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Enhancing Elementary Students' Social Science Learning Outcomes through Technology-Integrated STEM Learning

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Abstract: This study aims to investigates the effect of technology-integrated STEM learning on elementary students' social science studies learning outcomes. A quasi-experimental design with a pretest-posttest control group was employed, involving 40 fifth-grade students divided into an experimental group and a control group. The experimental group received STEM instruction integrated with digital technologies, including PhET Interactive Simulations, LabXplore, Social science Digital Lab, YouTube Kids, EduTV, Padlet, and Google Slides, while the control group received conventional STEM instruction. Data were analyzed using descriptive statistics, Shapiro-Wilk normality test, Levene's homogeneity test, independent samples t-test, N-Gain analysis, and Cohen's d effect size. The results showed that the experimental group achieved a higher posttest mean score than the control group. The N-Gain score of the experimental group (moderate) was higher than the control group (low), with a statistically significant difference. The effect size analysis indicated a large effect, demonstrating a substantial impact of the intervention. These findings concluded that technology-integrated STEM learning significantly improves students' conceptual understanding and engagement. The integration of interactive digital tools provides meaningful learning experiences that support scientific literacy and 21st century skills development in elementary education.

Keywords: elementary education; learning outcomes; social science; STEM learning; technology integration

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Introduction

The transformation of 21st-century education requires students to develop a range of competencies, including critical thinking, scientific literacy, collaboration, and problem-solving skills that can be applied in real-world contexts (Wardani & Fiorintina, 2023; Chetry, 2024). These competencies are essential for enabling learners to respond effectively to increasingly complex social, technological, and environmental challenges. Therefore, elementary education should not focus solely on the acquisition of factual knowledge but also emphasize the development of higher-order thinking skills and meaningful learning experiences. To support the mastery of these competencies, learning at the elementary level needs to be designed in an integrative, contextual, and experience-based manner, allowing students to actively construct knowledge through exploration, inquiry, and authentic problem-solving activities (Garg et al., 2026; Bonite et al., 2026; Subhan, 2025). One educational approach that aligns closely with these demands is STEM (Science, Technology, Engineering, and Mathematics)-based learning. The STEM approach promotes interdisciplinary integration by connecting concepts across multiple domains and encouraging students to apply their knowledge to solve practical problems. Through this process, students are guided to develop deeper conceptual understanding, scientific reasoning, creativity, and innovation while strengthening their ability to relate theoretical knowledge to real-life situations (Bybee, 2013; Johnson et al., 2023). As a result, STEM-based learning is increasingly recognized as an effective framework for preparing elementary students to meet the educational and workforce demands of the twenty-first century.

The implementation of STEM learning in Indonesia has been introduced across various educational levels, including elementary schools, particularly in the social science subject. As part of the *Merdeka*

Curriculum, social science subject integrates natural and social science concepts using a scientific approach that is relevant to students' real-life contexts (Uslan et al., 2025). However, its classroom implementation still faces several challenges. Teachers tend to rely on lecture based and one-way instructional methods, while students struggle to understand abstract concepts such as ecosystems, energy flow, and the interrelationships among biotic and abiotic components (Sabel et al, 2023; Thomas, 2024). To address these challenges, integrating technology into STEM learning has emerged as a promising solution (Tan et al, 2023). Alam & Mohanty (2023) argue that technology not only serves as a visualization tool but also creates an interactive and exploratory learning environment that facilitates students' independent knowledge construction. Digital simulations, educational animation videos, and virtual experiment applications can help students visualize complex scientific phenomena (Durkaya, 2023; Teplá et al., 2022) and enhance learning engagement. Research conducted by Alalwan (2022) demonstrated that the use of digital media in STEM learning significantly improved students' engagement and science learning outcomes.

Nevertheless, there is still limited research at the elementary level that explicitly integrates technology into STEM learning within the context of social science subject, particularly regarding the topic of biotic and abiotic component relationships in ecosystems. In fact, students' understanding of ecosystem interconnections is an essential part of the Learning Outcomes for Phase C in the *Merdeka* Curriculum. Therefore, this study focuses on integrating technology into STEM learning to improve elementary students' social science subject learning outcomes, emphasizing the understanding of biotic abiotic relationships and their impact on ecosystem balance. Despite the growing body of research on STEM education, studies focusing on the integration of technology in STEM learning at the elementary school level, particularly within the context of IPAS learning in Indonesia, remain limited. Furthermore, previous studies have not sufficiently explored how interactive digital tools can enhance students' understanding of ecosystem relationships involving biotic and abiotic components (Yao et al., 2023; Martín-Gámez et al., 2020; Hayes et al., 2017). Therefore, this study aims to address this gap. This study seeks to answer the following research question: Does technology-integrated STEM learning significantly improve elementary students' social science subject learning outcome s compared to conventional STEM learning?

This study contributes to the growing body of STEM education research by providing empirical evidence on the implementation of STEM-based learning in elementary school contexts and its potential to foster essential 21st-century competencies. Unlike many previous studies that focus primarily on cognitive achievement, this research highlights how STEM learning can create meaningful and contextual learning experiences that encourage students to actively engage in inquiry, collaboration, and problem-solving processes. The study also offers practical insights for teachers in designing interdisciplinary learning activities that connect scientific concepts with authentic real-life situations. Furthermore, the findings contribute to the development of innovative instructional practices that support the goals of contemporary education, particularly in preparing elementary students to become critical thinkers, scientifically literate individuals, and lifelong learners capable of responding to future challenges. Therefore, this study aims to investigates the effect of technology-integrated STEM learning on elementary students' social science studies learning outcomes.

Methods

This study employed a quantitative quasi-experimental method (Creswell, 2009) using a pretest-posttest control group design. This design was selected because it allows researchers to compare learning outcomes between groups while examining changes that occur before and after the intervention. The use of a quasi-experimental approach was considered appropriate due to the practical limitations of randomly assigning students to different classes in a school setting. Through the administration of pretests and posttests, the researchers were able to measure the effectiveness of the instructional treatment more accurately. Two parallel classes from one elementary school were selected through purposive sampling based on predetermined criteria relevant to the objectives of the study. The experimental group received technology-integrated STEM learning that incorporated digital tools and interactive learning activities to support student engagement and problem-solving skills.

The participants were 40 fifth-grade elementary school students (aged 10–11 years) from a public elementary school. This age group was considered appropriate because students at this developmental stage are capable of engaging in inquiry-based activities and collaborative problem-solving tasks commonly associated with STEM education. The sample was selected using purposive sampling to ensure that both groups had similar academic characteristics and learning conditions prior to the implementation of the intervention. Several factors were considered during the selection process, including students' previous academic performance, classroom environment, and accessibility to learning resources. Two parallel classes were assigned as the experimental and control groups to maintain consistency in instructional settings and minimize potential confounding variables. The use of parallel classes also helped preserve the natural classroom structure and reduced disruptions to regular school activities. Furthermore, selecting students from the same school ensured that both groups experienced similar institutional policies, curricular requirements, and educational contexts.

The learning process in the experimental group was designed based on the STEM learning syntax, consisting of five stages: Stimulation, Problem Definition, Exploration, Explanation, and Reflection & Engineering Design. The technologies used included PhET Interactive Simulations, LabXplore, IPAS Digital Lab, YouTube Kids, EduTV, Google Slides, Padlet, and Canva for Education. These technologies were selected to support conceptual understanding, inquiry-based learning, and student collaboration. Technologies used in the experimental group included: 1) PhET Interactive Simulations (Riastuti, et al, 2023); 2) LabXplore and IPAS Digital Lab for virtual experiments (Verawati & Purwoko. 2024); 3) YouTube Kids and EduTV for animated learning videos (Khubayi, et al, 2024); 4) Google Slides and Padlet for collaborative presentations and reflections (Abdulaziz, 2021).

The learning intervention in the experimental class was implemented using a technology-integrated STEM approach structured around five learning stages: Stimulation, Problem Definition, Exploration, Explanation, and Reflection. The learning process began with the stimulation stage, during which students watched educational animated videos from YouTube Kids and EduTV illustrating various ecosystem environments, including forests, rivers, and grasslands, as well as the interactions among plants, animals, soil, water, and sunlight. These videos were used to stimulate curiosity and encourage students to generate questions related to ecosystem balance, such as the consequences of plant loss in grasslands, river pollution on fish populations, and the influence of water, light, and soil on living organisms. Following a teacher-led discussion, students' questions were documented using a Padlet digital whiteboard. In the problem definition stage, students identified ecosystem-related problems presented in the videos, particularly those involving disruptions to food chains and ecosystem balance. Students worked collaboratively in small groups and completed Google Slides-based worksheets throughout the investigation process. Each group member was assigned a specific role, including observer, recorder, presenter, and digital researcher, while investigating contextual questions concerning temperature changes, water scarcity, and the role of sunlight within ecosystems.

The exploration stage involved virtual investigations using PhET Simulations and the IPAS Digital Lab. Through the "Ecosystems" simulation available on PhET, students manipulated ecosystem components by adding or removing organisms and observing the resulting effects on population dynamics. In addition, students utilized LabXplore to simulate photosynthesis and water-cycle processes by modifying variables such as light intensity and water availability to examine their effects on plant growth. Observations were systematically recorded in digital observation tables to support data-driven analysis. Subsequently, during the explanation stage, students discussed their findings and developed digital infographics or presentations using Google Slides or Canva for Education, presenting simulation results, relationships between biotic and abiotic components, and conclusions regarding ecosystem balance and imbalance. The learning sequence concluded with reflection and engineering design activities, during which students responded to open-ended questions about the role of technology in understanding ecosystems and strategies for maintaining ecosystem balance in their school environment. As a final project, students designed digital environmental conservation campaign posters using Padlet or Google Jamboard, integrating science, technology, and design elements. All technologies employed in this study, including PhET, YouTube EduTV, LabXplore, IPAS Digital Lab, Padlet, Google Slides, and Canva, were intentionally selected to support the achievement of Phase C IPAS learning objectives, promote conceptual understanding through interactive digital experimentation, and develop students' scientific skills, collaboration, communication, and technological literacy. Therefore, the technology-integrated STEM approach implemented in this study was measurable, relevant, and fully aligned with curriculum requirements.

The instruments used in this study included: (1) an social sceince learning outcomes test, (2) a student activity observation sheet, and (3) a teacher implementation fidelity observation sheet. All instruments were developed based on the learning objectives of social science learning Phase C, focusing on ecosystem concepts, particularly the relationships between biotic and abiotic components. The IPAS learning outcomes test was administered as both a pretest and posttest and consisted of 16 multiple-choice items with four answer options. The items measured cognitive levels ranging from C2 to C4, including identifying, explaining, analyzing, and concluding. Each correct answer was scored as 1 and incorrect answers as 0, resulting in a total score range of 0-16, which was then converted into a scale of 0-100. The student activity observation sheet consisted of 10 indicators across 5 aspects, namely participation, use of technology, project completion, curiosity, and collaboration. Each indicator was assessed using a 4-point Likert scale (1 = not observed to 4 = highly observed). Observations were conducted during the learning process by two observers.

The teacher implementation fidelity observation sheet included 10 indicators grouped into 5 aspects, such as adherence to STEM learning stages, use of digital technology, classroom management, responsiveness, and reflection. Each indicator was rated using a 4-point scale and supported by qualitative notes. The instruments were developed through a systematic process, including alignment with curriculum objectives, preparation of instrument blueprints, and item construction. Content validity was established through expert judgment involving education and STEM specialists. Reliability testing was conducted using Cronbach's Alpha for the test instrument and Cohen's Kappa for inter-observer agreement, indicating that the instruments were valid and reliable.

To ensure the quality of the instruments, both validity and reliability analyses were conducted prior to their use in the study. The validity of the IPAS learning outcomes test was examined using the Pearson Product-Moment correlation by correlating each item score with the total test score. Items with correlation coefficients (r-count) greater than the critical value of r-table at a significance level of 0.05 were considered valid. Based on the analysis, all selected items met the validity criteria and were retained for use in the pretest and posttest. The reliability of the test instrument was assessed using Cronbach's Alpha, which measures internal consistency. The analysis showed that the instrument achieved a reliability coefficient of $\alpha > 0.70$, indicating that the test was reliable and suitable for measuring students' learning outcomes. For the observation instruments (student activity and teacher implementation fidelity), content validity was established through expert judgment involving specialists in elementary education and STEM learning. In addition, inter-observer reliability was evaluated using Cohen's Kappa to measure the level of agreement between observers. The results indicated a high level of agreement (Kappa > 0.75), suggesting that the observation instruments were reliable.

The collected data were analyzed using both descriptive and inferential statistical techniques to comprehensively evaluate the effectiveness of the learning intervention. Descriptive statistics were employed to summarize and present students' learning outcomes, providing an overview of their performance before and after the implementation of the instructional treatment. To ensure that the data met the assumptions required for parametric analysis, inferential statistical procedures were conducted, including the Shapiro–Wilk test to assess data normality and Levene's test to examine the homogeneity of variances between groups. After confirming that these assumptions were satisfied, an independent samples t-test was performed to determine whether there were statistically significant differences in learning outcomes between the experimental and control groups. Furthermore, N-Gain analysis was utilized to measure the magnitude of students' learning improvement from pretest to posttest, thereby indicating the effectiveness of the intervention in enhancing conceptual understanding. To complement the significance testing, Cohen's d was calculated to determine the effect size of the treatment and evaluate the practical significance of the intervention. Together, these analyses provided a comprehensive assessment of both the statistical and educational impact of the implemented learning approach.

Result and Discussion

Descriptive Statistics

The descriptive analysis revealed that students who participated in technology-integrated STEM learning achieved better learning outcomes than those who experienced conventional instruction. The experimental class obtained a mean posttest score of 77.90 (SD = 8.87), whereas the control class achieved a mean score of only 59.30 (SD = 8.41). Similarly, the N-Gain analysis demonstrated a greater improvement in learning outcomes among students in the experimental class. The experimental group achieved an average N-Gain score of 0.37, which falls within the moderate category, with scores ranging from 0.31 to 0.50. In contrast, the control group obtained an average N-Gain score of 0.10, categorized as low, with scores ranging from 0.01 to 0.18. These findings indicate that technology-integrated STEM learning was more effective in facilitating students' conceptual understanding and promoting learning improvement than conventional teaching methods.

Prior to conducting hypothesis testing, assumption tests were performed to verify the suitability of the data for parametric statistical analysis. The normality test using the Shapiro–Wilk method showed significance values of 0.562 for the experimental class and 0.421 for the control class, both exceeding the threshold value of 0.05. These results indicate that the data were normally distributed. Furthermore, the homogeneity test using Levene's statistic produced a significance value of 0.395, which was also greater than 0.05, confirming that the variances of the two groups were homogeneous. Since both assumptions of normality and homogeneity were satisfied, the data met the requirements for conducting an independent samples t-test to compare the learning gains of the experimental and control groups.

The results of the independent samples t-test revealed a statistically significant difference in learning improvement between the two groups. The experimental class achieved a mean N-Gain score of 0.37, while the control class obtained a mean score of 0.10, resulting in a mean difference of 0.27. The statistical analysis yielded a t-value of 11.27 with 38 degrees of freedom and a significance value of $p < 0.001$, indicating that the observed difference was highly significant. These findings demonstrate that technology-integrated STEM learning had a significant positive effect on elementary students' social science learning outcomes. Moreover, the calculated effect size was exceptionally large (Cohen's d = 3.90), indicating that the impact of the intervention was not only statistically significant but also practically meaningful (**Table 1**). This substantial effect suggests that technology-integrated STEM learning provides a strong instructional advantage over conventional approaches, particularly in enhancing students' conceptual understanding, active engagement, and overall learning performance.

Table 1. Statistic Descriptive Results

Analysis	Indicator	Experimental Class	Control Class	Statistical Result
Descriptive Statistics	Posttest Mean (SD)	77.90 (8.87)	59.30 (8.41)	-
N-Gain Analysis	Mean N-Gain	0.37	0.10	-
	Min–Max N-Gain	0.31–0.50	0.01–0.18	-
Normality Test (Shapiro–Wilk)	Sig. Value	0.562	0.421	p > 0.05
Homogeneity Test (Levene's)	Sig. Value	-	-	0.395
Independent Samples t-Test	Mean N-Gain	0.37	0.10	t = 11.27; df = 38; p < 0.001
	Mean Difference	0.27	-	-
Effect Size	Cohen's d	3.90	-	Large effect

Learning Activities During Each Stage

Stage 1 - Stimulation (Initial Stimulation)

At the beginning of the lesson, students were introduced to the topic of ecosystems through educational animated videos from YouTube Kids and EduTV. These videos presented visual depictions of various natural environments such as forests, rivers, and grasslands, showing how plants, animals, soil, water, and sunlight interact to form balanced ecosystems. The purpose of this stage was to stimulate curiosity and activate students' prior knowledge. The teacher guided students to observe and reflect on the video content by posing inquiry questions such as "What happens if there are no plants in the grassland?", "Why do fish die when the river becomes polluted?", and "Do water, light, and soil affect living organisms?" After watching the videos, students engaged in a light classroom discussion facilitated by the teacher, while their ideas and questions were collaboratively recorded on a digital whiteboard (Padlet). This activity helped establish the foundation for the following investigative stages by encouraging students to think critically about real world ecological phenomena.

Stage 2 - Problem Definition

In this stage, students were encouraged to identify and define ecosystem related problems based on the phenomena observed in the videos. Examples of such problems included food chain disruptions caused by the loss of one species or environmental changes affecting plant growth. The teacher divided students into small collaborative groups and provided Google Slides based digital worksheets as tools for documenting their ideas, hypotheses, and planned investigations. Each member in the group was assigned a specific role observer, recorder, presenter, or digital researcher to promote responsibility and collaboration. The groups analyzed specific issues such as how temperature changes affect plant growth, the impact of water scarcity on ecosystems, and the role of sunlight in sustaining producers. This stage encouraged students to engage in problem identification, analytical thinking, and teamwork, laying the groundwork for the experimental exploration phase.

Stage 3 Exploration (Digital and Virtual Exploration)

During the exploration phase, students conducted digital and virtual experiments using Simulations and the IPAS Digital Lab. These platforms allowed students to manipulate ecosystem variables safely and observe dynamic outcomes. In the PhET "Ecosystems" simulation, students experimented by adding or removing living organisms and observing how changes in one species affected the populations of others. Using LabXplore, students simulated photosynthesis and the water cycle by adjusting light intensity and water levels to observe their impact on virtual plant growth. Throughout this process, students recorded their observations in digital data tables, documenting how disruptions in one ecosystem component influenced the overall system balance. This stage provided opportunities for hands on digital inquiry, allowing students to test hypotheses, analyze data, and connect virtual experiences with real world ecological concepts.

Stage 4 - Explanation

After completing their experiments, students entered the explanation stage, where they synthesized and communicated their findings. Each group discussed the results of their simulations, analyzed patterns, and drew conclusions about the relationships between biotic and abiotic components in ecosystems. Using Google Slides and Canva for Education, students collaboratively designed digital infographics and presentations that visually represented their findings. The presentations included simulation screenshots, graphs of population changes, and diagrams showing ecosystem interdependencies. Each group then presented their work to the class, engaging in peer feedback and teacher guided discussions. This stage strengthened students' abilities to analyze data, articulate scientific reasoning, and use digital tools to communicate evidence-based conclusions.

Stage 5 - Reflection & Engineering Design

In the final stage, students participated in a guided reflection session led by the teacher. Open ended questions such as "What role did technology play in helping you understand ecosystems?" and "How can we maintain ecosystem balance in our school environment?" encouraged students to connect their learning with broader environmental and ethical issues. As a culminating task, students designed digital environmental conservation campaign posters using Padlet or Google Jamboard. These projects integrated science, design, and technology elements to convey messages about ecosystem preservation. This activity not only fostered creativity and environmental awareness but also reinforced the principles of engineering design—identifying problems, designing solutions, and communicating outcomes effectively.

Throughout all stages, the technologies used PhET, YouTube EduTV, LabXplore, IPAS Digital Lab, Padlet, Google Slides, and Canva for Education were strategically integrated to: 1) Directly support the achievement of Phase C IPAS learning outcomes; 2) Enhance conceptual understanding through digital experiments and interactive simulations, and; 3) Develop scientific, collaborative, communicative, and technological literacy skills among students. This structured, technology enhanced STEM learning process provided a dynamic and engaging environment that fostered inquiry-based exploration and meaningful learning experiences in accordance with the Merdeka Curriculum framework.

Discussion

The findings of this study demonstrate that integrating technology into STEM learning has a significant and positive impact on students' social science learning outcomes. Students in the experimental class exhibited higher conceptual understanding, engagement, and active participation compared to those in the control group. This result aligns with the principles of constructivist learning theory (Efgivia et al., 2021), which posits that meaningful learning occurs when learners actively construct knowledge through authentic, interactive, and technology supported experiences rather than passively receiving information. Technological tools such as PhET Interactive Simulations, LabXplore, and animated science videos enabled students to visualize abstract scientific phenomena, perform virtual experiments safely, and engage in reflective discussions. These findings are consistent with research by (Riastuti et al., 2023; Verawati & Purwoko, 2024; Khubayi et al., 2024; Abdulaziz, 2021) who reported that digital media integration enhances students' scientific understanding. Furthermore, visual and interactive media stimulate multisensory engagement, allowing learners to connect theoretical knowledge with real world phenomena (Adiningtyas, 2026; Chisunum & Nwadiokwu, 2024). This connection is essential in developing scientific literacy and critical thinking skills, both of which are key competencies emphasized in 21st century education (Rahayu, 2017).

The positive effect observed can also be explained through the lens of Cognitive Load Theory, which suggests that well designed digital tools can help reduce extraneous cognitive load by simplifying complex information through visualization and simulation. By observing dynamic models of ecosystems, students could comprehend interrelationships between biotic and abiotic components more efficiently than through text-based explanations alone. This process supports deeper understanding and longer retention of scientific concepts (Ibrahim et al., 2025 Marougkas, et al., 2023). Moreover, the interactive and collaborative digital environment fostered by tools such as Padlet and Google Slides encouraged students to communicate, share, and evaluate ideas collectively. These digital platforms provided real time feedback (Yu et al., 2023) and opportunities for peer learning, which, according to Vygotsky's social constructivist framework (Saleem et al., 2021), play an essential role in knowledge construction through social interaction and scaffolding. The combination of individual exploration and group collaboration in a digital context nurtured not only cognitive skills but also socio emotional competencies (Morrison, 2024), including teamwork, communication, and digital citizenship.

The increase in student motivation, focus, and participation can be attributed to the sense of autonomy and ownership created by technology rich learning environments. Digital simulations and virtual experiments allowed students to manipulate variables, test hypotheses, and observe outcomes instantly, which enhanced their inquiry-based learning experiences. This finding aligns with studies by Baratov (2026); Papalazarou et al. (2024); and Bybee (2013), which emphasize that technology integration within STEM frameworks encourages inquiry, creativity, and problem-solving abilities skills that are indispensable for future learning and innovation. However, the success of technology integrated STEM learning cannot be separated from several contextual factors (Sokha, 2024; Johnson & Czernia, 2023). The study also highlights that teacher readiness, digital literacy, and adequate school infrastructure are crucial for effective implementation. Teachers must possess not only pedagogical knowledge but also technological competence to design, manage, and assess digital based learning effectively. Schools must also ensure stable internet access, functional devices, and ongoing professional development to sustain the integration of educational technology.

These findings are consistent with previous international studies indicating that technology-supported STEM learning enhances students' conceptual understanding and engagement. For instance, Alalwan (2022) reported that the use of digital media significantly improves student participation and learning outcomes, while Durkaya (2023) highlighted the effectiveness of virtual laboratories in facilitating deeper scientific understanding. Similar findings have been observed across various educational contexts, suggesting that digital simulations and virtual experiments provide meaningful opportunities for inquiry-based learning. Such technologies enable students to actively explore scientific concepts, visualize abstract phenomena, and engage in problem-solving processes, thereby supporting more effective and student-centered learning experiences.

In addition, while the results indicate significant improvement in learning outcomes, further research is needed to explore the long-term effects of technology integration on students' higher order thinking skills, problem solving abilities, and environmental awareness. Qualitative investigations, such as classroom observations and student interviews, could provide deeper insights into how digital tools influence cognitive and affective learning processes. Overall, this study reinforces the growing body of evidence that technology integrated STEM learning not only enhances academic achievement but also cultivates essential 21st century competencies. By combining scientific inquiry with technological innovation, educators can create engaging, inclusive, and transformative learning experiences that prepare students to navigate the challenges of an increasingly digital and interconnected world.

The findings of this study have important implications for elementary education, particularly in demonstrating that technology-integrated STEM learning can effectively enhance students' conceptual understanding, engagement, and overall learning outcomes in social science learning. The positive results suggest that integrating digital technologies with STEM-based instructional strategies provides meaningful and contextual learning experiences that support the development of essential 21st-century competencies. These findings may serve as a reference for teachers, curriculum developers, and policymakers seeking to implement innovative learning approaches that promote active participation and deeper understanding among elementary school students. However, several limitations should be acknowledged when interpreting the results. First, the sample size was relatively small and limited to one elementary school, which may restrict the generalizability of the findings to broader educational contexts. Second, the study primarily examined short-term learning outcomes and did not investigate long-term retention of knowledge or the development of higher-order thinking skills. Third, the research relied predominantly on quantitative data, which may not fully capture students' perceptions, experiences, and learning processes during the intervention. Therefore, future studies are recommended to involve larger and more diverse participant groups, employ mixed-method approaches, and explore the long-term impacts of technology-integrated STEM learning to provide a more comprehensive understanding of its effectiveness in elementary education.

Conclusion

The findings of this study demonstrate that technology-integrated STEM learning effectively improves elementary students' social science learning outcomes by providing interactive, inquiry-based, and meaningful learning experiences through simulations, virtual experiments, and digital collaboration platforms. The approach not only enhanced students' conceptual understanding of ecological relationships between biotic and abiotic components but also fostered scientific literacy, digital competence, collaboration, and learning motivation. These results indicate that the integration of digital technology within STEM learning can support the implementation of the Merdeka Curriculum by promoting contextual, student-centered, and 21st-century learning. Therefore, schools and educators should be encouraged to systematically adopt technology-integrated STEM practices, supported by adequate infrastructure and continuous teacher professional development. Nevertheless, future research is needed to investigate the long-term effects of this approach on higher-order thinking skills, creativity, environmental awareness, and knowledge retention, as well as to examine its effectiveness across different grade levels, subject areas, and educational contexts. Overall, technology-integrated STEM learning offers a promising pathway for strengthening elementary education and preparing students to meet the challenges of an increasingly digital and complex world.

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