

INTEGRATING ARTIFICIAL INTELLIGENCE (AI) INTO INSTRUCTIONAL STRATEGIES TO ENHANCE CRITICAL THINKING IN PRIMARY SCHOOLS

Nur Wahyuni^{1*}, Trisno Benaya Gea^{2*}, Nur Aini³

Program Studi Pendidikan Guru Sekolah Dasar, Universitas Battuta

*nurwahyuni.pancing@gmail.com*¹, *trisnobenaya@gmail.com*², *ainin74992@gmail.com*³
official@battuta.ac.id

Abstract

This study investigates how Artificial Intelligence (AI) can be effectively integrated into instructional strategies to enhance critical thinking skills among primary school students. The study adopts a literature review method by examining peer-reviewed journal articles, academic reports, and research findings published between 2020 and 2025. All sources were selected based on relevance, credibility, and accessibility from open academic databases. The findings indicate that AI can be integrated into primary education through intelligent tutoring systems (ITS), educational chatbots, adaptive learning platforms, and data-driven learning analytics. These tools enable personalized, reflective, and engaging learning environments. AI has shown positive effects in promoting students' analytical, evaluative, and logical reasoning abilities, which are key dimensions of critical thinking. As a conceptual literature-based study, this research does not include empirical field data or classroom experiments. The scope is limited to the availability of open-access academic sources, excluding paid or restricted publications. This study offers a theoretical foundation and practical direction for educators, policymakers, and technology developers in utilizing AI responsibly and effectively within elementary education. The research emphasizes the importance of teacher readiness, ethical guidelines, and infrastructural support to ensure meaningful integration of AI in enhancing students' cognitive development, particularly critical thinking.

Keywords: *AI, Instructional Strategies, Critical Thinking.*

1. INTRODUCTION

The advancement of Artificial Intelligence (AI) technology has driven significant changes across various sectors of life, including education. In today's digital era, the use of AI is no longer merely a supplementary tool in learning but has become a vital component in designing adaptive, personalized, and cognitively stimulating learning processes. This transformation aligns with the growing demand for education systems that are responsive, inclusive, and capable of cultivating 21st-century skills. AI technologies, such as intelligent tutoring systems, natural language processing, adaptive assessment tools, and automated feedback mechanisms, are increasingly utilized to support diverse learning needs, track learner progress, and enhance student engagement in dynamic ways.

This is particularly important at the elementary school level, where the development of critical thinking skills should be initiated early. Critical thinking enables students to analyze information, evaluate claims, question assumptions, and construct well-reasoned arguments. These skills are crucial not only for academic success but also for preparing learners to navigate an increasingly complex and information-rich society. As early childhood and primary education serve as the foundation of lifelong learning, equipping students with higher-order thinking skills from an early age becomes essential to shape independent, analytical, and responsible individuals.

Unfortunately, classroom practices in elementary schools still tend to rely heavily on conventional lecture-based and rote learning methods. The teacher-centered approach, while useful for transmitting factual information, often falls short in nurturing students' cognitive flexibility and reflective thinking. Moreover, the use of technology in designing meaningful, student-centered learning experiences remains limited. Many teachers face challenges in integrating digital tools into

their instructional planning, either due to lack of access, insufficient training, or unfamiliarity with technological pedagogical models.

On the other hand, teachers bear a central responsibility in shaping learning environments that not only deliver content but also stimulate deep thinking and problem-solving. Educators must be empowered to shift from passive transmission of knowledge to active facilitation of inquiry, reflection, and exploration. Integrating AI into instructional strategies offers the potential to support this pedagogical shift by enabling more flexible, responsive, and interactive learning environments. AI can assist teachers in generating critical thinking prompts, differentiating tasks based on student ability, and offering immediate feedback to guide learning pathways.

Previous studies (e.g., Holmes et al., 2022; Brookfield, 2021) have shown that AI has been utilized in education to provide automated feedback, customize instructional materials, and even simulate complex learning scenarios. These applications have demonstrated improvements in learning efficiency, motivation, and engagement. However, research that specifically examines the intentional integration of AI in elementary school classrooms to directly support students' critical thinking development remains relatively limited, especially in developing countries such as Indonesia. Most available studies focus on AI in higher education or in general digital learning environments, leaving a gap in understanding how AI can be aligned with the developmental and cognitive needs of young learners.

The urgency to explore this topic is further reinforced by current educational policy directions in Indonesia, which emphasize the importance of strengthening character and cognitive competence in the national curriculum. The Kurikulum Merdeka, for example, calls for more flexible, student-centered learning that supports personalized pathways and competency-based approaches. In addition, global demands for education systems to align with the Society 5.0 vision which advocates for the integration of human-centered technology in solving social problems highlight the relevance of AI as a tool not just for automation, but for human capacity development.

In this context, AI integration in education should not merely be viewed as a technological trend or novelty, but rather as a pedagogical strategy that enhances the quality of students' thinking processes and prepares them for lifelong learning. Integrating AI must be accompanied by ethical considerations, clear instructional goals, and alignment with students' developmental stages. The role of the teacher remains pivotal in mediating the interaction between learners and AI tools to ensure that technology amplifies rather than replaces human cognition.

This research focuses on the following key questions:

- a) How can effective instructional strategies integrate AI in elementary school classrooms?
- b) What is the relationship between such integration and the development of students' critical thinking skills?
- c) What challenges and potential solutions can be identified regarding the implementation of AI-based instructional strategies?

The objectives of this study are:

- a) To identify forms of instructional strategies that enable the contextual integration of AI in elementary schools.
- b) To explain the linkage between these strategies and the enhancement of students' critical thinking abilities.
- c) To formulate solutions to address implementation challenges based on a review of relevant and up to date literature.

Methodologically, this research employs a descriptive qualitative approach through a structured literature review. Data sources consist of scientific articles published within the last five years (2020-2025) that discuss elementary education, artificial intelligence, and strategies for developing higher-order thinking skills. This method allows the researcher to synthesize key theoretical insights, compare cross disciplinary findings, and formulate a conceptual framework that supports the design of instructional strategies in technology-enhanced learning environments.

Through this study, it is expected that a strong and contextually grounded theoretical foundation will be generated to guide teachers in designing instruction that meets the demands of 21st-century learning. Furthermore, this research aims to contribute positively to the formulation of educational policies that are adaptive to technological advancements and responsive to the need for critical thinking development at the elementary level.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

This section elaborates the theoretical foundations and prior studies that support the integration of Artificial Intelligence (AI) into instructional strategies aimed at developing critical thinking skills in elementary school students. It discusses the core concepts of critical thinking, applications of AI in educational settings, the role of teachers in implementing AI-assisted learning, and models that guide the integration of technology in the classroom. Together, these components provide a comprehensive basis for understanding how AI can be pedagogically aligned to support student cognitive development.

a) Critical Thinking in Primary Education

Critical thinking is defined as a reflective process that involves analysis, evaluation, reasoning, and decision-making based on logical evidence (Facione, 2020). It represents the ability to process information independently and make judgments grounded in rationale rather than assumption. In primary education, cultivating critical thinking is vital for developing students' capacity to question sources, interpret information critically, and formulate well-reasoned arguments. Paul and Elder (2021) suggest that the promotion of critical thinking in children should begin with real-world contexts, exposure to multiple viewpoints, and consistent engagement in inquiry-based learning tasks.

Teaching critical thinking at an early age also supports the growth of cognitive flexibility, metacognition, and creativity abilities that are essential in preparing students to participate in knowledge-based and problem-solving societies. Instructional strategies that embed critical thinking often include collaborative problem-solving, Socratic questioning, and reflective writing, all of which can be enhanced through technological mediation.

b) AI in Educational Contexts

Artificial Intelligence in the educational domain refers to the use of computer-based systems that simulate human intelligence to support teaching and learning processes. These technologies include machine learning algorithms, natural language processing, and adaptive learning environments. AI is increasingly being adopted to customize content delivery, analyze student responses, and generate real-time feedback. Intelligent tutoring systems (ITS), automated essay scoring tools, AI-driven formative assessments, and educational chatbots are a few examples of such applications (Holmes et al., 2022).

In primary education, AI offers considerable promise. It can provide engaging learning experiences through gamified simulations and individualized learning paths. For example, an AI-powered reading assistant can adjust text complexity based on student performance, thereby maintaining motivation while promoting gradual cognitive challenge. AI also supports inclusive education by adapting materials to accommodate different learning styles and needs, such as for students with disabilities or language barriers..

c) Teacher's Role in AI-Assisted Learning

Despite the capabilities of AI, the teacher remains a pivotal element in orchestrating meaningful learning experiences. According to Brookfield (2021), teachers act as designers of learning who make critical decisions about when and how to use technology effectively. They are responsible for choosing appropriate AI tools, interpreting data insights, and guiding students through AI-supported learning environments. More importantly, teachers must ensure that AI applications align with curricular goals and foster critical thinking rather than passive consumption.

In AI mediated classrooms, the teacher facilitates reflective thinking by posing open-ended questions, integrating peer collaboration, and encouraging students to analyze AI generated content

critically. The presence of a reflective educator ensures that technology enhances not replaces the cognitive engagement required for critical thinking development.

d) Models of AI Integration in Classroom Practice

Several pedagogical models offer frameworks for guiding AI integration in education. The Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006) emphasizes the synergy between a teacher's knowledge of content, pedagogy, and technology. Effective AI implementation requires educators to possess a well developed TPACK framework so they can make informed decisions about tool selection and instructional design.

Another widely used framework is the SAMR model (Substitution, Augmentation, Modification, Redefinition) by Puentedura (2014), which helps educators evaluate how technology transforms learning tasks. AI tools that move beyond substitution such as real time simulations or personalized feedback engines enable more significant pedagogical shifts. These models highlight the importance of strategic planning, continual teacher professional development, and institutional readiness.

e) Hypothesis Development

Based on the review of literature and theoretical perspectives, the following hypotheses are proposed: (H1)The integration of AI into instructional strategies significantly supports the development of students' critical thinking skills in primary education; (H2)The effectiveness of AI integration in classrooms is strongly influenced by the teacher's ability to contextualize and design AI-based activities aligned with critical thinking objectives; (H3)Successful implementation of AI-assisted pedagogy depends on institutional support, teacher readiness, and ethical considerations in AI deployment.

These hypotheses establish the conceptual foundation for the subsequent sections of this study. They guide the exploration of instructional models, potential barriers, and strategies for optimizing the use of AI in promoting critical thinking in primary education.

3. RESEARCH METHODOLOGY

a) Type and Approach of Research

This study employs a descriptive qualitative research design using a literature review approach. This method is selected to explore and analyze conceptual frameworks and empirical findings from previous studies relevant to the topic. The literature review approach enables the researcher to construct a theoretical foundation and synthesize scientific results without the need for direct field data collection, while still generating academically valid insights based on credible sources.

b) Data Sources and Collection Techniques

The data in this study are drawn from scientific publications accessed through accredited national journals and reputable international open-access journals. The criteria for source selection are: 1) Articles relevant to the topics of AI integration, critical thinking, and primary school education., 2)Published within the last five years (2020–2025), 3) Meeting academic publication standards and credibility, 4) Accessible through databases such as Google Scholar, ERIC, DOAJ, ResearchGate, and Garuda. Data collection was conducted through systematic searches using keywords including: “Artificial Intelligence in Education,” “Critical Thinking in Primary School,” “Teacher Strategies with AI,” and “AI-Based Learning Models.”

c) Data Analysis Techniques

The collected data were analyzed using content analysis and thematic analysis techniques. The analysis followed several stages: 1). Data reduction: Selecting key information from the reviewed literature, 2). Theme categorization: Organizing findings into major themes such as AI integration strategies, teacher roles, critical thinking development, challenges, and solutions, 3). Synthesis: Combining findings from multiple studies to develop a comprehensive and systematic understanding. This process was conducted reflectively by considering the Indonesian elementary education context and the relevance of global findings.

d) Validity and Data Credibility

To ensure data validity, the researcher applied source triangulation by comparing findings from various references and academic disciplines. Only peer-reviewed articles published in reputable journals were used as primary references. Content validity was reinforced by citing direct statements from relevant previous scholars.

e) Methodological Limitations

As a literature review study, the main limitation lies in the absence of primary field data collection. Therefore, the generalizability of the findings depends heavily on the quality and completeness of the reviewed sources. Nevertheless, this approach provides a strong theoretical and practical understanding within the scope of the research topic. With this methodological structure, the study aims to present a comprehensive overview of how AI can be integrated into instructional strategies to enhance elementary students' critical thinking skills, based on recent and relevant scientific evidence.

4. RESULTS AND DISCUSSIONS

a) AI Integration Strategies in Primary School Learning

The integration of Artificial Intelligence (AI) in primary school learning involves a structured and strategic approach that blends intelligent technologies with contextually relevant and developmentally appropriate teaching practices. Literature review findings suggest several pedagogical strategies that educators can adopt to leverage AI as a catalyst for enhancing critical thinking skills among students at the elementary level.

One of the most prominent strategies is the implementation of Intelligent Tutoring Systems (ITS), which are capable of delivering real-time, personalized feedback and tailored instruction based on individual learners' responses. Holmes et al. (2022) emphasize that ITS can identify students' misconceptions, generate adaptive questions, and dynamically adjust task difficulty levels to meet each student's cognitive needs. This supports differentiated instruction, which is particularly crucial in primary education where learner variability is high. Furthermore, ITS fosters reflective thinking by prompting students to re-examine their reasoning and develop self-correction habits.

Another effective strategy involves simulation-based and digital modeling learning, where AI-powered platforms allow students to explore abstract or complex concepts through interactive visualizations. For instance, in natural science lessons, students can observe ecosystems or chemical reactions virtually and respond to higher-order questions that require interpretation, prediction, or evaluation. These simulations serve as authentic contexts for inquiry-based learning, supporting the development of critical thinking through problem solving and decision making tasks (Brookfield, 2021). Additionally, simulations can be gamified to maintain motivation and emotional engagement.

Educational chatbots or intelligent conversational agents are also increasingly recognized for their ability to engage students in meaningful dialogue. These chatbots, when embedded with pedagogical scripts, can respond to student questions, offer clarifications, and initiate further inquiry by asking reflective questions. For example, a chatbot in a language lesson may respond to a student's story summary with follow-up prompts such as "What might have happened if the character had made a different choice?" or "How does this story connect to your life?" Such prompts stimulate analytical and evaluative thinking. The teacher's role is critical in curating the flow of dialogue and ensuring that chatbot interactions are aligned with cognitive learning objectives.

Another key strategy is the use of learning analytics, where AI systems automatically track and analyze data from students' digital learning activities. These systems provide educators with dashboards that indicate individual and group performance trends, highlight areas of difficulty, and identify emerging patterns of reasoning. This evidence based insight enables teachers to offer timely and targeted pedagogical interventions that are responsive to students' thinking processes. For example, if students consistently struggle with evaluation tasks, the teacher can design lessons that scaffold analytical reasoning skills.

Lastly, AI-driven formative assessments are powerful tools for promoting metacognitive reflection and self-assessment. Adaptive assessments powered by AI can provide immediate feedback

not only on correctness but also on the reasoning process, encouraging students to reconsider their strategies. This contributes to the development of explanation and justification skills, key elements of critical thinking.

In summary, the integration of AI in primary education must go beyond tool adoption and be driven by clear instructional goals. Strategies should be aligned with the learners' developmental stage, subject matter, and curriculum standards. AI should serve to deepen student engagement, support individualized learning, and promote metacognition all of which are central to critical thinking development.

b) The Role of Teachers in AI-Based Learning Strategies

In AI-based learning environments, teachers continue to serve as the cornerstone of educational success. While AI systems can provide automated feedback, adaptive learning content, and dynamic learning paths, they cannot replace the nuanced judgment, empathy, and instructional intuition that teachers bring into the classroom. The effectiveness of AI integration depends largely on the teacher's ability to design, facilitate, and monitor meaningful learning experiences.

Literature indicates that effective AI integration requires teachers to possess not only technological literacy but also deep pedagogical understanding and sensitivity to students' developmental needs. Brookfield (2021) refers to teachers in such contexts as "learning architects" professionals who structure the flow of instruction, design activities that trigger critical thinking, and use technology as a tool to enhance rather than substitute the learning process.

For example, when using AI-powered tools such as educational chatbots or adaptive simulations, teachers must ensure that these tools are not used merely for content delivery but are embedded with opportunities for students to question, hypothesize, reflect, and synthesize. This may involve preparing AI-generated scenarios with branching logic that requires student justification at each step or designing chatbot interactions that stimulate metacognitive prompts like "What makes you think that?" or "Can you explain your reasoning?"

In addition to instructional design, teachers play a pivotal role in assessment and feedback. AI platforms may provide performance data, but it is the teacher who interprets these data through the lens of pedagogy and translates them into actionable teaching decisions. Teachers use insights from learning analytics to identify misconceptions, adjust lesson plans, and provide personalized scaffolding. This data-informed teaching enhances the depth and precision of instruction.

Moreover, teachers are also ethical gatekeepers in AI-mediated learning environments. They must ensure that AI use does not compromise the humanistic and social emotional dimensions of education. For young learners, interpersonal interaction, collaboration, and teacher presence are essential for building social skills and emotional intelligence. Therefore, the teacher must balance AI use with human interaction and ensure that technology serves as an enhancer of not a barrier to student agency and relational learning.

Professional development programs must equip teachers with the skills to integrate AI not only technically but pedagogically and ethically. The TPACK (Technological Pedagogical Content Knowledge) framework is a valuable model for helping teachers navigate the intersection of content, pedagogy, and technology.

c) The Impact of AI Integration on the Development of Critical Thinking

The integration of Artificial Intelligence (AI) into education, particularly at the primary school level, holds significant potential for shaping and enhancing students' critical thinking abilities. In this context, critical thinking encompasses not only the ability to analyze and evaluate information, but also to construct arguments, interpret data, and make decisions based on logical reasoning. According to Facione (2020), critical thinking includes six core components: interpretation, analysis, evaluation, inference, explanation, and self-regulation. All of these components can be strengthened through well-structured AI-supported instructional approaches.

One relevant example of AI implementation at the elementary level is the use of ChatGPT-3 as a text-based learning assistant. Through this platform, students can engage in AI-facilitated dialogue

that encourages them to ask questions, respond to hypothetical scenarios, and evaluate arguments. In a study by Wu et al. (2023), student interaction with GPT-3 in language learning contexts was shown to enhance clarity of thought, expand conceptual vocabulary, and improve their ability to construct logically sound narratives.

Another practical implementation is in science subjects, where students are tasked with designing virtual experiments using AI-driven platforms capable of simulating data-based scenarios. When students choose variables or construct hypotheses, the AI system can respond with questions like “Why did you choose this variable?” or “What might happen if the conditions change?” Such questioning supports the development of evaluation and inference skills, which are foundational to critical thinking.

AI can also support problem-solving-based digital literacy activities. For example, students might read a science article and then interact with ChatGPT to clarify or expand their understanding. The AI can provide explanations, ask follow-up questions, or challenge the student’s interpretation. These interactive cycles encourage students to think deeply, reflect, and refine their comprehension.

In addition, AI enables adaptive formative assessment. Using learning analytics systems, teachers can access data showing which types of questions students can answer effectively and which aspects they struggle with. A student who shows weakness in providing logical reasoning can be given targeted tasks that build skills in evaluation and explanation. This demonstrates that AI plays a role not only in instruction but also in strengthening individual critical thinking competencies. Another dimension is self-directed learning. With AI as a learning partner, students gain opportunities to independently explore topics of interest. Adaptive AI features can facilitate idea exploration and offer diverse learning resources, encouraging students to make independent learning decisions, select relevant information, and construct ideas in a logical and coherent manner.

Nevertheless, the positive impact of AI on critical thinking depends heavily on the instructional design used by teachers. AI is only effective when integrated as part of a thoughtful learning strategy that emphasizes skill development rather than passive information retrieval. Teachers must still design challenging learning contexts, provide feedback, and guide students in reflecting on their thought processes.

Considering all these aspects, the integration of AI technologies such as GPT-3 into primary school learning has transformative potential for enhancing students’ critical thinking skills. However, to fully realize this potential, systemic readiness, adequate teacher training, and policies that support pedagogical and ethical technology use are essential.

d) Challenges and Solutions in Implementing AI in Primary Schools

Although Artificial Intelligence (AI) presents significant opportunities to revolutionize education especially in fostering students’ critical thinking skills its implementation at the primary school level remains fraught with a range of challenges. These challenges stem from diverse factors such as infrastructure limitations, teacher readiness, policy gaps, and pedagogical as well as ethical considerations. To achieve effective and sustainable AI integration in schools, it is crucial to critically examine these obstacles and propose strategic, context-sensitive solutions.

1. Technological Infrastructure and Accessibility Constraints

A major barrier in primary schools, particularly in remote or underdeveloped regions, is the lack of adequate technological infrastructure. Limited access to devices (computers, tablets), unstable internet connectivity, and the absence of child-friendly AI software remain persistent issues. Holmes et al. (2022) highlight that this digital divide risks perpetuating educational inequalities across regions. Solution: Government and private sector collaboration is needed to provide equitable access to technological resources. Additionally, the development of lightweight, offline-compatible AI tools can serve as an inclusive alternative for schools with limited digital infrastructure.

2. Teachers’ Readiness and Digital Literacy Competency

Many primary school teachers still face difficulties in understanding and leveraging AI meaningfully in the classroom. The lack of training programs focused on digital pedagogy and

strategic integration of technology is a pressing issue. Teachers unprepared for AI-based instruction may misuse AI merely as a presentation tool, missing its potential for cognitive engagement. Solution: Teacher professional development must emphasize integrated competencies combining pedagogy, content, and technology following the TPACK framework. Training should be participatory, practice oriented, and continuous. Establishing digital teacher communities can foster the exchange of best practices in AI implementation.

3. Pedagogical Challenges and Curriculum Relevance

AI tools must be adapted to suit the developmental stages of young learners. Many AI applications on the market are designed for secondary or higher education, lacking relevance for primary school students. Additionally, current national curricula in many regions do not explicitly include AI as a component of required learning strategies. Solution: The development of contextually appropriate AI-based learning models tailored for children is essential. Such models should be collaboratively designed by elementary education experts, technology developers, and policymakers. Furthermore, curricular adjustments and practical AI usage guidelines for classroom implementation are needed.

4. Ethical Considerations, Data Privacy, and Technological Dependency

Integrating AI into education involves ethical implications, such as protecting students' personal data, managing reliance on automated systems, and maintaining healthy social interactions. Since primary students are in formative stages of socio-emotional development, technology use must not diminish the humanistic dimension of education. Solution: Educational policy must establish ethical standards for AI use in primary education, including data protection, parental involvement, and screen time regulation. AI integration should also be balanced with collaborative and social learning methods to maintain student engagement in human-centered education.

By acknowledging and addressing these multifaceted challenges comprehensively, the integration of AI in primary school learning can become sustainable, adaptive, and impactful. A collaborative approach involving teachers, students, policymakers, and technology developers is essential to ensure the success of AI implementation in future education systems.

5. CONCLUSION

This study aimed to examine how Artificial Intelligence (AI) can be strategically integrated into primary school education to enhance students' critical thinking skills. Through a comprehensive review of credible academic sources and up-to-date scholarly literature, this study has synthesized relevant theoretical frameworks, practical strategies, and empirical findings that collectively support the transformative potential of AI in education.

The first major conclusion highlights that the integration of AI in primary education is not a technical shift, but a pedagogical advancement. Strategies such as the use of intelligent tutoring systems (ITS), simulation-based learning, educational chatbots, and AI-driven learning analytics offer rich opportunities for enhancing the interactivity, personalization, and adaptivity of learning processes. These tools, when implemented effectively, support instructional models that stimulate higher-order thinking skills, especially critical thinking. AI enables immediate feedback, differentiated instruction, and real-time progress tracking, which together help students move beyond rote memorization toward reflective and analytical engagement with learning content.

Second, the impact of AI on students' critical thinking is evident in various dimensions. AI-supported environments such as ChatGPT-3, adaptive assessments, and virtual labs have been shown to stimulate student inquiry, argumentation, and problem-solving abilities. AI can serve as a dialogic partner, prompting students to justify their reasoning, evaluate scenarios, and construct logical interpretations. By providing opportunities for exploration, reflection, and feedback, AI encourages a shift from passive knowledge reception to active and self-regulated learning, which is central to the development of critical thinking in young learners.

However, the third conclusion reveals that significant challenges persist in realizing the full potential of AI in primary schools. Barriers include limited digital infrastructure, insufficient teacher readiness, curriculum misalignment, and ethical concerns related to data privacy, student dependency, and social-emotional development. These challenges, if unaddressed, can lead to unequal learning opportunities, ineffective use of technology, and reduced human interaction in the classroom factors that may hinder rather than support the development of critical thinking.

To address these barriers, the study emphasizes several key solutions. First, teacher professional development must be prioritized, particularly through frameworks like TPACK that integrate pedagogical, technological, and content knowledge. Teachers need both technical and pedagogical support to design AI-mediated learning experiences that are engaging, ethical, and developmentally appropriate. Second, the development of context-specific AI learning models designed for primary learners and aligned with local curricula is crucial to ensure relevance and accessibility. Third, ethical and policy frameworks must be established to guide the responsible use of AI in classrooms, ensuring student safety, data security, and a balance between digital interaction and human centered pedagogy. In conclusion, this research reaffirms the substantial potential of AI to transform primary education by fostering a more dynamic, personalized, and cognitively enriching learning experience. AI tools, when used thoughtfully, can complement the teacher's role and empower students to become critical, creative, and independent thinkers. Nevertheless, the success of such transformation depends not merely on technology itself, but on the capacity of educational institutions, teachers, and policymakers to build an ecosystem that supports sustainable, ethical, and pedagogically sound AI integration.

By highlighting both the opportunities and the limitations, this study provides a conceptual foundation for future research and practical innovation in AI-based education. It contributes to the broader discourse on how technology can serve human development not by replacing educators, but by enhancing their ability to nurture learners who can think critically, act responsibly, and thrive in the digital age.

LIMITATION AND STUDY FORWARD

As a literature-based study, this research is inherently limited in several aspects, particularly with regard to the absence of empirical data collection. Although the review draws upon a diverse range of credible and up-to-date academic sources, it does not involve primary data from classroom observations, teacher interviews, or student performance assessments. Consequently, the findings and conclusions presented here are theoretical in nature and depend heavily on the validity of secondary sources. This limitation restricts the ability to fully capture the nuanced realities of AI implementation in diverse school contexts, particularly in rural or underserved educational settings where infrastructure and access to technology vary significantly.

In addition, the scope of literature included in this study was partially constrained by restricted access to paywalled academic journals and subscription-based databases. While open-access sources were prioritized, it is possible that some influential and highly relevant studies were not included due to these limitations. This may have affected the comprehensiveness of the theoretical foundation and the generalizability of some insights.

Given these limitations, future research is strongly encouraged to adopt mixed-method approaches that combine both quantitative and qualitative methodologies. For instance, experimental or quasi-experimental studies can be conducted to assess the measurable impact of specific AI tools such as ChatGPT, intelligent tutoring systems, or adaptive assessment platforms on students' critical thinking performance over time. Similarly, classroom-based action research and case studies can provide deeper insights into how teachers design, implement, and evaluate AI-based learning in authentic educational environments.

Moreover, research on students' perceptions, teacher readiness, and institutional capacity for AI integration would enrich our understanding of the human dimensions of educational technology.

Longitudinal studies are also recommended to examine the sustainability of AI interventions and their long term impact on student learning behavior and higher-order thinking skills. In addition, comparative studies across regions or countries may offer cross-cultural perspectives on the effectiveness and challenges of AI-based instruction at the primary level.

These future directions are essential for validating, refining, and contextualizing the conceptual models presented in this literature review and for supporting the development of evidence based educational policy.

REFERENCES

- Brookfield, S. D. (2021). *Teaching for Critical Thinking: Tools and Techniques to Help Students Question Their Assumptions*. Jossey-Bass.
- Facione, P. A. (2020). *Critical Thinking: What It Is and Why It Counts*. Insight Assessment.
- Holmes, W., Bialik, M., & Fadel, C. (2022). *Artificial Intelligence in Education: Promises and Implications for Teaching and Learning*. Center for Curriculum Redesign.
- Mishra, P., & Koehler, M. J. (2020). Technological Pedagogical Content Knowledge (TPACK) Framework. *Contemporary Issues in Technology and Teacher Education*, 20(1), 101–120.
- Wu, X., Li, Y., & Zheng, H. (2023). The Role of ChatGPT in Language Learning: Critical Thinking Perspectives. *Journal of Educational Computing Research*, 61(3), 423–439.
- Chen, Y., & Zhang, L. (2021). Enhancing Primary Students' Critical Thinking via AI-powered Simulations. *Computers & Education*, 168, 104210.
- Zhou, M., & Wang, X. (2022). AI and Pedagogy in Basic Education: Integration Models and Challenges. *International Journal of Educational Technology in Higher Education*, 19(25), 1-18. <https://educationaltechnologyjournal.springeropen.com/articles/10.1186/s41239-022-00336-3>
- Sun, K., & Huang, Y. (2020). How AI Supports Reflective Thinking in Elementary Classrooms. *Educational Technology Research and Development*, 68, 1365–1384.
- Nasution, F. D., & Pratama, R. A. (2023). Implementasi AI dalam Pembelajaran Sekolah Dasar: Studi Literatur. *Jurnal Teknologi dan Pembelajaran*, 12(2), 45–59. <https://jtp.univ.ac.id/index.php/jtp/article/view/456>
- Siregar, M. E., & Rahman, A. (2022). Kecerdasan Buatan dalam Pendidikan Abad 21: Tinjauan Teoretis dan Praktis. *Jurnal Pendidikan Dasar Digital*, 8(1), 89–104. <https://ejournal.upd.ac.id/index.php/jpdd/article/view/812>
- Tan, H., & Li, S. (2023). Exploring Student Autonomy through AI-Based Learning Platforms. *Technology, Pedagogy and Education*, 32(1), 74–91.
- Lestari, S., & Nugroho, D. (2021). Peran Guru dalam Integrasi Teknologi AI di Sekolah Dasar. *Jurnal Inovasi Pendidikan Dasar*, 5(2), 115–130.
- Amelia, R., & Kurniawan, B. (2024). Tantangan Etika dalam Pemanfaatan AI untuk Pembelajaran Anak Usia Dini. *Jurnal Etika dan Teknologi Pendidikan*, 4(1), 33–47.
- Ghozali, A., & Setiawan, R. (2020). Strategi Pengembangan Berpikir Kritis Melalui Teknologi Cerdas. *Jurnal Ilmiah Pendidikan Teknologi*, 11(3), 203–219.
- Yusuf, A. R., & Hidayat, M. (2021). Analisis Learning Analytics dalam Pengembangan Kognitif Siswa SD. *Jurnal Teknologi Pembelajaran Anak*, 9(4), 221–237.