Journal of Learning Innovation and Educational Technology
https://jurnal.suriaacademicpress.com/index.php/Jliet

DOI:https://doi.org/10.67467/jliet.v1i1.109 Vol. 1, No. 1, June 2026 |pp. 30-46

Artificial Intelligence-Supported Personalized Learning for Enhancing Students' Critical Thinking Skills: A Systematic Literature Review

Muharleni[1], Neni Sriwahyuni[2]
[1]Universitas Negeri Padang, Indonesia
[2]STAI YPI Al-Ikhsan Painan, Indonesia
Corresponding author: muharleni.spdi@gmail.com

Article History
Submission: 2026-04-05
Received: 2026-04-05
Revised: 2026-06-21
Accepted: 2026-07-02
Publish: 2026-07-05

Keywords:
Artificial Intelligence; Personalized Learning; Critical Thinking Skills; Systematic Literature Review; Artificial Intelligence in Education.

ABSTRACT

The rapid advancement of Artificial Intelligence (AI) has transformed education toward more personalized, adaptive, and learner-centered approaches. Although numerous studies have reported the benefits of AI in improving learning quality, comprehensive evidence explaining the relationship between AI, personalized learning, and students' critical thinking skills remains limited. This study aims to examine the implementation of AI in personalized learning, identify its opportunities and challenges, and propose a conceptual model explaining how AI contributes to the development of students' critical thinking skills. This research employed a Systematic Literature Review (SLR) following the PRISMA 2020 guidelines. Literature was retrieved from five international databases, including Scopus, Web of Science, ERIC, IEEE Xplore, and Google Scholar. Following the identification, screening, and eligibility processes, 42 articles published between 2021 and 2025 were selected and analyzed using a thematic synthesis approach. The findings indicate that AI functions as an enabling technology supporting personalized learning through adaptive learning systems, learning analytics, intelligent tutoring systems, and Generative Artificial Intelligence. The contribution of AI to students' critical thinking is not direct but is mediated by enhanced student engagement, self-regulated learning, and metacognitive awareness. However, the implementation of AI also faces significant challenges related to teachers' pedagogical readiness, AI literacy, digital infrastructure, data privacy, algorithmic bias, and ethical governance. This study proposes a conceptual model integrating Artificial Intelligence, personalized learning, student engagement, self-regulated learning, and critical thinking skills, providing a theoretical contribution to the field of Artificial Intelligence in Education (AIEd) while offering practical implications for educators, policymakers, and future research.

INTRODUCTION

The rapid digital transformation of the past two decades has shifted education from a one-size-fits-all approach toward more adaptive, flexible, and learner-centered models. A major driver of this transformation is Artificial Intelligence (AI), which enables the analysis of learning data, identification of learning patterns, personalized recommendations, and real-time feedback. As a result, AI has become a strategic component of modern educational ecosystems rather than merely a technological innovation. Technologies such as Intelligent Tutoring Systems (ITSs), adaptive learning systems, learning analytics, recommender systems, and Generative Artificial Intelligence

(GenAI) have significantly enhanced learning by personalizing instructional content, adjusting learning difficulty, and continuously monitoring students' progress to create more meaningful learning experiences ("[No Title Found]," n.d.; Yuensook et al., 2025).

In this context, personalized learning has gained increasing attention as an instructional approach that adapts learning objectives, content, pacing, strategies, and assessment to students' individual characteristics, abilities, interests, and learning preferences. AI plays a central role in supporting personalized learning by analyzing learner behavior, predicting learning needs, and delivering adaptive recommendations. Recent advances in machine learning, educational data mining, learning analytics, and large language models (LLMs) have further strengthened AI-driven personalized learning, making instruction more adaptive, interactive, and responsive to individual learners (Murtaza et al., 2022; Oyebola Olusola Ayeni et al., 2024; Strielkowski et al., 2025).

The integration of AI into personalized learning is particularly important in twenty-first-century education, which emphasizes higher-order thinking skills (HOTS), especially critical thinking. Students are expected to evaluate information critically, construct evidence-based arguments, and make informed decisions in an increasingly complex digital environment. AI can facilitate these competencies by providing interactive, problem-based, and reflective learning experiences through adaptive feedback, simulations, and authentic learning tasks. When supported by effective pedagogical design, AI has the potential to foster deeper analysis, reasoning, and critical thinking beyond the limitations of traditional teacher-centered instruction (Liu et al., 2025; Martínez et al., 2025; Merino-Campos, 2025).

The emergence of Generative Artificial Intelligence (GenAI) has further expanded the potential of AI in personalized learning. Unlike earlier AI technologies that primarily focused on data analysis and automation, GenAI can generate contextualized text, images, code, and instructional materials tailored to learners' needs. Applications such as ChatGPT, Gemini, Claude, and other large language models (LLMs) have transformed how students search for information, generate ideas, reflect on learning, and solve academic problems. Recent studies suggest that the pedagogical use of GenAI can enhance student engagement, improve academic writing, support research activities, and foster critical thinking through personalized feedback and reflective dialogue. However, these benefits largely depend on instructional design, teachers' AI competencies, and students' ability to critically evaluate AI-generated outputs (Hikmawati & Mohammad, 2025; Izquierdo-Condoy et al., 2025; Lin & Zhang, 2024).

Despite its considerable potential, AI-supported personalized learning also presents significant challenges. Existing research highlights concerns related to algorithmic bias, information accuracy, data privacy, cybersecurity, unequal access to digital technologies, and students' increasing dependence on AI. The uncritical use of GenAI may lead to cognitive overreliance, where learners accept AI-generated responses without sufficient analysis, verification, or reflection. Furthermore, limited AI literacy among both teachers and students may reduce the effectiveness of AI integration in educational settings. Therefore, AI should be positioned as a tool that supports human thinking rather than replacing learners' cognitive processes. The successful implementation of AI depends not only on technological sophistication but also on pedagogical readiness, ethical governance, institutional support, and responsible AI practices (Gligorea et al., 2023; Halkiopoulos & Gkintoni, 2024; Hashim et al., 2022).

Although research on AI in education has grown rapidly, much of the literature continues to focus on technological development, adaptive learning systems, and improvements in learning outcomes. Comparatively less attention has been given to understanding how AI-based personalized learning contributes to the development of students' critical thinking skills. Previous systematic reviews indicate that AI research has predominantly emphasized adaptive learning systems, learning recommendation systems, educational data mining, machine learning, and intelligent tutoring systems. For example, Hashim et al. reported that AI research mainly addresses technologies supporting personalized learning such as MOOCs, adaptive learning, gamification,

learning analytics, and intelligent tutoring systems, while studies examining AI's impact on critical thinking remain relatively limited. Likewise, Gligorea et al. argued that AI applications in e-learning have largely concentrated on learning personalization and adaptive assessment rather than the cultivation of higher-order thinking skills (Bayly-Castaneda et al., 2024a; Du Plooy et al., 2024; Dutta et al., 2024; Essa et al., 2023).

Recent advances in Generative Artificial Intelligence (GenAI) have shifted educational research from viewing AI solely as a tool for learning automation to recognizing it as a cognitive partner that supports students' reasoning and knowledge construction. Applications such as ChatGPT, Gemini, Claude, and other large language models (LLMs) have demonstrated the potential to improve academic discussion, problem-solving, scientific writing, and reflective learning through interactive dialogue. However, empirical findings remain mixed. While many studies report that GenAI enhances engagement, creativity, and critical thinking when integrated with appropriate pedagogical strategies, others caution that excessive reliance on AI may lead to automation bias, cognitive offloading, and reduced independent reasoning. A systematic review by Liu et al. further suggests that the influence of GenAI on critical thinking is dual in nature, offering substantial educational benefits while also posing risks when learners fail to critically evaluate AI-generated outputs (Anwar, 2025; Bayly-Castaneda et al., 2024b, 2024a).

Beyond pedagogical considerations, the successful implementation of AI in personalized learning is influenced by institutional, technological, and ethical factors. Studies emphasize that effective AI integration requires adequate digital infrastructure, high-quality learning data, teachers' digital competence, students' AI literacy, and institutional policies that promote responsible AI use. Halkiopoulos and Gkintoni argue that AI can strengthen learner motivation, engagement, and personalized instruction through adaptive assessment and data-driven recommendations. Nevertheless, challenges related to algorithmic bias, system transparency, data privacy, and equitable access remain significant concerns. Similarly, Murtaza et al. highlight that AI-powered personalized learning requires the integration of multiple components including learner data, adaptive learning mechanisms, recommender systems, and content delivery modules to create meaningful and individualized learning experiences.

The literature reveals three major research gaps. First, previous studies have largely emphasized AI technologies and the effectiveness of personalized learning, while the role of AI in fostering critical thinking skills remains insufficiently explored. Second, research on AI and critical thinking has primarily focused on the use of Generative AI in higher education, with limited attention to integrating AI, personalized learning, adaptive learning, and critical thinking within a unified conceptual framework. Third, existing studies tend to discuss either the opportunities or the challenges of AI separately, resulting in a lack of comprehensive understanding of the interplay among pedagogical, technological, and ethical dimensions. These gaps highlight the need for a holistic conceptual model explaining how AI can effectively support the development of students' critical thinking through personalized learning.

Building upon these research gaps, this study proposes a conceptual synthesis that integrates three key constructs: Artificial Intelligence (AI), Personalized Learning, and Critical Thinking Skills into a comprehensive analytical framework. Unlike previous studies that primarily examine AI technologies or personalized learning independently, this article explores how AI functions as a cognitive partner that supports adaptive learning, enhances student engagement, and promotes critical thinking through learner-centered instructional design. Furthermore, the study examines the opportunities and challenges of AI implementation from pedagogical, technological, and ethical perspectives, providing a more holistic understanding of AI-supported personalized learning.

Accordingly, this study aims to analyze the implementation of AI in supporting personalized learning and to identify its opportunities and challenges in enhancing students' critical thinking skills through a Systematic Literature Review (SLR). Specifically, the study seeks to: (1) examine recent developments in the application of AI for personalized learning; (2) analyze the contribution

of AI to the development of students' critical thinking skills; (3) identify the pedagogical, technological, and ethical challenges associated with AI implementation; and (4) propose a conceptual framework that explains the relationship among AI, personalized learning, and critical thinking. The findings are expected to contribute to the growing body of knowledge in Artificial Intelligence in Education (AIEd) while providing practical recommendations for educators, educational technology developers, and policymakers in designing adaptive, personalized, ethical, and learner-centered educational environments that foster essential twenty-first-century critical thinking skills.

LITERATURE REVIEW

Artificial Intelligence in Education (AIEd)

Artificial Intelligence (AI) has emerged as one of the most influential technologies driving the transformation of modern education. In educational settings, AI extends beyond automating administrative tasks by supporting teaching and learning through data analysis, content personalization, adaptive assessment, and real-time feedback. The concept of Artificial Intelligence in Education (AIEd) refers to the application of AI technologies including machine learning, natural language processing (NLP), learning analytics, knowledge tracing, computer vision, and large language models (LLMs) to enhance learning experiences and support evidence-based pedagogical decision-making.

The evolution of AIEd reflects a shift from traditional computer-assisted instruction toward intelligent learning environments capable of adapting dynamically to learners' needs. Technologies such as Intelligent Tutoring Systems (ITSs), Adaptive Learning Systems, and Educational Recommender Systems enable personalized instruction by identifying learning needs, predicting learning difficulties, and recommending appropriate learning resources and activities. Research has consistently demonstrated that these technologies improve learning effectiveness, student motivation, and engagement when integrated with sound pedagogical practices.

More recently, the emergence of Generative Artificial Intelligence (GenAI) has further expanded the scope of AIEd. Through large language models (LLMs), learners can engage in interactive dialogue, receive contextualized explanations, generate learning materials, and obtain personalized feedback. However, the educational value of GenAI depends on effective instructional design, users' prompt engineering skills, and their ability to critically evaluate AI-generated outputs. Therefore, AIEd should be viewed as the integration of technology, pedagogy, and ethics, rather than merely the adoption of AI-based tools.

Personalized Learning

Personalized learning is a learner-centered instructional approach that tailors learning experiences to students' individual needs, abilities, interests, characteristics, and learning pace. Unlike traditional instructional models that apply uniform teaching strategies, personalized learning adapts learning objectives, content, instructional activities, learning resources, and assessment methods to accommodate individual differences.

The implementation of personalized learning has become increasingly effective with the support of AI. Using learning analytics, educational data mining, and machine learning, AI continuously analyzes learner data to construct individual learning profiles. Based on these profiles, AI recommends appropriate learning materials, adjusts instructional difficulty, and provides adaptive feedback that aligns with each learner's progress. As a result, AI enhances both instructional efficiency and learning quality.

Recent advances in Generative AI have further strengthened personalized learning by enabling AI to function not only as a content provider but also as an intelligent learning partner. Through interactive conversations, alternative explanations, and personalized learning activities,

GenAI creates more engaging, reflective, and meaningful learning experiences while supporting students' individual learning needs.

Critical Thinking Skills

Critical thinking is widely recognized as one of the core competencies required for success in the twenty-first century. It encompasses the ability to analyze information, evaluate evidence, construct logical arguments, solve problems, and make informed decisions based on rational judgment. Within education, critical thinking is viewed not only as a learning outcome but also as a cognitive process developed through active, reflective, and authentic learning experiences.

Instruction that promotes critical thinking encourages students to examine multiple perspectives, ask meaningful questions, investigate problems, and reflect on their reasoning processes. In this context, AI can positively support critical thinking when used as a tool for exploration, inquiry, and reflection rather than simply providing instant answers. Studies on Generative AI indicate that AI can foster critical thinking through academic dialogue, adaptive feedback, problem-based simulations, and the generation of multiple solution alternatives. Nevertheless, inappropriate AI use may lead to automation bias and cognitive offloading, where learners rely excessively on AI without critically evaluating its outputs. Therefore, critical thinking remains an essential competency for ensuring the responsible and effective use of AI in education.

Conceptual Relationship between Artificial Intelligence, Personalized Learning, and Critical Thinking

Drawing upon constructivist learning theory and student-centered learning, the relationship among Artificial Intelligence, personalized learning, and critical thinking can be understood as an interconnected educational framework. AI provides technological support through learning analytics, adaptive learning, Intelligent Tutoring Systems, and Generative AI, enabling instructional processes to be tailored to individual learner characteristics. Such personalization enhances student engagement, self-regulated learning, and metacognitive awareness, which in turn contribute to the development of critical thinking skills.

Accordingly, the influence of AI on critical thinking is not direct but is mediated by the quality of personalized learning supported through effective instructional design. Within this framework, AI functions as an enabling technology, while personalized learning serves as the pedagogical mechanism linking technological capabilities with students' cognitive development. This conceptual relationship provides the theoretical foundation for the present study and supports the conceptual model proposed in the Results and Discussion section.

METHOD

This study employed a Systematic Literature Review (SLR) to systematically synthesize empirical evidence on the implementation of Artificial Intelligence (AI) in personalized learning and its contribution to enhancing students' critical thinking skills. The SLR approach was selected because it enables the comprehensive integration of previous studies, identifies research trends and gaps, and provides stronger conceptual insights than conventional narrative reviews. The review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure transparency, rigor, and reproducibility throughout the identification, screening, eligibility assessment, and synthesis stages.

Literature Search Strategy

The literature search was conducted between January and July 2026 using five major international databases: Scopus, Web of Science (WoS), ERIC, IEEE Xplore, and Google Scholar. To capture recent developments following the rapid adoption of Generative Artificial Intelligence

(GenAI) in education, the search was limited to articles published between 2021 and 2025. Boolean operators (AND and OR) were applied using the following search string:

("Artificial Intelligence" OR "Generative Artificial Intelligence"
OR "Large Language Model" OR "ChatGPT")
AND ("Personalized Learning" OR "Adaptive Learning")
AND ("Critical Thinking")
AND ("Education")

Inclusion and Exclusion Criteria

Retrieved articles were screened using predefined inclusion and exclusion criteria to ensure the quality and relevance of the selected studies. The criteria are presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

Aspect	Inclusion Criteria	Exclusion Criteria
Publication type	Peer-reviewed journal articles	Conference proceedings, books, theses
Publication status	Peer-reviewed	Non-peer-reviewed
Publication year	2021–2025	Before 2021
Language	English	Languages other than English
Research topic	AI, Personalized Learning, and Critical Thinking	Unrelated topics
Accessibility	Full-text available	Abstract only

Study Selection

The article selection process followed the four PRISMA 2020 stages: identification, screening, eligibility, and inclusion. After retrieving articles from all databases, duplicate records were removed. The remaining studies were screened based on their titles, abstracts, and keywords. Eligible articles then underwent a full-text review to confirm their relevance to the research objectives. Only studies meeting all eligibility criteria were included in the final synthesis.

Data Extraction and Analysis

Relevant information from each selected study was extracted using a standardized data extraction form, including author(s), publication year, country, educational level, research design, AI technology employed, personalized learning approach, critical thinking indicators, and key findings. The extracted data were analyzed using thematic synthesis, allowing studies with similar concepts to be grouped into common themes and interpreted systematically.

The analysis consisted of three stages: open coding, descriptive theme development, and analytical theme generation. First, key findings from each study were coded according to the research objectives. Similar codes were then organized into major themes, including adaptive learning, learning analytics, intelligent tutoring systems, Generative AI, AI literacy, student engagement, and AI ethics. Finally, relationships among these themes were synthesized to develop a conceptual model explaining how AI supports personalized learning and contributes to the development of students' critical thinking skills.

Quality Assurance

To enhance the credibility of the review, three quality assurance strategies were implemented: (1) only peer-reviewed journal articles were included; (2) multiple international databases were

searched to reduce source bias; and (3) all selection procedures were documented in accordance with the PRISMA 2020 guidelines, ensuring transparency and enabling future replication of the review.

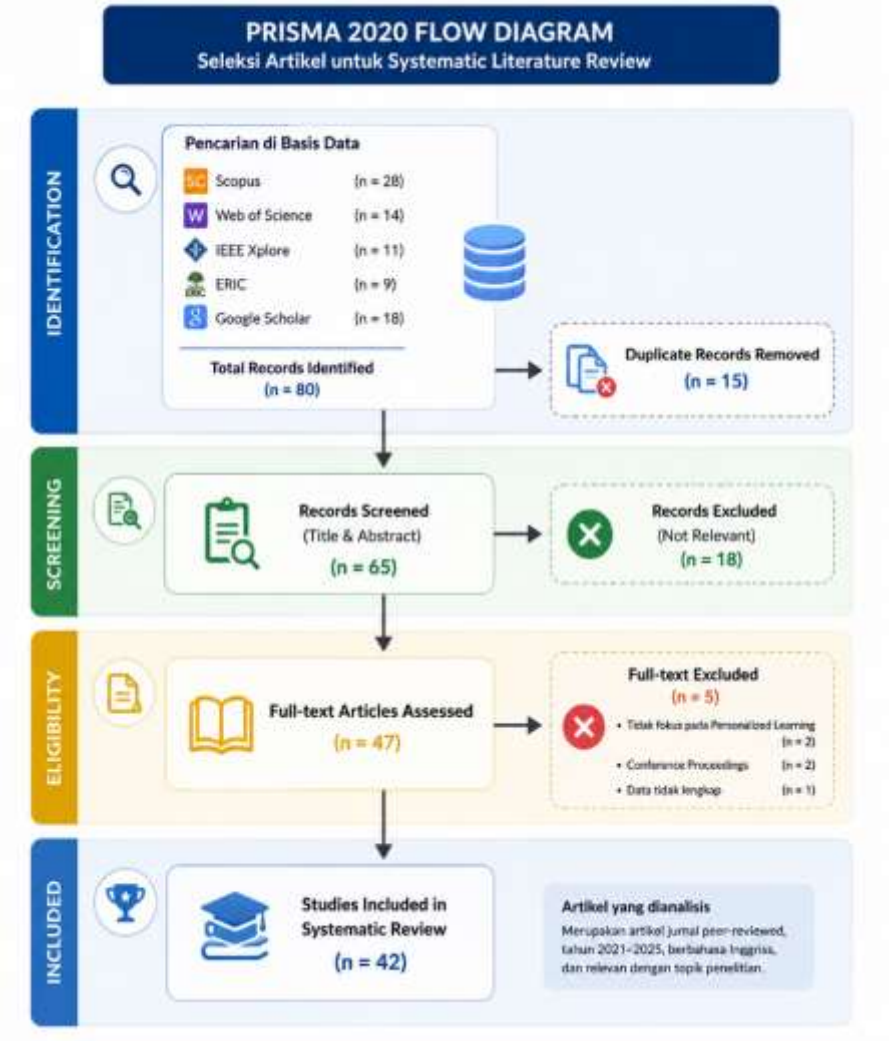

Figure 1. PRISMA 2020 Flow Diagram of the Study Selection Process

Data from each eligible study were extracted using a standardized data extraction form that included information on the authors, publication year, country of study, educational level, research design, AI technology employed, personalized learning approach, critical thinking indicators, and key findings. The extracted data were synthesized using thematic synthesis, a qualitative analytical technique that organizes findings into themes with similar meanings to generate a comprehensive conceptual interpretation.

The analysis consisted of three stages: open coding, descriptive theme development, and analytical theme generation. Initially, key findings from each study were coded according to the research objectives. Similar codes were then grouped into major themes, including adaptive learning, learning analytics, intelligent tutoring systems, Generative AI, AI literacy, student engagement, and AI ethics. Finally, relationships among these themes were synthesized to develop a conceptual framework explaining the contribution of AI to personalized learning and the development of students' critical thinking skills.

To enhance the credibility of the review, three quality assurance strategies were adopted: (1) only peer-reviewed journal articles were included; (2) multiple international databases were

searched to minimize source bias; and (3) the entire selection process was documented in accordance with the PRISMA 2020 guidelines, ensuring transparency and facilitating future replication.

RESULTS AND DISCUSSION

Characteristics of the Included Studies

A total of 42 studies met the inclusion criteria and were included in the final review. All selected articles were published between 2021 and 2025 in internationally recognized journals indexed by Scopus and/or Web of Science. Most studies were conducted within the fields of Artificial Intelligence in Education (AIEd), Educational Technology, Learning Sciences, and Computer-Assisted Learning. Regarding research methodology, Systematic Literature Reviews were the most common, followed by quantitative studies, mixed-methods research, experimental studies, and case studies.

In terms of educational context, most studies focused on higher education, whereas research involving primary and secondary education remained relatively limited. This finding suggests that AI-supported personalized learning has been adopted more extensively in higher education than in school settings. Geographically, the majority of studies originated from countries with advanced educational technology ecosystems, including the United States, China, the United Kingdom, Australia, Spain, and Malaysia, indicating that AI in education research is still concentrated in regions with well-developed digital infrastructures.

Table 3. Characteristics of the Included Studies (n = 42)

Characteristic	Frequency	Percentage (%)
Publication Year		
2021	5	11.9
2022	8	19.0
2023	11	26.2
2024	12	28.6
2025	6	14.3
Research Method		
Systematic Literature Review	14	33.3
Quantitative	12	28.6
Mixed Methods	7	16.7
Experimental	5	11.9
Case Study	4	9.5
Educational Level		
Higher Education	28	66.7
Secondary Education	9	21.4
Primary Education	5	11.9

Themes Identified through Thematic Synthesis

The thematic synthesis identified four major themes:

1. AI as a driver of personalized learning**;**
2. The contribution of AI to the development of critical thinking skills**;**
3. Challenges in implementing AI for personalized learning**; and**
4. A conceptual framework for AI-supported personalized learning**.**

These findings indicate that recent research has shifted beyond the development of AI technologies toward examining how AI can create more personalized learning experiences while fostering higher-order thinking skills, particularly critical thinking.

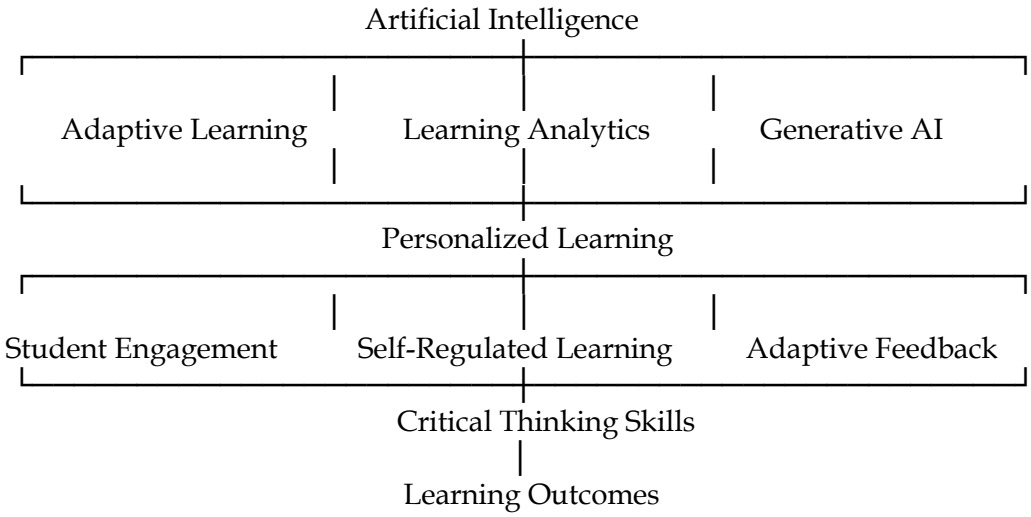

Figure 2. Conceptual Framework Derived from the Thematic Synthesis

AI as a Driver of Personalized Learning

The synthesis revealed a strong consensus that Artificial Intelligence (AI) has transformed education from a one-size-fits-all instructional model to a more adaptive, personalized, and data-driven approach. By analyzing students' learning interactions, assessment results, navigation patterns, and digital learning activities, AI can automatically identify individual learning characteristics and provide personalized recommendations, including learning materials, task difficulty, and instructional activities. Consequently, AI serves not only as a technological tool but also as a pedagogical decision-support system that enhances the effectiveness and efficiency of teaching and learning.

The reviewed studies identified several dominant AI technologies supporting personalized learning, including adaptive learning systems, learning analytics, Intelligent Tutoring Systems (ITSs), recommender systems, and Generative Artificial Intelligence (GenAI). Although these technologies differ in functionality, they share the common objective of delivering learning experiences tailored to individual learner needs. Furthermore, AI-supported personalized learning consistently contributes to higher learning motivation, student engagement, and self-regulated learning, reinforcing AI's role as a catalyst for learner-centered educational transformation.

Table 4. Major Themes of AI Implementation in Personalized Learning

Theme	Frequency (n)	Percentage (%)
Adaptive Learning	36	85.7
Learning Analytics	32	76.2
Intelligent Tutoring Systems	27	64.3
Generative AI	25	59.5
Recommender Systems	22	52.4
Adaptive Assessment	18	42.9

The Role of Artificial Intelligence in Enabling Personalized Learning

The findings indicate that AI has fundamentally reshaped personalized learning by enabling instructional processes to adapt to students' abilities, learning preferences, prior knowledge, and individual progress. Unlike conventional instructional models that provide uniform learning experiences, AI continuously analyzes learner data through learning analytics and generates

adaptive recommendations that support individualized learning pathways. This transformation positions AI not merely as an educational technology but as an intelligent learning partner that enhances pedagogical decision-making. These findings are consistent with Hashim et al., who emphasized that AI has accelerated the adoption of personalized learning through adaptive learning, learning analytics, Intelligent Tutoring Systems, and educational recommender systems .

Among the reviewed studies, adaptive learning systems emerged as the most widely implemented AI application. These systems analyze learners' behaviors including study time, task performance, error patterns, and content preferences to dynamically adjust learning sequences, task difficulty, feedback, and instructional strategies. Similarly, learning analytics plays a central role by collecting and interpreting learning data to help educators monitor student progress, predict learning difficulties, identify at-risk learners, and implement timely interventions. These findings demonstrate that personalized learning extends beyond content customization to encompass continuous, data-driven instructional improvement.

The rapid development of Generative Artificial Intelligence (GenAI) has introduced new opportunities for personalized learning. Unlike earlier AI applications that primarily focused on recommendation and prediction, GenAI can generate learning materials, case simulations, reflective questions, personalized feedback, and interactive academic dialogue. Through large language models (LLMs) such as ChatGPT, students can engage in more interactive and inquiry-based learning experiences that support idea generation, argument development, and reflective thinking. However, the educational effectiveness of GenAI depends on instructional design, prompt quality, students' ability to critically evaluate AI-generated information, and teachers' capacity to design higher-order learning activities.

Despite its substantial benefits, the successful implementation of AI is influenced not only by technological capability but also by pedagogical quality. Without appropriate instructional design, AI functions primarily as an automation tool rather than a facilitator of meaningful learning. In contrast, when integrated within constructivist and learner-centered approaches, AI promotes interaction, reflection, and active engagement. In this context, teachers remain central as learning designers, facilitators, and mentors, while AI serves as a complementary technology that supports rather than replaces human pedagogical expertise.

Beyond improving academic achievement, AI-supported personalized learning has been associated with increased learning motivation, student engagement, self-regulated learning, and instructional efficiency. These outcomes align with self-regulated learning theory, which suggests that students are more motivated when learning experiences match their individual needs and capabilities. By providing timely feedback, adaptive learning goals, and personalized recommendations, AI creates responsive learning environments that enable students to maximize their learning potential.

Finally, the reviewed studies indicate that AI-based personalized learning should not be interpreted as individualized learning at the expense of social interaction. Instead, well-designed AI systems can also facilitate collaborative learning by forming adaptive learning groups, recommending suitable peer partners, and supporting reflective discussions through personalized feedback. Thus, AI serves as a mediator that balances individualized and collaborative learning experiences. Overall, the findings suggest that AI has become a foundational component of modern personalized learning by integrating learning analytics, adaptive technologies, and intelligent feedback to create more responsive, engaging, and learner-centered educational environments. However, its effectiveness ultimately depends on sound pedagogical design, teacher competence, learner readiness, and the responsible integration of AI into educational practice.

Contribution of AI-Based Personalized Learning to the Development of Students' Critical Thinking Skills

Critical thinking is widely recognized as one of the essential competencies for the twenty-first century. In the digital era, students are expected not only to acquire information but also to evaluate the credibility of sources, analyze multiple perspectives, construct evidence-based arguments, and make informed decisions. The synthesized findings indicate that Artificial Intelligence (AI) can significantly contribute to the development of critical thinking by creating learning environments that are personalized, adaptive, interactive, and reflective. Unlike conventional instruction, AI-supported personalized learning adapts learning experiences to students' cognitive abilities, learning needs, and individual progress, thereby providing more meaningful and intellectually challenging learning experiences.

The review further suggests that the relationship between AI and critical thinking is indirect rather than causal. AI contributes to critical thinking through the quality of personalized learning environments it supports. Technologies such as adaptive feedback, learning analytics, Intelligent Tutoring Systems (ITSs), and Generative Artificial Intelligence (GenAI) enable learners to engage with instructional materials that match their current level of understanding. By aligning learning activities with individual needs, AI encourages students to explore ideas, formulate arguments, test hypotheses, and reflect on their reasoning processes, thereby fostering higher-order thinking skills.

One of the most notable findings is the growing role of Generative Artificial Intelligence (GenAI) as a dialogic learning partner. Unlike earlier adaptive systems that primarily recommended learning resources, GenAI enables learners to participate in interactive academic dialogue through natural language communication. Students can ask questions, request clarification, generate ideas, and explore alternative solutions in real time. Such dialogic interaction promotes deeper analysis, reflection, and reasoning. The reviewed studies consistently indicate that GenAI enhances analytical thinking, argumentation, and reflective learning when used to stimulate inquiry rather than simply provide answers.

However, the effectiveness of GenAI depends largely on instructional design. AI should not replace human thinking but instead serve as a tool that expands learning opportunities. When students passively accept AI-generated responses without evaluation or verification, they may become vulnerable to automation bias and cognitive offloading, reducing opportunities for independent reasoning. In contrast, integrating AI into problem-based learning, inquiry-based learning, and project-based learning encourages students to develop analytical, evaluative, and metacognitive skills. These findings suggest that pedagogical quality is more influential than technological sophistication in determining the educational value of AI.

The review also demonstrates that AI-supported personalized learning enhances metacognitive awareness by helping students plan, monitor, and evaluate their own learning processes. Immediate and adaptive feedback enables learners to identify misconceptions, compare alternative solutions, and refine their learning strategies. This process strengthens self-regulated learning, which has been widely recognized as a key foundation for critical thinking. From a constructivist perspective, AI functions as a scaffolding tool that supports learners in achieving higher levels of cognitive development rather than replacing human intellectual activity.

Beyond cognitive development, AI-based personalized learning also improves student engagement, which indirectly contributes to stronger critical thinking. When learning activities match students' abilities and interests, they become more actively involved in learning, demonstrate higher intrinsic motivation, and participate more confidently in discussion and inquiry. Consequently, the development of critical thinking is influenced not only by AI itself but also by the learner-centered environment that AI helps create.

Despite these positive findings, the reviewed studies also report inconsistent results across different educational contexts. While most studies found positive effects of AI on critical thinking, others suggested that these benefits depend on several moderating factors, including the type of AI technology, instructional design, learner characteristics, teachers' readiness, and users' AI literacy.

These findings highlight that the relationship between AI and critical thinking is complex and context-dependent.

Overall, the evidence suggests that AI-supported personalized learning has considerable potential to enhance students' critical thinking skills when implemented through pedagogically sound instructional designs that promote inquiry, argumentation, reflection, and problem solving. AI provides adaptive learning support, while personalized learning ensures that instruction aligns with individual learner needs. Together, these elements create learning environments that not only improve academic performance but also foster critical, reflective, and adaptive learners prepared for the challenges of the AI era.

Challenges in Implementing Artificial Intelligence in Personalized Learning: Pedagogical, Technological, and Ethical Perspectives

Although the findings demonstrate the significant potential of Artificial Intelligence (AI) to enhance personalized learning, its implementation continues to face pedagogical, technological, and ethical challenges. The reviewed studies indicate that successful AI integration depends not only on sophisticated algorithms but also on teachers' pedagogical competence, digital infrastructure, data governance, and responsible AI policies. Therefore, AI adoption should be viewed as a comprehensive transformation of the educational ecosystem rather than merely a technological innovation.

One of the most critical challenges is teachers' pedagogical readiness. Many studies emphasize that AI has limited educational value unless teachers can effectively integrate it into learner-centered instructional strategies. In many educational settings, AI is still primarily used to automate content delivery, assessment, and administrative tasks rather than to facilitate higher-order thinking. This finding suggests a paradigm shift from teachers as knowledge transmitters to learning designers, facilitators, and mentors. AI becomes educationally meaningful when embedded within active learning approaches such as problem-based learning, inquiry-based learning, project-based learning, and case-based learning, where technology supports rather than replaces human pedagogy.

Another recurring issue is the limited level of AI literacy among both teachers and students. AI literacy extends beyond the ability to operate AI applications; it also includes understanding how AI systems function, recognizing their limitations, interpreting AI-generated outputs, and critically evaluating the reliability of information. Without these competencies, learners may develop automation bias, accepting AI-generated responses without sufficient verification or reflection. Consequently, AI literacy should become an integral component of future curricula to promote critical, reflective, and responsible AI use.

From a technological perspective, digital infrastructure remains a major barrier, particularly in developing countries. Effective AI implementation requires reliable internet access, adequate computing resources, secure data management, and integration with Learning Management Systems (LMSs). Unequal access to these resources may widen educational disparities between institutions with advanced technological capacity and those with limited infrastructure. Therefore, government investment in inclusive digital infrastructure is essential for equitable AI adoption.

Ethical considerations represent another major concern. Most reviewed studies identify data privacy, information security, algorithmic transparency, accountability, and algorithmic bias as key issues in AI-supported education. Because personalized learning relies on large volumes of learner data, inadequate data governance may compromise privacy and produce biased recommendations. Accordingly, AI implementation should be guided by the principles of fairness, transparency, accountability, and privacy protection to ensure ethical and trustworthy educational practices.

The rapid growth of Generative Artificial Intelligence (GenAI) also introduces challenges related to academic integrity. While GenAI can assist students in writing, coding, problem-solving,

and content generation, excessive dependence on AI may encourage plagiarism, reduce independent thinking, and increase cognitive offloading. Rather than replacing students' reasoning processes, AI should function as a thinking partner that stimulates inquiry, reflection, and critical analysis. The educational value of AI lies not in generating answers, but in fostering deeper learning and intellectual engagement.

Finally, the review indicates that most existing studies evaluate AI primarily through traditional indicators such as academic achievement, task completion, or user satisfaction. Future research should adopt broader evaluation frameworks that include critical thinking, creativity, collaboration, communication, digital literacy, and complex problem-solving skills. Such an approach would provide a more comprehensive understanding of AI's educational impact beyond technological efficiency.

Overall, the findings suggest that the challenges of AI-supported personalized learning cannot be addressed through technological innovation alone. Sustainable implementation requires the integration of pedagogical innovation, AI literacy, digital infrastructure, ethical governance, and supportive educational policies. The synergy among these dimensions will determine whether AI becomes a transformative educational technology capable of developing learners who are not only academically successful but also critical, adaptive, ethical, and prepared for the demands of the AI era.

Theoretical Implications and a Conceptual Model of AI-Supported Personalized Learning

The synthesis indicates that the relationship between Artificial Intelligence (AI) and critical thinking is neither direct nor deterministic. Previous studies have largely treated AI as an independent variable that directly improves learning outcomes, motivation, or engagement. However, the present review suggests that AI should be viewed as an enabling technology that supports higher-order thinking through personalized learning rather than directly enhancing critical thinking. This perspective extends existing research by emphasizing the pedagogical mechanisms through which AI influences learning.

The findings further reveal that personalized learning serves as the primary mechanism linking AI capabilities with the development of critical thinking. By employing learning analytics, machine learning, adaptive learning, and Generative AI, AI systems build learner profiles and tailor instructional content, learning activities, task difficulty, and feedback to individual needs. Such personalization creates meaningful learning experiences that encourage exploration, argumentation, reflection, and evidence-based reasoning. From a constructivist perspective, these processes provide essential conditions for developing critical thinking through active knowledge construction.

The review also identifies student engagement and self-regulated learning as key mediating mechanisms. Personalized learning increases students' engagement by aligning instruction with their abilities and learning needs, while adaptive feedback supports learners in monitoring progress, identifying misconceptions, and improving learning strategies. These processes strengthen metacognitive awareness, which subsequently contributes to the development of critical thinking skills.

In addition, the effectiveness of AI-supported personalized learning is influenced by several contextual factors. The reviewed studies consistently highlight teachers' AI competency, students' AI literacy, digital infrastructure, and AI ethics and governance as important moderators. AI is unlikely to produce meaningful educational outcomes without adequate pedagogical support, digital readiness, and responsible implementation. Therefore, successful AI integration depends not only on technological capability but also on the quality of the educational ecosystem.

Based on these findings, this study proposes a conceptual model in which AI functions as an enabling technology, personalized learning acts as the pedagogical mechanism, student engagement and self-regulated learning serve as mediators, and critical thinking skills represent the primary educational outcome. The relationships among these constructs are moderated by teacher AI

competency, AI literacy, digital infrastructure, and ethical AI governance. This model provides a more comprehensive explanation of how AI contributes to critical thinking and offers a theoretical foundation for future empirical research.

Theoretical Contributions

This study offers three major theoretical contributions.

1. It extends the Artificial Intelligence in Education (AIEd) literature by conceptualizing AI as an enabling technology that enhances critical thinking through pedagogical mechanisms rather than through direct technological effects.
2. It integrates AI, personalized learning, student engagement, self-regulated learning, metacognitive awareness, and critical thinking into a unified conceptual framework, providing a clearer explanation of how AI-supported learning influences higher-order thinking.
3. It identifies four key moderating factors teacher AI competency, AI literacy, digital infrastructure, and AI ethics and governance that determine the effectiveness of AI implementation. These findings emphasize that successful AI integration depends on the quality of the educational ecosystem as much as on technological advancement.

Synthesis of Previous Studies

The reviewed literature reveals three major trends.

First, most studies focus on the development of AI technologies such as adaptive learning, Intelligent Tutoring Systems, learning analytics, recommender systems, and machine learning to improve personalized learning, while comparatively limited attention has been given to their contribution to critical thinking.

Second, the emergence of Generative AI has shifted research from adaptive instructional systems toward AI as a learning partner capable of supporting academic dialogue, reflection, problem-solving, and argument development. Nevertheless, most studies continue to evaluate AI using conventional indicators such as learning achievement, motivation, or user satisfaction rather than critical thinking.

Third, research on AI, personalized learning, and critical thinking remains fragmented. Existing studies typically examine these constructs separately without explaining their pedagogical relationships. This review addresses this gap by proposing a conceptual model in which personalized learning mediates the relationship between AI and critical thinking through enhanced student engagement, self-regulated learning, and metacognitive awareness, thereby contributing to the advancement of Artificial Intelligence in Education (AIEd).

CONCLUSION

This study examined the implementation of Artificial Intelligence (AI) in personalized learning and explored its opportunities and challenges in enhancing students' critical thinking skills through a Systematic Literature Review (SLR). Based on the synthesis of 42 eligible studies, the findings indicate that AI has become a key driver of educational transformation toward more personalized, adaptive, and data-driven learning. Technologies such as adaptive learning systems, learning analytics, Intelligent Tutoring Systems (ITSs), and Generative Artificial Intelligence (GenAI) enable instruction to be tailored to learners' individual characteristics, needs, and progress.

The review further demonstrates that AI influences critical thinking indirectly through personalized learning. By enhancing student engagement, self-regulated learning, and metacognitive awareness, AI creates learning environments that promote deeper analysis, reflection, problem-solving, and evidence-based reasoning. Accordingly, AI should be

regarded as an enabling technology that strengthens human learning processes rather than replacing learners' cognitive activities.

Despite its considerable potential, AI implementation continues to face important challenges, including teachers' pedagogical readiness, AI literacy, digital infrastructure, data privacy, algorithmic transparency, academic integrity, and ethical AI governance. These findings highlight that the successful adoption of AI requires the integration of technology, pedagogy, ethics, and educational policy to ensure that AI supports meaningful and responsible learning.

The principal contribution of this study is the development of a conceptual model that integrates Artificial Intelligence, personalized learning, student engagement, self-regulated learning, metacognitive awareness, and critical thinking skills into a unified analytical framework. The model extends the Artificial Intelligence in Education (AIEd) literature by explaining the pedagogical mechanisms through which AI supports the development of critical thinking. It also provides a theoretical foundation for future empirical studies employing quantitative approaches such as Structural Equation Modeling (SEM) or Partial Least Squares Structural Equation Modeling (PLS-SEM).

This review has several limitations. It included only English-language journal articles published between 2021 and 2025 and did not conduct a quantitative meta-analysis; therefore, the magnitude of AI's effect on critical thinking could not be estimated. Future research should expand database coverage, incorporate meta-analytic methods, and empirically validate the proposed conceptual model across different educational levels, disciplines, and cultural contexts.

DECLARATIONS

Author Contributions

M.M and M.S contributed to the conceptualization and design of the study, development of the systematic literature review methodology, literature search and selection, data extraction and analysis, thematic synthesis, interpretation of the findings, and preparation, review, and editing of the manuscript. Both authors approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

Ethical Approval

Ethical approval was not required because this study employed a Systematic Literature Review (SLR) approach and analyzed previously published scholarly literature. The study did not involve human participants, animals, direct interaction with research participants, or the collection of primary personal data.

Data Availability

The data supporting the findings of this study were obtained from the implementation and evaluation of the developed digital instructional materials involving teachers and fourth-grade students. The availability of the underlying research data is subject to applicable institutional policies and the protection of participants' privacy and confidentiality.

Acknowledgments

The authors have no acknowledgments to declare.

AI-Assisted Tools Disclosure

The authors declare that any use of AI-assisted tools in the preparation of this manuscript was limited to language refinement and/or other editorial support. All AI-assisted outputs, if used, were reviewed, revised, and verified by the authors, who remain fully responsible for the accuracy, originality, interpretation, and final content of the manuscript.

REFERENCES

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review. *Educational Research Review*, 20, 1–11.

Akçayır, M., & Akçayır, G. (2017). *Educational Research Review*, 20, 1–11.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, 6(4), 355–385.

Bacca-Acosta, J., Baldiris, S., Fabregat, R., & Graf, S. (2022). Trends in augmented reality applications for education: A systematic review. *Education and Information Technologies, 27*(4), 4513–4536.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How People Learn*. National Academy Press.

Braun, V., & Clarke, V. (2022). *Thematic Analysis: A Practical Guide*. London: Sage Publications.

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education. *eLearning & Software for Education*, 1, 133–141.

Garzón, J., et al. (2019). *Virtual Reality*, 23(4), 447–459.

Garzón, J., Pavón, J., & Baldiris, S. (2019). Systematic review and meta-analysis of augmented reality in educational settings. *Virtual Reality*, 23(4), 447–459.

Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: A systematic literature review. *Educational Technology Research and Development, 69*(1), 1–32.

Ibáñez, M. B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers & Education, 123*, 109–123.

Ibáñez, M. B., & Delgado-Kloos, C. (2018). *Computers & Education*, 123.

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education. *Education and Information Technologies, 23*(4), 1515–1529.

Jensen, L., & Konradsen, F. (2018). *Education and Information Technologies*, 23.

Kitchenham, B., & Charters, S. (2007). *Guidelines for Performing Systematic Literature Reviews in Software Engineering*. Keele University.

Makransky, G., & Petersen, G. B. (2021). *Educational Psychology Review*.

Makransky, G., & Petersen, G. B. (2021). Immersive virtual reality and learning. *Educational Psychology Review*, 33, 1–26.

Makransky, G., & Petersen, G. B. (2021). The cognitive affective model of immersive learning. *Educational Psychology Review, 33*(3), 937–958.

Makransky, G., et al. (2019). Immersive VR and learning outcomes. *Learning and Instruction*, 60, 225–236.

Makransky, G., et al. (2019). *Learning and Instruction*, 60.

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction, 60*, 225–236.

Mayer, R. E. (2021). *Multimedia Learning* (3rd ed.). Cambridge University Press.

OECD. (2023). *Digital Education Outlook 2023*. OECD Publishing.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71. https://doi.org/10.1136/bmj.n71

Parong, J., & Mayer, R. (2018). Learning science in immersive VR. *Journal of Educational Psychology*, 110(6), 785–797.

Radianti, J., et al. (2020). A systematic review of immersive VR in higher education. *Computers & Education*, 147.

Radianti, J., et al. (2020). *Computers & Education*, 147.

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education, 147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Selwyn, N. (2016). *Education and Technology*.

Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing our lives with immersive VR. *Frontiers in Robotics and AI*, 3.

Slater, M., & Sanchez-Vives, M. V. (2016). *Frontiers in Robotics and AI*.

Suryani, N., et al. (2022). AR and VR in Indonesian education. *Jurnal Pendidikan Teknologi*.

Sweller, J. (2011). Cognitive load theory. *Psychology of Learning and Motivation*, 55.

Sweller, J., van Merriënboer, J., & Paas, F. (2019). Cognitive architecture and instructional design: Twenty years later. *Educational Psychology Review, 31*(2), 261–292.

UNESCO. (2023). *Global Education Monitoring Report 2023: Technology in Education*.

UNESCO. (2023). Technology in education report.

Wu, H. K., et al. (2020). *Computers & Education*.

Wu, H. K., et al. (2020). Current status of AR in education. *Computers & Education*.

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2023). Current status, opportunities, and challenges of AR and VR in education. *Computers & Education*, 198, 104789.

Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. *Journal of Planning Education and Research, 39*(1), 93–112. https://doi.org/10.1177/0739456X17723971