, adds a new dimension because these systems can generate explanations, examples, feedback, prompts, summaries, learning scenarios, and formative assessment materials in natural language.

In this study, GenAI is operationally defined as AI technology capable of producing new text-based or multimodal learning content in response to user prompts. Within adaptive learning, GenAI is not treated merely as a general information-search tool, but as a pedagogical support mechanism that can generate differentiated materials, give immediate feedback, provide alternative explanations, and assist students in reflecting on their learning progress. Adaptive learning is operationally defined as a learning approach that adjusts learning content, task difficulty, feedback, pacing, and learning pathways based on students' abilities, needs, interests, and performance evidence (Shemshack & Spector, 2020; Gligorea et al., 2023; Molenaar, 2022). Therefore, the independent construct in this review is GenAI-supported learning assistance, while the mechanism is adaptive learning, and the dependent construct is student learning outcomes.

Student learning outcomes in this article refer to measurable educational achievements that can be observed through academic performance, conceptual understanding, problem-solving ability, critical thinking, digital literacy, communication skills, collaboration, learning independence, and metacognitive awareness. This operationalization is important because the general phrase 'student competence' is too broad if it is not connected to indicators that can be reviewed and evaluated. In the Society 5.0 and Education 5.0 context, learning outcomes are not limited to memorizing knowledge, but include the ability to use digital technology responsibly, evaluate information critically, collaborate with others, and solve contextual problems through human-centered use of technology (Holmes & Tuomi, 2022; Long & Magerko, 2020; Miao & Holmes, 2023; Ng et al., 2021; UNESCO, 2024a).

The integration of GenAI into adaptive learning is increasingly relevant because conventional teaching often struggles to address different levels of student readiness in one classroom. GenAI can help teachers prepare multiple versions of explanations, create remedial and enrichment tasks, design problem-based questions, and provide formative feedback more quickly. At the student level, GenAI can serve as a learning companion by offering step-by-step explanations, examples, vocabulary support, writing feedback, and prompts for reflection. Studies on large language models in education highlight their potential for supporting personalized learning, feedback, and access to learning resources, while also warning about hallucination, bias, academic integrity problems, and overreliance (Chan & Hu, 2023; Farrokhnia et al., 2024; Grassini, 2023; Kasneci et al., 2023; Lim et al., 2023; Lo, 2023; Tlili et al., 2023).

Despite its potential, the use of GenAI in adaptive learning cannot be separated from ethical, pedagogical, and institutional challenges. GenAI outputs may sound convincing but still contain inaccurate information. Students may also use AI to produce assignments without engaging in genuine thinking processes. Furthermore, adaptive learning systems may require student data, raising concerns about privacy, data governance, algorithmic bias, and unequal access to technology. Miao and Holmes (2023), Khosravi et al. (2022), and UNESCO (2024b) emphasize that GenAI in education should be guided by human-centered values, teacher readiness, transparency, inclusion, and responsible governance. Based on these issues, this study aims to synthesize current literature on how GenAI can be used in adaptive learning to improve student learning outcomes. The review addresses three research questions: (1) How is GenAI utilized in adaptive learning?; (2) What learning outcomes are supported by GenAI-enhanced adaptive learning?; and (3) What challenges and implementation strategies are reported in the literature? By answering these questions, the article provides a clearer, more replicable, and methodologically transparent synthesis of GenAI-enhanced adaptive learning (Ogunleye et al., 2024).

Method

This study used a systematic literature review design with qualitative thematic synthesis. A systematic literature review was selected because the study did not collect direct field data, but synthesized existing academic literature to identify patterns, evidence, gaps, and implementation strategies. The procedure was guided by literature review methodology (Snyder, 2019) and adapted from PRISMA 2020 reporting principles for transparent identification, screening, eligibility assessment, and inclusion of sources (Page et al., 2021). The search was conducted across Scopus-indexed sources, ERIC, ScienceDirect, SpringerLink, MDPI, DOAJ, and Google Scholar. The keywords were combined using Boolean operators: ("generative AI" OR "ChatGPT" OR "large language model" OR "LLM") AND ("adaptive learning" OR "personalized learning" OR "intelligent tutoring system") AND ("student learning outcomes" OR "student competence" OR "digital literacy" OR "critical thinking" OR "problem-solving" OR "self-regulated learning").

Additional searches used the terms "AI ethics in education", "AI in education systematic review", and "generative AI teaching and learning".

The inclusion criteria were: (1) publications from 2019 to 2025; (2) peer-reviewed journal articles, systematic reviews, conference papers, or authoritative institutional reports; (3) sources directly discussing GenAI, AI in education, adaptive learning, personalized learning, learning outcomes, digital literacy, or AI ethics; (4) full text available in English; and (5) clear relevance to teaching and learning. The exclusion criteria were: (1) popular articles without academic basis; (2) sources without author identity or publication year; (3) articles discussing AI in general without connection to education; (4) duplicated records; (5) sources whose findings could not be connected to the research questions; and (6) unverified future-dated references. This criterion was added specifically to prevent the use of problematic future citations. The literature screening process was conducted in four stages. First, records were identified through database searching and backward reference checking. Second, duplicate and irrelevant titles were removed. Third, abstracts were reviewed for relevance to GenAI, adaptive learning, and learning outcomes. Fourth, full texts were assessed based on topical relevance, methodological clarity, publication credibility, and contribution to the synthesis. The final review corpus consisted of 24 sources. Because the study is a literature synthesis rather than a meta-analysis, effect sizes were not calculated. Instead, the review focused on qualitative patterns, conceptual convergence, and reported implementation challenges.

Quality appraisal was conducted using a simple rubric adapted for educational literature reviews. Each source was evaluated based on five indicators: topical relevance, methodological clarity, source credibility, recency, and contribution to answering the research questions. Sources rated as weak on two or more indicators were not prioritized in the synthesis. The coding process used thematic content analysis. The first cycle of coding identified evidence related to personalization, feedback, differentiation, assessment, learning independence, digital literacy, teacher readiness, ethics, privacy, access, and academic integrity. The second cycle grouped these codes into three themes: (1) GenAI functions in adaptive learning; (2) student learning outcomes supported by GenAI; and (3) challenges and responsible implementation strategies. To increase validity, source triangulation was applied by comparing findings from systematic reviews, empirical studies, conceptual papers, and institutional guidance documents. The study also acknowledges a methodological limitation: the screening and coding process was conducted as a qualitative synthesis and did not include inter-rater reliability testing. Therefore, the findings should be read as a structured evidence synthesis rather than a statistical meta-analysis.

Table 1. Summary of the Literature Search and Selection Process

Stage	Procedure	Result
Identification	Records located through academic databases and reference checking	102 records
Deduplication	Duplicate records and clearly unrelated titles removed	84 records remained
Screening	Titles and abstracts screened for relevance to GenAI, adaptive/personalized learning, and learning outcomes	36 full texts assessed
Eligibility	Full texts checked against inclusion/exclusion criteria and source quality indicators	24 sources included
Synthesis	Thematic coding and cross-source comparison were conducted	3 main themes generated

Table 2. Inclusion and Exclusion Criteria for Literature Selection

Criterion	Included	Excluded
Publication year	2019-2025	Unverified future-dated or outdated sources not central to the review
Source type	Peer-reviewed journals, conference papers, systematic reviews, institutional reports	Popular articles, anonymous writings, unsupported websites
Topic relevance	GenAI, AI in education, adaptive learning, personalized learning, learning outcomes, AI ethics	General AI sources without educational relevance
Method clarity	Studies with clear method, review process, or conceptual framework	Sources without clear scholarly basis
Language/full text	English full text available	Unavailable or incomplete documents

Results and Discussions

Utilization of Generative AI in Adaptive Learning

The synthesis shows that GenAI contributes to adaptive learning through six main functions: personalization of content, immediate feedback, differentiated task design, formative assessment support, reflective learning assistance, and independent learning support. These functions are consistent with the broader development of AI in education, where intelligent systems are used to recommend resources, identify learning needs, analyze student performance, and provide individualized support (Zawacki-Richter et al., 2019; Chen et al., 2020; Zhang & Aslan, 2021).

The first function is content personalization. GenAI can generate explanations at different levels of complexity, provide examples suited to students' prior knowledge, and transform difficult concepts into simpler language. In adaptive learning, this is important because students do not always progress at the same pace. Students who have difficulty can receive remedial explanations, while students with stronger understanding can receive enrichment tasks. This supports the concept of personalized education in which learning pathways are adjusted to learner characteristics and performance data (Maghsudi et al., 2021; Gligorea et al., 2023).

The second function is immediate feedback. GenAI can respond to student answers quickly by identifying errors, suggesting improvements, and offering alternative explanations. Immediate feedback is valuable because students can correct misconceptions before they become fixed. However, teacher verification remains necessary because GenAI feedback may include inaccuracies or incomplete reasoning. Therefore, GenAI feedback should be integrated into teacher-guided formative assessment rather than used as an unverified final authority (Kasneci et al., 2023; Lo, 2023).

The third function is differentiated task design. Teachers can use GenAI to create tiered questions, problem-based cases, reflective prompts, and learning activities for students with different ability levels. This reduces the time required to prepare differentiated materials while still allowing teachers to evaluate the pedagogical appropriateness of AI-generated content. The fourth function is reflective learning support. GenAI can ask students to explain their reasoning, compare answers, identify weaknesses, and create a personal study plan. In this way, GenAI supports metacognitive awareness and self-regulated learning (Kong & Yang, 2024).

The fifth function is independent learning assistance. Students can use GenAI outside the classroom to ask for clarification, summaries, examples, language correction, or study guidance. This has potential to expand learning access. Nevertheless, independent use must be accompanied by AI literacy so that students can verify information, avoid copying, and understand ethical limits. Miao and Holmes (2023), Ng et al. (2021), and UNESCO (2024a) emphasize that responsible AI use requires students to understand both the capability and limitation of AI systems.

Table 3. The Role of Generative AI in Adaptive Learning and Its Contributions

Adaptive learning aspect	GenAI utilization	Learning contribution	Key sources
Content personalization	Generates explanations, summaries, and examples according to students' level	Supports differentiated understanding and flexible pacing	Maghsudi et al. (2021); Gligorea et al. (2023)
Immediate feedback	Provides corrections, hints, and alternative explanations	Helps students correct misconceptions earlier	Kasneci et al. (2023); Lo (2023)
Differentiated tasks	Creates remedial, standard, and enrichment tasks	Helps teachers adjust task difficulty	Zhang & Aslan (2021); Crompton & Burke (2023)
Reflective learning	Prompts students to explain reasoning and evaluate their answers	Strengthens metacognition and self-regulated learning	Holmes & Tuomi (2022); UNESCO (2024a)
Independent learning	Acts as an on-demand learning companion outside class	Supports flexible learning and access to resources	Tlili et al. (2023); Miao & Holmes (2023)

Student Learning Outcomes Supported by GenAI-Enhanced Adaptive Learning

The literature indicates that GenAI-enhanced adaptive learning can support several learning outcomes when it is used under pedagogical guidance. The first outcome is improved conceptual understanding. Students can request alternative explanations, examples, and analogies that help them understand abstract concepts. This does not automatically guarantee learning, but it provides additional scaffolding that teachers can use to support students with different levels of readiness (Shemshack & Spector, 2020; Gligorea et al., 2023).

The second outcome is critical thinking and problem-solving. GenAI can generate case studies, simulations, analytical questions, and problem-based tasks that ask students to compare alternatives, justify decisions, and evaluate information. However, critical thinking will only improve if students are required to question and revise AI outputs rather than simply accept them. For this reason, learning activities should include verification tasks, source comparison, oral explanation, reflection, and teacher feedback (Kasneci et al., 2023; Bozkurt et al., 2024).

The third outcome is digital literacy and AI literacy. Students who use GenAI responsibly learn how to write prompts, evaluate AI-generated answers, recognize hallucinations, check sources, protect data, and understand ethical boundaries. UNESCO (2024a, 2024b) frames AI literacy as part of responsible participation in an AI-supported society. Thus, GenAI use in learning should not only help students complete tasks but also teach them how AI works, where it can fail, and how it should be used ethically.

The fourth outcome is communication and academic writing. GenAI can help students improve sentence structure, organize ideas, build outlines, and practice academic expression. This support is beneficial when students treat AI as a writing tutor and remain responsible for the content, arguments, and citations. The fifth outcome is self-regulated learning. GenAI can help students summarize material, design study schedules, generate practice questions, and reflect on their progress. This function is most useful when teachers provide clear rules on acceptable use and require students to document their learning process. Overall, GenAI-enhanced adaptive learning can improve learning outcomes through three pathways: personalization, interaction, and competency transformation. Personalization adjusts content and learning tasks to student needs. Interaction provides feedback, dialogue, and scaffolding. Competency transformation strengthens digital literacy, critical thinking, communication, and learning independence. These outcomes are aligned with the human-centered orientation of Society 5.0, where technology should strengthen human capability rather than replace human learning processes.

Table 4. Mapping of Learning Outcomes, Generative AI Activities, and Associated Risks

Learning outcome	Operational indicator	GenAI-supported activity	Risk if unmanaged
Conceptual understanding	Students can explain concepts using their own words	Alternative explanations, examples, summaries, concept checks	Students may accept inaccurate explanations
Critical thinking	Students can analyze, compare, and evaluate information	Case analysis, reflective questions, counterarguments	Students may copy AI output without evaluation
Problem-solving	Students can apply concepts to contextual problems	Scenario generation, step-by-step reasoning practice	Overreliance on AI-generated solutions
Digital and AI literacy	Students can use, verify, and critique AI outputs ethically	Prompt practice, source verification, bias discussion	Low awareness of hallucination and privacy risks
Communication	Students can organize and express ideas clearly	Writing feedback, outline development, language practice	Loss of originality if AI text is copied
Self-regulated learning	Students can plan, monitor, and evaluate their own learning	Study plan, formative quiz, reflective prompts	Learning becomes shortcut-oriented

Challenges and Responsible Implementation Strategies

The first major challenge is teacher readiness. GenAI will not automatically improve learning if teachers do not understand how to design prompts, evaluate AI outputs, protect student data, and integrate AI into learning objectives. Teachers remain the pedagogical directors who decide whether AI-generated content is accurate, appropriate, inclusive, and aligned with curriculum goals. Therefore, professional development

should focus not only on technical operation but also on AI pedagogy, assessment design, ethics, and classroom management (Celik et al., 2022; Crompton & Burke, 2023; UNESCO, 2024b).

The second challenge is information validity. GenAI can produce fluent answers that may contain false, incomplete, or biased information. This problem is especially risky when students use AI as the only source of learning. To address this, teachers need to require source verification, comparison with textbooks or journal articles, and explanation of why an AI answer is accepted or rejected. This strategy turns AI use into a critical literacy activity rather than passive consumption.

The third challenge is academic integrity. If assignments only ask for generic essays or factual summaries, students can easily submit AI-generated work without learning. Assessment should therefore focus on process-based evidence such as drafts, annotated sources, oral defense, reflection logs, portfolios, project outputs, and contextual problem-solving. These assessment forms make it harder for students to outsource the entire learning process to AI and easier for teachers to observe authentic understanding (Moorhouse et al., 2023; Perkins, 2023; Rudolph et al., 2023; Swiecki et al., 2022).

The fourth challenge is student dependence. GenAI may reduce cognitive effort if students use it only to obtain instant answers. To prevent this, AI use should be framed as a learning partner with boundaries. Students may use AI to brainstorm, receive feedback, or compare explanations, but they must still formulate arguments, verify facts, and demonstrate understanding (Darvishi et al., 2024). The fifth challenge is unequal access. Schools with better internet, devices, and paid AI tools may benefit more than under-resourced schools. Therefore, institutional policy must consider fair access, inclusive platform selection, and support for students who do not have adequate digital resources.

The sixth challenge is privacy and data security. Adaptive learning often depends on student data, such as performance, learning speed, errors, interests, and interaction records. Schools must ensure that AI platforms comply with privacy principles, minimize unnecessary data collection, and protect students from misuse of data. Finally, implementation must be supported by clear guidelines explaining acceptable AI use, citation or disclosure expectations, prohibited practices, teacher supervision mechanisms, and consequences of misuse.

Table 5. Implementation Challenges, Learning Impacts, and Responsible Strategies for Generative AI

Challenge	Impact on learning	Responsible strategy
Teacher readiness	AI is used without pedagogical direction	Training in AI pedagogy, prompt design, verification, and assessment redesign
Information validity	Students may learn inaccurate or biased content	Require source checking, comparison, and teacher validation
Academic integrity	Assignments may be completed by AI without real learning	Use portfolios, oral defense, reflection, projects, and process-based rubrics
Student dependence	Critical thinking and learning independence may decline	Set boundaries: AI as support, not answer replacement
Access gap	Only students with good devices or paid tools benefit	Provide equitable access, school-supported platforms, and offline alternatives
Data privacy	Student learning data may be exposed or misused	Adopt privacy policy, data minimization, and secure platform selection
Ethical use	Students may not understand bias, authorship, or disclosure rules	Integrate AI literacy and responsible-use guidelines into curriculum

The synthesis confirms that GenAI is most useful when embedded in a collaborative learning model. In this model, GenAI supports personalization and feedback, teachers provide pedagogical and ethical guidance, and students remain active learners who evaluate, revise, and apply information. This model is consistent with human-centered AI perspectives, which argue that AI should expand human agency rather than automate learning in ways that weaken student thinking (Holmes & Tuomi, 2022; Miao & Holmes, 2023; Molenaar, 2022; Ouyang & Jiao, 2021).

Conclusions

This systematic literature review concludes that GenAI-enhanced adaptive learning has strong potential to support student learning outcomes when it is implemented through clear pedagogical design. GenAI can help personalize content, provide immediate feedback, create differentiated learning tasks, support formative

assessment, guide reflection, and assist independent learning. These functions directly address the need for flexible and student-centered learning in the Society 5.0 context. The outcomes most consistently supported by the literature include conceptual understanding, critical thinking, problem-solving, digital and AI literacy, communication, and self-regulated learning. However, these outcomes do not emerge automatically from the use of AI. They depend on how teachers design learning activities, how students are required to verify and reflect on AI outputs, and how institutions regulate ethical and responsible use. The review also identifies several major challenges: teacher readiness, hallucination or information inaccuracy, academic integrity, student dependence, unequal access, data privacy, and ethical uncertainty. To address these challenges, schools need AI-use policies, teacher training, AI literacy programs, secure platforms, process-based assessment, and learning designs that position AI as a support tool rather than a substitute for student thinking. The practical implication of this study is that educators should use GenAI to strengthen adaptive learning while preserving human agency, teacher authority, and authentic student learning. Future research should test GenAI-enhanced adaptive learning through empirical designs such as quasi-experimental studies, classroom-based action research, or mixed-method studies that measure learning outcomes directly. This is important because the current study is a literature synthesis and does not provide statistical evidence of effect size or direct classroom impact

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