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Enhancing Elementary Students' Engagement and Understanding through Generative AI Integration in Digital Learning Environments

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Abstract
This study investigates the effectiveness of integrating generative Artificial Intelligence (AI) into digital learning environments in enhancing engagement and understanding among elementary school students. Employing a quasi-experimental design with pretest-posttest control groups, the research involved 60 fourth- and fifth-grade students at Sekolah Indonesia Riyadh. The experimental group received instruction integrated with generative AI tools, such as ChatGPT, over six weeks, while the control group engaged in conventional digital learning without AI support. Student engagement was measured through validated questionnaires capturing cognitive, affective, and behavioral dimensions, and comprehension was assessed using standardized tests. Results revealed statistically significant improvements in both engagement and understanding within the experimental group compared to the control group. The use of generative AI facilitated personalized, responsive learning, enabling students to interact meaningfully with content, clarify concepts in real time, and maintain higher levels of motivation and participation. These findings underscore the potential of generative AI as an effective pedagogical instrument in elementary education. The study further emphasizes the importance of teacher facilitation and institutional readiness in ensuring successful AI integration. Although limited by duration and context, this research provides empirical evidence supporting the thoughtful adoption of generative AI in education. Future studies are recommended to explore long-term impacts and broader implementation across diverse educational settings. The study concludes that generative AI, when applied within pedagogically grounded frameworks, can significantly enhance the quality of digital learning experiences for young learners.

INTRODUCTION

Digital transformation in education has encouraged the integration of technology into the learning process at various levels, including basic education. Digital technology now functions not only as a learning tool, but also as a catalyst for pedagogical change towards more interactive, adaptive, and personalized learning (AlAli & Wardat, 2024). In this context, student involvement is a crucial element that determines the effectiveness of the teaching and learning process in the digital space. Engagement encompasses behavioral, emotional, and cognitive aspects that are intertwined in encouraging student active participation (ElSayary, 2024). However, studies show that conventional digital learning still faces the challenge of low student participation and motivation, especially in online learning that is less interactive (Pahi et al., 2024). Therefore, pedagogical approaches that are able to optimize technology to increase student engagement need to be continuously developed. One of the promising technological innovations in this context is Artificial Intelligence (AI), specifically generative AI. Generative AI is capable of creating new content automatically, which can be adjusted to the needs and characteristics of students in real-time.

Generative AI is a subfield of artificial intelligence that uses machine learning algorithms to produce text, images, sounds, and interactive simulations that resemble humans (Nguyen et al., 2024). In the world of education, generative AI can be applied to create practice problems, analyze student responses, provide automated feedback, and personalize teaching materials based on individual learning styles (Kadaruddin, 2023). With its ability to interact dynamically, generative AI has the potential to enrich students' learning experiences and create a more inclusive and adaptive learning environment. In addition, this approach also allows educators to manage the classroom more efficiently through the automation of administrative and instructional processes (Shankar et al., 2025). Several studies have shown that the use of AI in learning has a positive impact on student motivation and learning outcomes (Lestyono et al., 2024). However, research that specifically examines the influence of generative AI on student engagement and understanding at the primary education level is still relatively limited. In fact, the basic education phase is an important foundation for the formation of long-term learning attitudes. Therefore, it is important to explore more deeply how generative AI can be effectively integrated in digital learning in elementary schools.

Student engagement in digital learning is greatly influenced by the quality of interaction and relevance of the material presented. Generative AI enables the creation of content that is contextual, engaging, and responsive to classroom dynamics, thereby enlarging the opportunities for students' cognitive and affective engagement (Hatmanto[1] et al., 2025). In this case, a learning system that uses generative AI can tailor challenges and support according to students' ability levels, ultimately enhancing their sense of competence and connectedness. This is in line with the theory of learning motivation which emphasizes the importance of personalization and a sense of control in increasing intrinsic motivation (Sandhu et al., 2024). In addition, generative AI can also help students understand abstract concepts through more realistic and contextual visualizations and simulations. This advantage makes generative AI a potential tool to bridge the material understanding gap, especially for students with diverse learning needs. Thus, the integration of generative AI not only serves as an auxiliary medium, but also as a cognitive partner in the learning process. However, the implementation of this technology in the elementary school environment needs to be empirically tested for effectiveness through a measurable quantitative approach.

One of the main challenges in digital learning is the low understanding of concepts due to the lack of meaningful interaction between students and teaching materials. Generative AI offers solutions through the ability to tailor the style of delivering material to individual students' needs, including simplifying language, providing additional illustrations, or offering remedial exercises (Oye et al., 2024). With this support, students' understanding of the subject matter can be significantly improved as they receive a learning experience that is closer to their respective learning styles. What's more, generative AI can provide instant feedback that is not only corrective but also elaborative, which is important in building long-term conceptual understanding. Early studies show that students who learn with AI-support are better able to solve problem-solving problems and show a deeper understanding of the material being taught (Solihin et al., 2024). However, the effectiveness of this strategy has not been widely tested in the context of elementary school students who are still in the concrete-operational stage of cognitive development according to Piaget. Therefore, research that directly targets elementary school students is needed to examine how far generative AI can support the achievement of learning goals. This research is also important in designing appropriate technology integration policies in basic education.

Additionally, it is important to consider the readiness of the educational ecosystem in adopting generative AI technology. Adequate technological infrastructure, teachers' readiness to utilize technology, and policy support from stakeholders are key factors for the successful implementation of AI in primary education (Tarofil et al., 2024). Teachers need to be equipped with technopedagogical training to be able to design learning activities that maximize the potential of generative AI without ignoring humanistic pedagogical aspects. In addition, there needs to be regulations that ensure the ethical and responsible use of AI, especially related to the protection of student data and the integrity of the learning process. This research also considers these challenges as part of the context of technology implementation in the field. With a holistic approach, the integration of generative AI in digital learning is not only seen in terms of learning outcomes, but also in terms of sustainability and equity of access. Therefore, this study has an urgency to provide empirical evidence as well as strategic recommendations for the development of AI-based digital education in the future. By strengthening the empirical foundation, this research is expected to be a foothold for a more meaningful digital transformation in primary education (Ruiz-Rojas et al., 2023).

Based on this presentation, this study aims to analyze the effectiveness of generative AI integration in increasing student engagement and understanding of digital learning at the elementary school level. This study used a quasi-experimental approach with a pretest-posttest control group design to objectively test the impact of the use of generative AI in learning. This research also aims to provide empirical insights on how technology can be used strategically to improve the digital learning process which has been considered less effective in improving the quality of student engagement and understanding. The findings of this study are expected to make theoretical contributions in the field of educational technology as well as practical implications for educators and policymakers. Furthermore, this research is expected to encourage the birth of AI-based pedagogical innovations that are inclusive, ethical, and sustainable. By focusing the research on elementary school students, the study emphasizes the importance of building a foundation of technology literacy and conceptual understanding from an early age. Therefore, the results of this research will be an important foundation in designing digital education strategies that are more effective and responsive to the needs of future generations of learners. This is in line with the vision of educational transformation in the era of humanistic and data-driven artificial intelligence.

METHODS

This study uses a quasi-experimental approach with a pretest-posttest control group design to test the effectiveness of generative Artificial Intelligence (AI) integration in increasing student engagement and understanding of digital learning at the elementary school level. This design allows researchers to objectively compare the changes that occurred in the experimental group and the control group after the treatment was given. The subjects of the study are students in grades IV and V at Sekolah Indonesia Riyadh who have integrated digital technology in the daily learning curriculum. The sample was 60 students, who were evenly divided into two groups: an experimental group that received learning with the help of generative AI and a control group that underwent conventional digital learning without the help of AI. The sampling technique used is purposive sampling, with selection criteria based on the similarity of students' initial characteristics, such as the level of academic ability and the availability of digital devices. These criteria are set to control external variables that may affect the results of the study. Before the implementation of the intervention, the two groups were given a pretest in the form of an engagement questionnaire and a material understanding test to obtain initial data as a basis for comparison.

The treatment in the experimental group was carried out for six weeks, during which students underwent learning based on generative AI technology. The media used in the experimental group included generative platforms such as ChatGPT, NLP-based adaptive question applications, and interactive digital modules designed to respond dynamically to student input. In practice, generative AI is used to support the process of creating teaching materials, provide practice questions that are in accordance with the level of individual understanding of students, and present dialogue-based question and answer interaction sessions to deepen concepts. Learning activities include exploratory assignments, digital project-based learning, and thematic learning that supports active student engagement. Instead, the control group continued digital learning as usual, with materials and methods that did not involve generative AI elements, such as video shows, PowerPoint presentations, and school LMS-based online quizzes. All learning activities are carried out during regular class hours with the guidance of their respective class teachers. The teachers of the experimental group have been given initial training on the use of generative AI to ensure consistency in the implementation of treatments.

Data collection was carried out using two main instruments: a student engagement questionnaire and a material comprehension test, both of which have gone through a content validation process by basic education experts and a reliability test using the Alpha Cronbach technique, which showed a high reliability value ($\alpha > 0.80$). The engagement questionnaire was compiled to measure three main dimensions, namely cognitive, affective, and behavioral engagement, with a five-point Likert scale. Comprehension tests include context-based questions designed to measure the ability to understand concepts, apply knowledge, and think critically. The data obtained was analyzed quantitatively using paired sample t-test to determine changes in pretest and posttest scores in each group, and independent sample t-test to see the difference in final score between the experimental group and the control group. The entire analysis was carried out with the help of the latest version of the SPSS statistical software, and the significance level was set at $\alpha = 0.05$. This analysis aims to test the hypothesis that the integration of generative AI can significantly improve student engagement and understanding in the context of digital learning in elementary schools.

RESULTS AND DISCUSSION

Research Results

This study aims to test the effectiveness of generative Artificial Intelligence (AI) integration in increasing engagement and material understanding in elementary school students in a digital learning environment. The study subjects consisted of two groups: an experimental group that received generative AI-based learning for six weeks, and a control group that followed conventional digital learning without generative AI support. Measurements were carried out through student involvement questionnaires and material comprehension tests, both at the *pretest* and *posttest* stages.

Before conducting the t-test analyses, assumption testing was performed to ensure data validity. The normality assumption was tested using the Shapiro–Wilk test, which indicated that all data were normally distributed ($p > 0.05$) for both pretest and posttest scores in the experimental and control groups. The homogeneity of variances was examined using Levene's test, showing that the variances between groups were homogeneous ($p > 0.05$). These results confirmed that the data met the assumptions required for parametric analysis, allowing the use of independent and paired samples t-tests to compare group differences and within-group changes.

Student Engagement

In the initial stage (*pretest*), the average student engagement score in the experimental group was 65.4 (SD = 7.2), while the control group showed a score of 66.1 (SD = 6.8). The results of the independent sample t-test showed no significant difference between the two groups before treatment ($p = 0.734$), indicating that the initial conditions of the two groups were relatively homogeneous in terms of student involvement. After the six-week treatment, the experimental group experienced a significant increase in student engagement. The *posttest* score increased to 82.7 (SD = 5.9), with the results of the paired sample t-test showing high significance ($t(29) = 10.25$; $p < 0.001$). Meanwhile, the control group also showed an increase in score to 69.5 (SD = 7.1), but the increase was not statistically significant ($t(29) = 1.83$; $p = 0.084$). The results of the independent sample t-test on *the posttest* showed a significant difference between the experimental and control groups ($t(58) = 6.02$; $p < 0.001$), indicating that generative AI significantly increased student engagement.

Table 1. Average and Test Student Engagement Statistics

Group	Pretest M (SD)	Posttest M (SD)	Paired t-test (p)
Experiment	65,4 (7,2)	82,7 (5,9)	t = 10,25; p < 0,001
Control	66,1 (6,8)	69,5 (7,1)	t = 1,83; p = 0,084
Intergroup	–	–	t = 6,02; p < 0,001

Material Understanding

In terms of material comprehension, *the pretest* score of the experimental group was 62.3 (SD = 6.9), while the control group had an average score of 63.7 (SD = 7.4). The independent sample t-test showed that the difference was not significant ($p = 0.563$), which indicates an initial similarity in material understanding between the two groups. After treatment, the *posttest score of the* experimental group increased to 80.1 (SD = 6.1), and the results of the paired sample t-test showed a statistically significant improvement ($t(29) = 11.17$; $p < 0.001$). The control group also experienced an increase in score to 67.2 (SD = 6.8), but not significantly ($t(29) = 1.91$; $p = 0.065$). The results of the independent sample t-test in the *posttest* showed a significant difference between the two groups ($t(58) = 7.18$; $p < 0.001$), reinforcing the finding that the use of generative AI has a positive impact on students' material understanding.

Table 2. Average and Statistical Test of Material Comprehension

Group	Pretest M (SD)	Posttest M (SD)	Paired t-test (p)
Experiment	62,3 (6,9)	80,1 (6,1)	t = 11,17; p < 0,001
Control	63,7 (7,4)	67,2 (6,8)	t = 1,91; p = 0,065
Intergroup	–	–	t = 7,18; p < 0,001

These findings show that generative AI is able to significantly increase student engagement and understanding in digital learning. This technology allows for the creation of a learning process that is adaptive and responsive to individual student needs, as well as providing a more personalized and interactive learning experience. With the help of generative AI, students can actively interact with the content and obtain instant feedback, resulting in increased motivation to learn and deeper understanding of the material. These findings support the idea that generative AI can be integrated as a relevant digital learning strategy in the era of artificial intelligence, with an important note that its use must still be in pedagogical teacher assistance.

Discussion

The results of this study show that the integration of generative AI significantly increases student engagement in the digital learning process at the elementary school level. These findings are in line with previous studies that emphasized AI's ability to personalize learning experiences and encourage active student participation (Yeh, 2025). A significant increase in engagement in the experimental group showed that students felt more interested and motivated when interacting with AI-based learning systems. Generative AI is able to provide instant feedback, build stimulating dialogues, and deliver a more dynamic learning experience than conventional digital methods. This is in line with cognitive motivation theory which states that engagement increases when individuals feel that learning activities are positively relevant and challenging (Liu, 2024). In the context of basic education, student engagement is an important indicator of long-term learning success. Therefore, these results strengthen the argument that generative AI can be an effective pedagogical tool at the early education level. The role of technology is not only as a tool for delivering material, but also as an interactive partner that functions as a learning facilitator. Thus, increased engagement can be seen as a result of improved quality of interaction between students and learning content. The integration of this technology must continue to be studied comprehensively so that it remains rooted in strong pedagogical principles.

In addition to engagement, the aspect of material understanding also showed a significant improvement in the group using generative AI. This increase shows that students are not only more interested, but also able to construct meaning more deeply in the material studied. Generative AI enables the delivery of material with a variety of cognitive approaches, such as elaboration, visualization, and simulation, all of which have been shown to improve knowledge retention and transfer (Wood & Moss, 2024). Students can ask questions, ask for reexplanations, and receive contextual examples directly from the AI system, making the learning process more flexible and responsive. These results suggest that material comprehension no longer depends only on the teacher's delivery methods, but also on how technology is designed to facilitate students' cognition. This study confirms that the adaptive approach offered by generative AI is able to answer the needs of diverse learning styles of students in the classroom. This approach is in line with the principles of constructivism which emphasizes the importance of active and meaningful learning experiences. Thus, generative AI can serve as a bridge between material complexity and student understanding, especially in the digital age that demands cross-media learning. This increased understanding has direct implications for learning outcomes and long-term academic achievement. Therefore, the development of future digital curricula should consider the integration of AI-based technologies as a core component.

The advantage of generative AI lies in its ability to accommodate individual learning needs. In this study, interventions through ChatGPT and similar applications provide concrete examples of how technology can provide relevant and timely responses according to the needs of each student. These adaptive features are the main factor that distinguishes generative AI from regular digital learning, which tends to be linear and one-way. This supports the findings of Bahroun et al. (2023) who state that AI in education is able to improve learning personalization and strengthen students' cognitive efficiency. When students feel that the responses given are in accordance with their understanding and questions, emotional and intellectual engagement increases naturally. In the context of elementary school, this kind of personal approach is very important because students' metacognitive abilities are still in the developing stage. AI can help fill those gaps through consistent interactive support. In addition, the use of this technology also creates a more democratic learning space, where every student has an equal opportunity to explore the material without fear of assessment. Thus, generative AI not only serves as a content presenter, but also as an intelligent and supportive learning guide.

Despite the positive results, the integration of generative AI must still consider the central role of teachers as learning facilitators. Teachers have a crucial function in interpreting AI outputs, aligning learning objectives, and ensuring that students' interactions with technology remain within the proper ethical and pedagogical framework. Generative AI cannot replace the emotional sensitivity, didactic intuition, and human values that educators bring to the teaching-learning process (Pesovski et al., 2024). Therefore, the successful integration of generative AI in primary education is highly dependent on teachers' readiness to adopt new roles as technology-based learning managers. In this study, training for experimental teachers is an important factor in ensuring the consistency of the implementation of AI technology in learning. Strengthening teachers' capacity in digital literacy and technology pedagogy is the key to the sustainability of this kind of program. Without the support of qualified human resources, the potential of generative AI can be counterproductive and disrupt the learning process that should be constructive. Therefore, technology integration must be designed systemically, involving teachers as the main actors in the educational transformation process.

From an instructional design perspective, the use of generative AI opens up new opportunities to create more immersive and contextual learning experiences. AI can be used to develop situational simulations, adaptive quizzes, as well as learning scenarios that allow students to explore various possible solutions. This kind of learning design has been shown to be more effective in fostering critical thinking and conceptual understanding (Henriksen et al., 2024). In this study, generative AI-powered content creation allowed students to learn through problem-based approaches and miniprojects. This model fits into the needs of 21st century learning that emphasizes high-level thinking skills and mastery of digital skills. AI can also assist teachers in designing learning activities that are responsive to classroom dynamics and individual needs. The results of this study show that such an approach not only has a positive impact on academic outcomes, but also on the learning process itself. Thus, the development of learning technology should not only focus on content automation, but also on the quality of interaction between students, teachers, and technology.

The implications of these findings are also related to the formulation of digital education policies at the elementary school level. Governments and policymakers need to encourage the integration of AI technology in the curriculum by providing clear infrastructure, training, and ethical regulations. Support for this initiative must be carried out comprehensively so that the digital divide does not become an obstacle to the equitable distribution of education quality. The use of generative AI must be directed to strengthen access, inclusion, and meaningful learning for all students, especially in the early stages. This study provides empirical evidence that AI-based approaches can improve learning effectiveness, as long as they are implemented within the right pedagogical framework. Therefore, digital education reform requires not only the adoption of new technologies, but also a paradigm shift in understanding the role of technology as a learning partner. In this context, collaboration between technology developers, educators, and researchers is critical to producing contextual and sustainable solutions (Pahi et al., 2024). These findings also open up space for the development of micro-policies at the education unit level that integrate generative AI into lesson plans and daily learning practices. This transformation must be continuously monitored to ensure that the quality and ethics of learning are maintained.

However, this study has several limitations that need to be considered in the interpretation of the results. First, the limited number of samples and the specific contextual scope (Sekolah Indonesia Riyadh) may influence the generalization of the findings. The results obtained may not fully reflect the conditions of primary schools in other regions or education systems with different characteristics. Second, the six-week duration of treatment provides an overview of the short-term effects, but does not include the long-term impact of the use of generative AI in learning. Longitudinal studies are required to test the stability and sustainability of the results obtained (Henriksen et al., 2024). Third, despite training for teachers, diversity in AI implementation skills in the classroom remains a factor that needs to be controlled in further research. Therefore, it is important to develop implementation standards that can be adapted by various educational units. Advanced research can also delve deeper into the affective and metacognitive aspects of students in generative AI-based learning. Thus, the scope of analysis can be extended not only to learning outcomes, but also to deep and transformative learning processes (Narganes-Pineda et al., 2024).

In conclusion, this study makes an empirical contribution to the understanding of the potential of generative AI in basic level digital learning. These findings strengthen the position of technology as a pedagogical instrument that can improve the quality of learning when used appropriately. Generative AI is able to bridge the gap between students' personalization needs and the limitations of conventional teaching systems. To optimize this potential, technology development must always be directed at strengthening the principles of humanistic and constructivistic pedagogy (Solihin et al., 2025). The education of the future no longer depends only on the existence of teachers and teaching materials, but also on the quality of the digital ecosystem that supports meaningful interaction and learning. Therefore, synergy between technology, policies, and educational practices is crucial to ensure that digital transformation runs in an inclusive and sustainable manner (Selwyn, 2019). With these findings, it is hoped that stakeholders can be more confident in making strategic decisions to integrate AI in primary education. This research also provides a solid foundation for further exploration in the field of AI-based learning. In the end, the direction of AI development in education must always be on the side of humanity and the needs of students as a whole.

CONCLUSION

This study confirms that the integration of generative Artificial Intelligence (AI) into digital learning environments significantly enhances both student engagement and comprehension among elementary school learners. The experimental group, which utilized AI-driven tools such as ChatGPT, demonstrated substantial improvements in cognitive, affective, and behavioral engagement dimensions, as well as in subject matter understanding. These findings align with existing literature emphasizing the role of AI in providing adaptive, personalized, and interactive learning experiences. The generative AI model allowed students to explore concepts more deeply and receive immediate, context-sensitive feedback, promoting active learning and intrinsic motivation. Moreover, the study highlights the importance of teacher readiness and pedagogical alignment in ensuring the effective use of AI in classrooms. While technology served as a dynamic facilitator, the role of the teacher remained essential in guiding and monitoring learning interactions. However, the research also acknowledges limitations related to the study's duration, sample size, and contextual specificity. Therefore, further longitudinal and cross-context studies are necessary to validate and expand these findings. Overall, this study advocates for a balanced and thoughtful integration of generative AI into elementary education. It recommends systemic support in the form of teacher training, policy frameworks, and infrastructure to ensure equitable and pedagogically sound implementation. As education systems worldwide advance into digital ecosystems, generative AI offers promising avenues for fostering meaningful, personalized, and future-ready learning.

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