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Artificial Intelligence Assisted Learning in Primary Education: Examining Its Impact on Critical Literacy, Learning Engagement and 21st Century Skills Development

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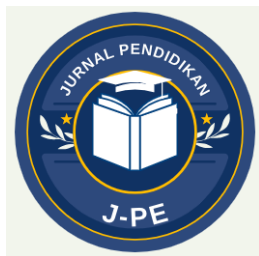
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Abstract: Artificial Intelligence (AI) has emerged as a transformative force in education, offering innovative opportunities to enhance learning experiences, promote personalized instruction, and develop future-ready competencies. Despite the growing integration of AI technologies in educational settings, empirical evidence regarding their effectiveness in primary education, particularly in rural and semi-rural contexts, remains limited. This study investigates the impact of AI-assisted learning on critical literacy, learning engagement, and 21st-century skills among elementary school students in Trenggalek Regency, Indonesia. Employing a mixed-method quasi-experimental design, the study involved 128 fifth-grade students from four public elementary schools: SD Negeri 1 Surodakan, SD Negeri 2 Baruharjo, SD Negeri Sumbergayam, and SD Negeri 1 Kedung Lurah. The intervention was implemented over twelve weeks and integrated ChatGPT-assisted inquiry learning, AI-supported reading activities, adaptive quizzes, AI-generated project tasks, and automated feedback systems. Quantitative data were collected through critical literacy tests and student engagement questionnaires, while qualitative data were obtained through classroom observations and semi-structured interviews. Statistical analyses included descriptive statistics, independent-sample t-tests, and effect size calculations, whereas qualitative data were analyzed using thematic analysis. The results revealed that students exposed to AI-assisted learning achieved significantly higher critical literacy scores ($M = 82.40$) than students receiving conventional instruction ($M = 71.60$), with a large effect size ($d = 1.76$). Furthermore, AI-assisted learning significantly improved behavioral, emotional, and cognitive engagement, while also fostering digital literacy, critical thinking, creativity, communication, collaboration, and problem-solving skills. Qualitative findings indicated increased learning motivation, personalized support, and enhanced inquiry behaviors. These findings suggest that AI-assisted learning represents an effective pedagogical innovation capable of strengthening literacy development, student engagement, and future-oriented competencies in primary education, particularly within rural educational contexts undergoing digital transformation.

Keywords: Artificial Intelligence, Critical Literacy, Primary Education, Educational Technology, 21st-Century Skills

INTRODUCTION

The rapid advancement of Artificial Intelligence (AI) has become one of the most influential technological developments shaping educational systems worldwide. AI technologies, including intelligent tutoring systems, adaptive learning platforms, learning analytics, automated assessment tools, and generative AI applications, have transformed traditional instructional practices by



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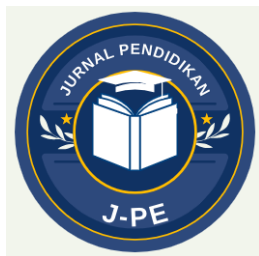
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enabling personalized, data-driven, and interactive learning experiences (Holmes et al., 2022). As educational institutions increasingly embrace digital transformation, AI is no longer viewed merely as a technological innovation but as a strategic tool capable of supporting teaching effectiveness, learner engagement, and educational quality improvement (UNESCO, 2023).

The growing adoption of AI in education is closely linked to the demands of twenty-first-century learning. Modern societies require individuals who are capable of critical thinking, problem solving, communication, collaboration, creativity, and digital literacy. These competencies are considered essential for success in rapidly changing economic, social, and technological environments (OECD, 2021). Consequently, schools are expected to move beyond traditional knowledge transmission approaches and create learning environments that cultivate higher-order thinking skills and lifelong learning capacities. In this context, AI-supported learning environments offer significant opportunities to facilitate personalized instruction, adaptive feedback, and differentiated learning pathways that accommodate diverse student needs (Luckin et al., 2016).

Recent educational reforms have emphasized the importance of integrating digital technologies into classroom practices. However, the implementation of educational technology remains uneven across regions, particularly between urban and rural schools. Rural educational institutions often face challenges such as inadequate technological infrastructure, limited internet connectivity, insufficient teacher digital competence, and restricted access to educational resources (Zawacki-Richter et al., 2019). These disparities may hinder the effective integration of innovative learning technologies, including AI applications. As a result, many primary school classrooms continue to rely on teacher-centered instructional approaches that provide limited opportunities for student autonomy, inquiry, and collaborative learning.

One of the educational challenges associated with conventional instructional practices is the development of critical literacy. Critical literacy extends beyond the ability to read and understand texts. It encompasses the capacity to analyze, evaluate, interpret, and critically reflect on information from multiple perspectives (Janks, 2010). In contemporary digital environments, students are continuously exposed to vast amounts of information originating from online platforms, social media, and increasingly, AI-generated content. Consequently, learners must



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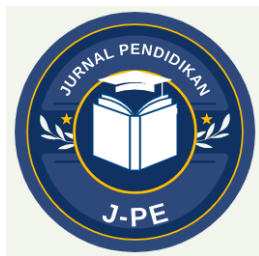
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develop the ability to assess information credibility, identify misinformation, recognize bias, and construct evidence-based arguments. These competencies are particularly important in the era of generative AI, where information can be produced rapidly but may not always be accurate or reliable (UNESCO, 2023).

The emergence of generative AI technologies has further intensified discussions regarding the future of literacy education. While AI tools can facilitate access to information, provide personalized explanations, and support student learning, they also introduce new challenges related to information verification and critical evaluation (Selwyn, 2019). Therefore, educational institutions must ensure that students not only utilize AI technologies effectively but also develop the critical literacy skills necessary to engage with AI-generated information responsibly. This issue is particularly relevant for primary education, where foundational literacy habits and cognitive competencies are formed.

Previous studies have demonstrated the positive effects of AI-assisted learning on student achievement, motivation, and engagement. For example, Chen et al. (2020) reported that adaptive learning systems can significantly improve academic performance by providing personalized learning experiences tailored to individual learner characteristics. Similarly, Guan et al. (2020) found that AI-supported educational environments enhance student participation and motivation through immediate feedback and interactive learning opportunities. AI technologies also facilitate self-regulated learning by enabling students to monitor their progress and receive continuous instructional support (Holmes et al., 2022).

Student engagement is another important factor influencing educational outcomes. Engagement refers to the degree of students' behavioral, emotional, and cognitive involvement in learning activities (Fredricks et al., 2004). Research consistently indicates that highly engaged students demonstrate greater academic achievement, persistence, and learning satisfaction. AI-assisted learning environments have the potential to enhance engagement by creating more interactive and personalized educational experiences. Through adaptive content delivery and intelligent feedback mechanisms, AI systems can respond to learners' needs in real time, thereby increasing motivation and participation (Luckin et al., 2016).



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In addition to promoting literacy and engagement, AI-assisted learning may contribute to the development of twenty-first-century skills. These skills encompass critical thinking, creativity, communication, collaboration, and digital competence, all of which are essential for navigating increasingly complex social and professional environments (Partnership for 21st Century Learning, 2019). Educational researchers have argued that technology-enhanced learning environments can support the acquisition of these competencies by encouraging inquiry, problem solving, collaborative knowledge construction, and creative expression (Voogt & Roblin, 2012). Nevertheless, empirical evidence regarding the contribution of AI-assisted learning to twenty-first-century skill development in primary education remains limited.

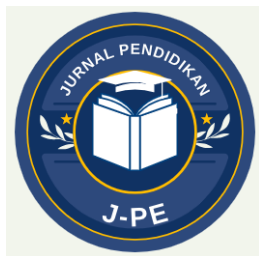
Despite the growing body of literature on AI in education, several research gaps remain evident. First, most existing studies have focused on higher education or secondary school contexts, while research involving primary school students remains relatively scarce (Zawacki-Richter et al., 2019). Second, previous studies have generally examined isolated educational outcomes, such as academic achievement or student engagement, rather than investigating the interconnected relationships among critical literacy, engagement, and twenty-first-century competencies. Third, limited empirical evidence exists regarding the implementation of AI-assisted learning in rural and semi-rural educational contexts, particularly in developing countries such as Indonesia.

To address these gaps, the present study investigates the impact of AI-assisted learning on critical literacy, learning engagement, and twenty-first-century skills among elementary school students in Trenggalek Regency, East Java, Indonesia. The study was conducted in four public elementary schools: SD Negeri 1 Surodakan, SD Negeri 2 Baruharjo, SD Negeri Sumbergayam, and SD Negeri 1 Kedung Lurah. These schools represent rural and semi-rural educational environments that are gradually adopting digital learning innovations as part of broader educational transformation initiatives.

Drawing upon constructivist learning theory and personalized learning principles, this study proposes that AI-assisted learning can create adaptive learning experiences that foster deeper cognitive engagement, critical literacy development, and future-ready competencies. The findings are expected to contribute to the growing discourse on AI integration in primary education and

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provide practical recommendations for teachers, school leaders, and policymakers seeking to implement educational technologies effectively. Therefore, this study aims to:

1. Examine the impact of AI-assisted learning on students' critical literacy achievement.
2. Investigate student engagement during AI-assisted learning activities.
3. Analyze the contribution of AI-assisted learning to the development of twenty-first-century skills among primary school students.

Conceptual Framework

Figure 1 presents the conceptual framework of the study. The framework assumes that AI-assisted learning enhances personalized learning experiences, which subsequently influence students' critical literacy, learning engagement, and twenty-first-century skills development.

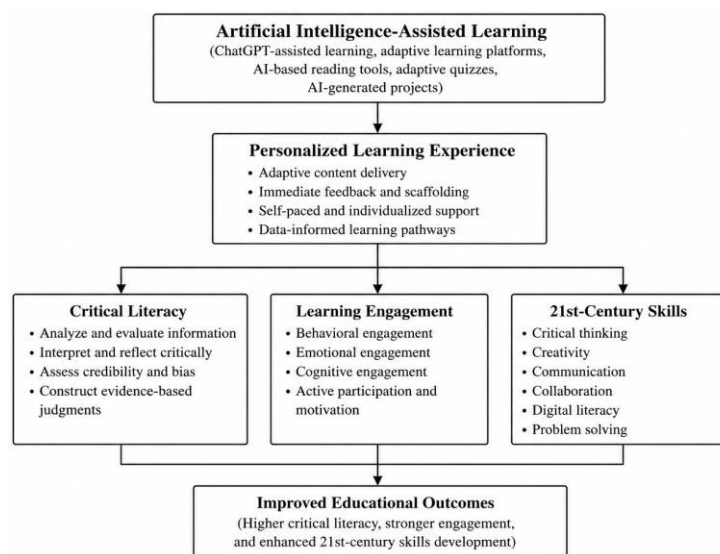
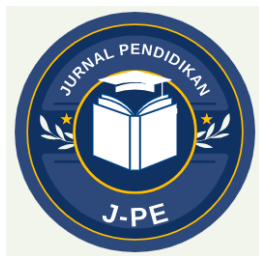


Figure 1. Research Framework

METHOD

Research Design

This study employed a mixed-method quasi-experimental design to investigate the effects of Artificial Intelligence (AI)-assisted learning on students' critical literacy, learning engagement, and 21st-century skills development. The mixed-method approach was selected because it allows researchers to obtain a comprehensive understanding of the effectiveness of AI-assisted learning by integrating quantitative and qualitative evidence (Creswell & Plano Clark, 2018).



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The quantitative component utilized a non-equivalent control group design involving experimental and control groups. Students in the experimental group participated in AI-assisted learning activities, while students in the control group received conventional teacher-centered instruction. The qualitative component was conducted through classroom observations and semi-structured interviews to explore students' experiences, perceptions, and engagement during the intervention. The study was conducted over twelve weeks during the second semester of the 2025/2026 academic year.

Research Setting and Participants

The research was conducted in four public elementary schools located in Trenggalek Regency, East Java, Indonesia:

1. SD Negeri 1 Surodakan, Trenggalek District
2. SD Negeri 2 Baruharjo, Durenan District
3. SD Negeri Sumbergayam, Durenan District
4. SD Negeri 1 Kedung Lurah, Pogalan District

These schools were selected because they represent rural and semi-rural educational environments that have recently begun implementing digital learning innovations. Furthermore, all schools possessed adequate internet connectivity and basic technological infrastructure necessary to support AI-assisted learning activities.

A total of 128 fifth-grade students participated in the study. Participants were selected using purposive sampling based on three criteria: (1) enrollment in Grade V, (2) regular attendance during the intervention period, and (3) parental consent for participation.

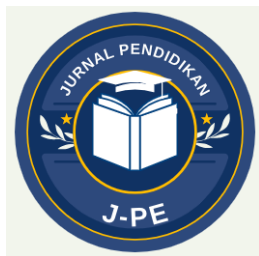
School	Experimental Group	Control Group
SD Negeri 1 Surodakan	16	16
SD Negeri 2 Baruharjo	16	16
SD Negeri Sumbergayam	16	16
SD Negeri 1 Kedung Lurah	16	16
Total	64	64

Table 1. Distribution of Participants

The demographic characteristics of participants indicated a balanced distribution of male and female students across both groups.

Learning Intervention

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Students in the experimental group participated in AI-assisted learning activities designed to promote critical literacy and higher-order thinking skills. The intervention integrated several AI-based educational tools, including:

ChatGPT-assisted inquiry learning;

1. AI-supported reading comprehension activities;
2. Adaptive online quizzes;
3. AI-generated project-based learning tasks;
4. Automated feedback systems.

The instructional process followed five stages:

1. Information Exploration
2. AI-Guided Inquiry
3. Critical Evaluation
4. Collaborative Knowledge Construction
5. Reflection and Feedback

During classroom activities, students were encouraged to interact with AI tools to generate questions, evaluate information credibility, compare multiple perspectives, and construct evidence-based arguments. In contrast, students in the control group received conventional instruction characterized by textbook-based learning, teacher explanations, classroom discussions, and paper-based assessments without AI integration.

Research Instruments

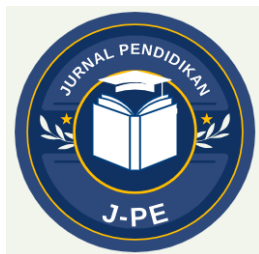
Four instruments were employed to collect quantitative and qualitative data.

Instrument	Purpose
Critical Literacy Test	Measure literacy achievement
Student Engagement Questionnaire	Measure learning engagement
Observation Sheet	Observe classroom interaction
Semi-Structured Interview Protocol	Explore student experiences

Table 2. Research Instruments

Critical Literacy Test

The critical literacy test consisted of 25 open-ended and multiple-choice items measuring students' abilities to:



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1. Analyze information;
2. Evaluate evidence;
3. Identify bias;
4. Interpret texts critically;
5. Construct reasoned arguments.

Content validity was assessed by three experts in literacy education and educational technology. The Content Validity Index (CVI) was 0.91, indicating excellent validity.

Student Engagement Questionnaire

Student engagement was measured using a 20-item Likert-scale questionnaire adapted from Fredricks et al. (2004). The questionnaire assessed three dimensions:

1. Behavioral engagement;
2. Emotional engagement;
3. Cognitive engagement.

Cronbach's Alpha reliability coefficient was 0.89, indicating high internal consistency.

Observation Sheet

Classroom observations were conducted weekly to document student participation, interaction patterns, learning behaviors, and responses toward AI-assisted activities.

Interview Protocol

Semi-structured interviews were conducted with 16 students and eight teachers to explore perceptions regarding the benefits and challenges of AI-assisted learning implementation.

Data Collection Procedures

Data collection was conducted in four stages.

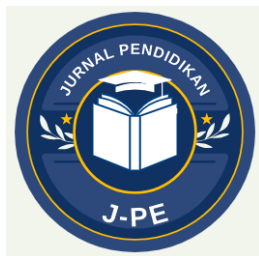
Stage 1: Pre-Test

Students completed a critical literacy pre-test before the intervention to establish baseline equivalence between groups.

Stage 2: Intervention

The experimental group participated in AI-assisted learning activities for twelve weeks, while the control group received conventional instruction covering the same curriculum content.

Stage 3: Post-Test



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Following the intervention, students completed post-tests and engagement questionnaires.

Stage 4: Qualitative Data Collection

Classroom observations and interviews were conducted throughout the intervention period to provide contextual understanding of quantitative findings.

Data Analysis

Quantitative Analysis

Quantitative data were analyzed using IBM SPSS Statistics version 27.

The analysis included:

1. Descriptive statistics (mean and standard deviation);
2. Normality testing using the Shapiro–Wilk test;
3. Homogeneity testing using Levene’s Test;
4. Independent sample t-test;

Effect size analysis using Cohen’s d.

The significance level was established at $p < .05$.

Qualitative Analysis

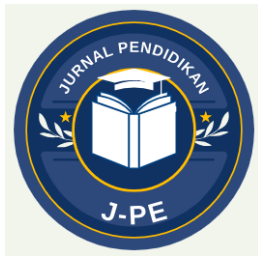
Qualitative data were analyzed using thematic analysis following Braun and Clarke’s (2006) six-step procedure:

1. Familiarization with data;
2. Initial coding;
3. Theme generation;
4. Theme review;
5. Theme definition;
6. Report writing.

Triangulation among observations, interviews, and quantitative findings was employed to enhance trustworthiness and credibility.

Ethical Considerations

Ethical approval was obtained from the participating schools prior to data collection. Written informed consent was obtained from parents, teachers, and school administrators. Participants were informed about the purpose of the study, confidentiality procedures, and their right to



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withdraw at any stage without consequences. All data were anonymized to ensure participant privacy and compliance with ethical standards for educational research.

RESULTS AND DISCUSSION

Result

Preliminary Analysis

Prior to hypothesis testing, assumption testing was conducted to ensure that the data met the requirements for parametric statistical analysis.

Variable	Group	W	p-value
Critical Literacy	Experimental	0.973	0.112
Critical Literacy	Control	0.968	0.084
Learning Engagement	Experimental	0.978	0.173
Learning Engagement	Control	0.971	0.097

Table 3. Normality Test Results (Shapiro–Wilk)

All p-values exceeded .05, indicating that the data were normally distributed.

Variable	Levene's F	p-value
Critical Literacy	1.421	0.236
Learning Engagement	1.106	0.295

Table 4. Homogeneity Test Results

The homogeneity test demonstrated that variance was equal across groups ($p > .05$), satisfying the assumptions for independent-sample t-tests.

Impact of AI-Assisted Learning on Critical Literacy

The first objective of the study was to examine the influence of AI-assisted learning on students' critical literacy achievement.

Group	N	Mean	SD
Experimental	64	82.40	5.80
Control	64	71.60	6.40

Table 5. Descriptive Statistics of Critical Literacy Scores

Students exposed to AI-assisted learning achieved substantially higher critical literacy scores than those receiving conventional instruction.

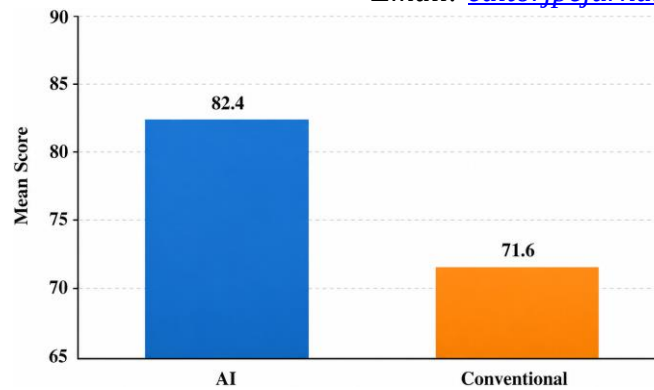
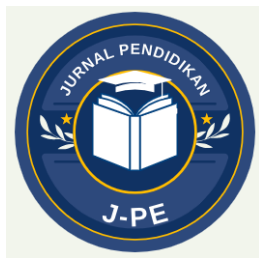


Figure 2. Critical Literacy Achievement Comparison

Variable	t	df	p	Cohen's d
Critical Literacy	10.05	126	< .001	1.76

Table 6. Independent Sample t-Test for Critical Literacy

The independent-sample t-test revealed a statistically significant difference between groups, $t(126) = 10.05$, $p < .001$. The effect size (Cohen's $d = 1.76$) indicated a very large educational effect.

To gain deeper insights, critical literacy was analyzed across four dimensions.

Dimension	Experimental	Control
Information Analysis	84.6	72.8
Evidence Evaluation	81.9	70.4
Bias Identification	80.8	69.7
Argument Construction	82.3	73.5

Table 7. Critical Literacy Dimensions

The greatest improvement was observed in information analysis and evidence evaluation, suggesting that AI-supported inquiry activities enhanced students' analytical abilities.

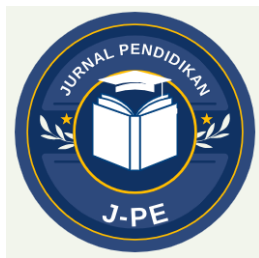
Impact of AI-Assisted Learning on Learning Engagement

The second objective focused on student engagement during AI-assisted learning.

Dimension	Experimental	Control
Behavioral Engagement	84.3	72.1
Emotional Engagement	81.7	70.8
Cognitive Engagement	86.5	73.4
Overall Engagement	84.2	72.1

Table 8. Learning Engagement Scores

Students in AI-assisted classrooms demonstrated higher engagement across all dimensions.



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Variable	t	df	p	Cohen's d
Learning Engagement	9.32	126	< .001	1.64

Table 9. Independent Sample t-Test for Learning Engagement

The results indicate a statistically significant difference in engagement levels between groups, with a large effect size.

Among the three dimensions, cognitive engagement achieved the highest score, indicating that students became more actively involved in critical thinking and knowledge construction processes during AI-assisted learning.

Development of 21st-Century Skills

The third objective examined the contribution of AI-assisted learning to students' twenty-first-century skills.

Skill	Mean Score
Critical Thinking	84.8
Creativity	81.5
Communication	79.7
Collaboration	78.9
Digital Literacy	85.2
Problem Solving	83.6

Table 10. Twenty-First-Century Skills Development

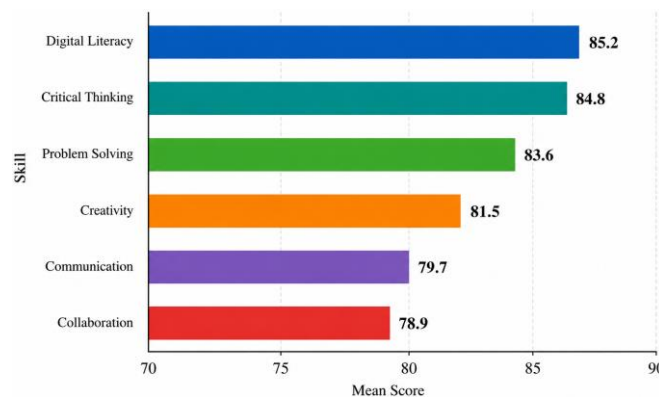
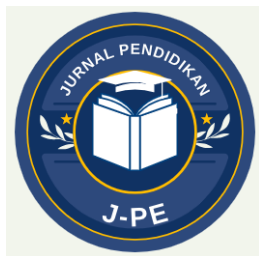


Figure 3. Twenty-First-Century Skills Profile

The highest score was observed in digital literacy, followed by critical thinking and problem-solving skills. These findings suggest that AI-assisted learning contributes substantially to students' preparedness for technology-rich learning environments.

Qualitative Findings



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Qualitative data from classroom observations and interviews provided further evidence supporting the quantitative findings.

Three major themes emerged.

Theme 1: Increased Learning Motivation

Students consistently reported that AI-assisted activities were enjoyable and engaging. Many participants expressed excitement about receiving immediate feedback and exploring multiple learning resources independently.

"When I ask questions, the AI gives answers immediately, so learning becomes more interesting and easier to understand." (Student 7)

Theme 2: Personalized Learning Support

Students appreciated the individualized learning experience enabled by AI technologies.

"I can learn according to my own pace and ask again when I do not understand something." (Student 12)

Teachers also reported that AI-assisted learning helped accommodate diverse learning needs within the classroom.

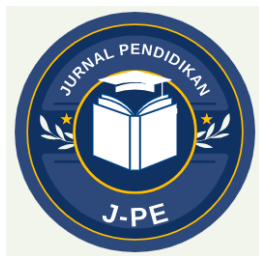
Theme 3: Enhanced Critical Thinking and Inquiry

Classroom observations revealed that students became more active in questioning information, comparing sources, and evaluating evidence.

"Students no longer accept information directly. They check, compare, and discuss information before making conclusions." (Teacher 3)

Integration of Quantitative and Qualitative Findings

The integration of quantitative and qualitative findings demonstrated strong convergence. Quantitative analyses revealed significant improvements in critical literacy, learning engagement, and twenty-first-century skills among students exposed to AI-assisted learning. These findings were reinforced by qualitative evidence indicating increased motivation, personalized learning experiences, and enhanced inquiry behaviors. The results suggest that AI-assisted learning functions as an effective pedagogical innovation capable of supporting literacy development, engagement, and future-ready competencies among primary school students in rural educational contexts.



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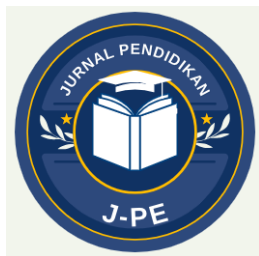
Discussion

The present study examined the impact of Artificial Intelligence (AI)-assisted learning on critical literacy, learning engagement, and 21st-century skills development among fifth-grade students in four public primary schools in Trenggalek Regency, Indonesia. The findings revealed that students who participated in AI-assisted learning significantly outperformed their peers in conventional classrooms across all measured outcomes. The quantitative findings demonstrated statistically significant improvements in critical literacy achievement, student engagement, and 21st-century competencies, while qualitative findings provided further evidence regarding students' learning experiences, motivation, and cognitive development. These findings contribute to the growing body of literature concerning the role of AI in primary education and provide empirical evidence from rural and semi-rural educational contexts that remain underrepresented in existing research.

AI-Assisted Learning as a Catalyst for Critical Literacy Development

One of the most significant findings of this study is the substantial improvement in students' critical literacy achievement following participation in AI-assisted learning activities. Students in the experimental group achieved significantly higher scores than those in the control group, with particularly strong performance in information analysis, evidence evaluation, bias identification, and argument construction. These findings suggest that AI-assisted learning environments can facilitate the development of critical literacy competencies by encouraging students to engage actively with information rather than passively consuming content.

The improvement in critical literacy can be explained through the lens of constructivist learning theory. According to Vygotsky (1978), learning occurs when individuals actively construct knowledge through interactions with their environment and more knowledgeable others. In AI-assisted learning environments, AI tools function as cognitive partners that provide scaffolding, feedback, and opportunities for inquiry. Students are encouraged to ask questions, compare information from multiple sources, evaluate evidence, and formulate reasoned conclusions. These activities align closely with the principles of critical literacy, which emphasize analysis, reflection, interpretation, and evaluation (Janks, 2010).



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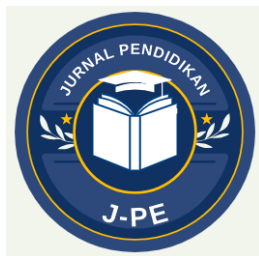
The findings also support UNESCO's (2023) argument that AI should be used not only as a source of information but also as a tool for developing critical thinking and information literacy. In the era of generative AI, students are increasingly exposed to automatically generated content that may contain inaccuracies, bias, or misinformation. Consequently, educational systems must prepare learners to evaluate information critically and make informed judgments. The current study demonstrates that AI-assisted learning can create opportunities for students to develop these essential competencies through guided inquiry and reflective learning processes.

Another possible explanation for the improvement in critical literacy relates to the personalized nature of AI-assisted learning. Unlike conventional classroom instruction, AI technologies provide immediate feedback and adaptive support tailored to individual learners' needs. Holmes et al. (2022) argue that personalized learning environments allow students to engage with content at an appropriate level of difficulty, thereby promoting deeper understanding and higher-order thinking. Students in this study frequently interacted with AI tools to clarify concepts, explore alternative perspectives, and refine their arguments, all of which contributed to enhanced literacy performance.

The findings are consistent with previous research indicating that AI-supported learning environments improve cognitive outcomes. Chen et al. (2020) found that AI-based educational systems significantly enhance academic achievement by providing personalized instructional pathways. Similarly, Zawacki-Richter et al. (2019) reported that AI applications can support analytical reasoning and problem-solving through adaptive feedback mechanisms. The large effect size observed in the present study suggests that these benefits extend beyond academic achievement and include broader literacy competencies that are increasingly important in contemporary digital societies.

Enhancing Student Engagement through Personalized Learning Experiences

A second major finding concerns the positive influence of AI-assisted learning on student engagement. The experimental group demonstrated significantly higher behavioral, emotional, and cognitive engagement compared to students receiving conventional instruction. Among these dimensions, cognitive engagement achieved the highest score, indicating that students became



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more intellectually invested in learning activities and demonstrated greater willingness to explore ideas, solve problems, and construct knowledge independently.

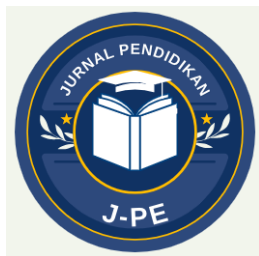
This finding can be interpreted through Self-Determination Theory (Ryan & Deci, 2020), which suggests that motivation increases when individuals experience autonomy, competence, and relatedness. AI-assisted learning environments provide opportunities for students to learn at their own pace, access personalized feedback, and explore topics of interest. These features support students' sense of autonomy and competence, thereby increasing intrinsic motivation and engagement.

Qualitative findings further reinforce this interpretation. Students consistently reported that AI-assisted learning was more enjoyable, interactive, and meaningful than conventional instruction. Many participants highlighted the value of receiving immediate responses to questions and being able to revisit explanations whenever necessary. Such experiences reduced frustration and increased confidence, resulting in greater participation during classroom activities.

The findings also align with Fredricks et al.'s (2004) multidimensional framework of engagement, which conceptualizes engagement as comprising behavioral, emotional, and cognitive components. AI-assisted learning appears to support all three dimensions simultaneously. Behaviorally, students participated more actively in classroom activities. Emotionally, they expressed greater interest and enjoyment. Cognitively, they demonstrated increased investment in problem-solving and critical inquiry.

Previous studies have similarly reported positive relationships between AI-supported learning and student engagement. Luckin et al. (2016) argued that intelligent educational systems can create highly responsive learning environments that adapt to learners' needs and preferences. Guan et al. (2020) found that AI-enhanced educational experiences promote active participation and sustained motivation. The present study extends these findings by demonstrating that such benefits are achievable even in rural and semi-rural educational contexts where technological innovation is often limited.

The importance of increased engagement should not be underestimated. Engagement is widely recognized as a key predictor of academic success, persistence, and lifelong learning (Fredricks et al., 2004). Therefore, the positive impact of AI-assisted learning on engagement may



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have long-term implications for students' educational trajectories and future academic performance.

AI-Assisted Learning and the Development of 21st-Century Skills

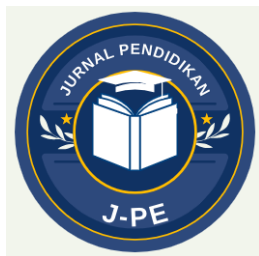
A third significant finding concerns the role of AI-assisted learning in promoting 21st-century skills development. Students demonstrated particularly strong performance in digital literacy, critical thinking, problem solving, creativity, communication, and collaboration. These findings suggest that AI-assisted learning contributes not only to subject-specific outcomes but also to broader competencies required for success in contemporary societies.

The results align closely with the Partnership for 21st Century Learning (2019) framework, which identifies critical thinking, creativity, communication, collaboration, and digital literacy as essential competencies for future citizens and workers. Through AI-assisted activities, students engaged in inquiry-based learning, evaluated information, generated solutions, communicated ideas, and collaborated with peers. These experiences provided authentic opportunities to practice and develop skills that extend beyond traditional academic achievement.

Digital literacy emerged as the highest-scoring competency. This outcome is particularly relevant given the increasing digitalization of education and society. OECD (2021) emphasizes that digital literacy is no longer optional but rather a foundational skill required for effective participation in modern communities. AI-assisted learning naturally requires students to interact with digital tools, evaluate online information, and navigate technology-rich environments, thereby strengthening digital competence.

The strong performance in critical thinking and problem-solving skills further highlights the educational value of AI integration. AI-assisted inquiry activities encouraged students to formulate questions, investigate problems, compare evidence, and justify conclusions. These processes align with higher-order cognitive skills identified in Bloom's revised taxonomy and contemporary competency frameworks. The findings support Voogt and Roblin's (2012) argument that technology-enhanced learning environments can promote the acquisition of complex cognitive competencies through authentic and collaborative learning experiences.

Creativity also emerged as an important outcome of AI-assisted learning. Students frequently used AI-generated prompts and project-based activities to generate ideas, explore alternatives, and



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produce original work. Fullan (2023) argues that educational innovation should focus on cultivating deep learning competencies, including creativity and innovation. The present findings suggest that AI technologies can serve as catalysts for creative thinking when integrated within pedagogically sound learning environments.

The Role of Personalized Learning as a Mediating Mechanism

The conceptual framework proposed that personalized learning experiences would mediate the relationship between AI-assisted learning and educational outcomes. The findings provide strong support for this assumption. Across quantitative and qualitative data sources, students repeatedly emphasized the value of individualized support, adaptive feedback, and self-paced learning opportunities.

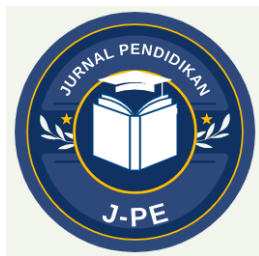
Personalized learning has long been recognized as an effective approach for addressing learner diversity and promoting educational equity (Holmes et al., 2022). Traditional classrooms often struggle to accommodate individual differences in prior knowledge, learning pace, and learning preferences. AI technologies address this challenge by providing adaptive learning pathways that respond dynamically to students' needs.

The qualitative evidence suggests that personalization contributed significantly to students' confidence, motivation, and willingness to engage in learning tasks. Students appreciated being able to revisit explanations, explore additional examples, and receive feedback tailored to their specific difficulties. Such experiences likely enhanced both engagement and achievement by reducing cognitive overload and supporting meaningful learning.

These findings reinforce previous research indicating that personalization is one of the most significant advantages of AI-assisted learning (Luckin et al., 2016). Rather than replacing teachers, AI technologies function as supportive tools that extend instructional capacity and facilitate individualized learning experiences.

Educational Implications

The findings of this study have several important implications for educational policy and practice. First, AI-assisted learning should be integrated strategically into primary education curricula as a means of promoting critical literacy and future-ready competencies. Educational institutions should move beyond viewing AI as merely a technological tool and instead recognize



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its potential as a pedagogical resource that supports inquiry, reflection, and knowledge construction.

Second, teacher professional development is essential for successful AI integration. Teachers require not only technical skills but also pedagogical knowledge regarding how AI can be used to support meaningful learning experiences. The Technological Pedagogical Content Knowledge (TPACK) framework emphasizes the importance of integrating technology, pedagogy, and subject matter expertise (Mishra & Koehler, 2006). Professional development initiatives should therefore focus on helping teachers develop these integrated competencies.

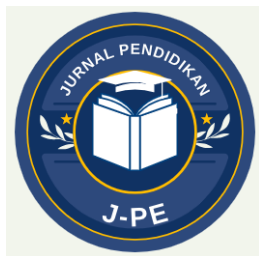
Third, policymakers should establish guidelines for the ethical and responsible use of AI in education. Issues related to data privacy, algorithmic bias, digital equity, and information accuracy must be addressed to ensure that AI technologies support rather than undermine educational goals.

Finally, the findings suggest that AI-assisted learning may offer particular benefits for rural and semi-rural educational contexts. By providing personalized support and access to diverse learning resources, AI technologies can help address some of the challenges associated with geographical isolation and resource limitations.

Limitations and Future Research

Despite its contributions, this study has several limitations. The sample was limited to four primary schools in a single regency, which may restrict the generalizability of findings. The intervention period was also relatively short, lasting only twelve weeks. Consequently, long-term effects of AI-assisted learning remain unclear.

Future research should examine longitudinal impacts of AI integration, compare different AI platforms, and investigate the role of teacher readiness in mediating educational outcomes. Researchers should also explore ethical considerations, student perceptions of AI trustworthiness, and the relationship between AI literacy and digital citizenship. Such investigations will contribute to a more comprehensive understanding of how AI can be integrated effectively and responsibly within primary education systems.



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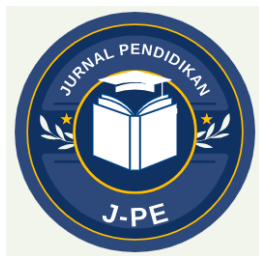
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CONCLUSION

This study examined the effectiveness of Artificial Intelligence (AI)-assisted learning in enhancing critical literacy, learning engagement, and 21st-century skills among fifth-grade students in four public primary schools in Trenggalek Regency, Indonesia. The findings provide compelling evidence that AI-assisted learning significantly improves educational outcomes compared to conventional instructional approaches. Students who participated in AI-supported learning environments achieved substantially higher critical literacy scores and demonstrated stronger abilities in information analysis, evidence evaluation, bias identification, and argument construction. In addition, AI-assisted learning positively influenced behavioral, emotional, and cognitive engagement, indicating that students became more actively involved in learning processes and more motivated to participate in classroom activities. The integration of quantitative and qualitative findings further revealed that AI technologies facilitated personalized learning experiences through adaptive support, immediate feedback, and self-paced learning opportunities. These features enabled students to engage more deeply with learning materials, develop higher-order thinking skills, and construct knowledge actively rather than passively receiving information. Furthermore, the study demonstrated that AI-assisted learning contributes significantly to the development of essential 21st-century competencies, including digital literacy, critical thinking, creativity, communication, collaboration, and problem-solving. These findings support contemporary educational theories emphasizing learner-centered instruction, constructivist learning, and personalized learning environments, while also extending existing research by providing empirical evidence from rural and semi-rural primary school contexts that have been underrepresented in the literature.

From a practical perspective, the findings highlight the substantial potential of AI-assisted learning as a strategic innovation for supporting educational transformation in primary schools. The results suggest that AI should not be viewed merely as a technological tool but as a pedagogical resource capable of fostering critical literacy, learner engagement, and future-ready competencies. Consequently, educational stakeholders should consider integrating AI technologies into primary education curricula while ensuring that implementation is guided by sound pedagogical principles and ethical considerations. Teachers require ongoing professional



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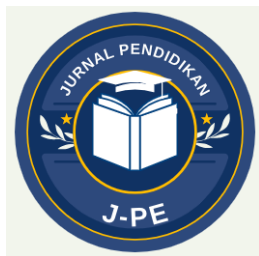
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development to effectively utilize AI tools in ways that promote inquiry, reflection, collaboration, and critical evaluation. Policymakers should also develop comprehensive frameworks addressing digital infrastructure, equitable access, data privacy, and responsible AI use to maximize educational benefits while minimizing potential risks. Although the study was limited to four schools and a twelve-week intervention period, its findings indicate that AI-assisted learning can play a significant role in reducing educational disparities and improving learning quality in rural educational settings. Future research should explore long-term impacts, compare different AI platforms and instructional models, investigate teacher readiness and digital competence, and examine the ethical implications of AI integration in schools. Such efforts will contribute to a more comprehensive understanding of how AI can be leveraged responsibly and effectively to prepare young learners for the challenges and opportunities of an increasingly digital world.

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