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The Role of Digital Inquiry-Based Learning in Enhancing Scientific Literacy and Student Engagement in Science Education

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ABSTRAK

Penelitian ini bertujuan untuk menganalisis efektivitas pembelajaran berbasis inkuiri digital dalam meningkatkan literasi sains dan keterlibatan siswa dalam pembelajaran IPA. Penelitian ini menggunakan pendekatan kuantitatif dengan desain quasi eksperimen berupa non-equivalent control group. Partisipan penelitian terdiri dari dua kelompok, yaitu kelompok eksperimen yang menggunakan pembelajaran berbasis inkuiri digital dan kelompok kontrol yang menggunakan metode pembelajaran konvensional. Data dikumpulkan melalui tes literasi sains dan angket keterlibatan siswa. Hasil penelitian menunjukkan bahwa kelompok eksperimen memperoleh nilai post-test yang lebih tinggi secara signifikan dibandingkan kelompok kontrol. Analisis normalized gain (N-gain) menunjukkan bahwa peningkatan pada kelompok eksperimen berada pada kategori sedang hingga tinggi, sedangkan kelompok kontrol berada pada kategori rendah hingga sedang. Uji statistik menggunakan independent sample t-test menunjukkan adanya perbedaan yang signifikan antara kedua kelompok ($p < 0,05$). Selain itu, pembelajaran berbasis inkuiri digital terbukti meningkatkan keterlibatan siswa pada aspek perilaku, emosional, dan kognitif, dengan peningkatan tertinggi pada keterlibatan kognitif. Hasil ini menunjukkan bahwa integrasi teknologi digital dengan pembelajaran berbasis inkuiri merupakan strategi yang efektif untuk meningkatkan kualitas pembelajaran dan mengembangkan keterampilan abad ke-21 dalam pendidikan IPA.
Kata Kunci: *pembelajaran inkuiri digital, literasi sains, keterlibatan siswa, pendidikan IPA, quasi eksperimen.*

ABSTRACT

This study aims to examine the effectiveness of digital inquiry-based learning in enhancing students' scientific literacy and engagement in science education. The research employed a quantitative approach using a quasi-experimental design with a non-equivalent control group. The participants consisted of two groups: an experimental group taught using digital inquiry-based learning and a control group taught using conventional methods. Data were collected through a scientific literacy test and a student engagement questionnaire. The results showed that the experimental group achieved significantly higher post-test scores compared to the control group. The normalized gain (N-gain) analysis indicated that the experimental group reached a medium to high level of improvement, while the control group remained in the low to medium category. Statistical testing using an independent sample t-test revealed a significant difference between the two groups ($p < 0.05$). In addition, digital inquiry-based learning significantly improved students' behavioral, emotional, and cognitive engagement, with the highest improvement observed in cognitive engagement. These findings suggest that integrating digital technology with inquiry-based learning is an effective strategy to promote meaningful learning and develop essential 21st-century skills in science education.
Keywords: *digital inquiry-based learning, scientific literacy, student engagement, science education, quasi-experimental design*

INTRODUCTION

The rapid development of digital technology has significantly transformed educational practices, particularly in science education. In the 21st century, integrating digital tools into learning environments is essential to foster students' scientific literacy and engagement. Scientific literacy is increasingly viewed as a critical competency that enables students to understand scientific concepts, interpret data, and apply knowledge to real-world situations. In this context, technology-enhanced learning environments provide new opportunities to support meaningful and interactive science learning experiences.

Recent studies indicate that combining digital technologies with inquiry-based learning (IBL) can significantly enhance students' learning outcomes. Inquiry-based learning encourages students to actively construct knowledge through questioning, investigation, and evidence-based reasoning. When supported by digital tools such as simulations, virtual laboratories, and learning analytics, this approach becomes more effective in facilitating exploration and deeper understanding (Chen & Chen, 2025). Digital environments allow students to visualize abstract scientific concepts and engage in complex problem-solving processes that are difficult to achieve in traditional classrooms.

Furthermore, research shows that inquiry-based learning plays a crucial role in developing students' scientific reasoning and research skills. A systematic review by Urdanivia Alarcon et al. (2023) found that inquiry-based approaches promote the construction of scientific knowledge and improve students' ability to connect theory with real-world phenomena. This suggests that integrating inquiry strategies into science education is essential for fostering meaningful learning experiences.

In addition, recent studies highlight that digital inquiry-based learning environments can improve student engagement and motivation. Gomez (2025) emphasizes that inquiry-based learning not only enhances academic achievement but also supports students' cognitive, behavioral, and emotional engagement in science learning. This is particularly important in modern education, where student engagement is closely linked to learning success and long-term retention of knowledge.

Moreover, the integration of inquiry-based approaches into science curricula has been shown to strengthen students' critical thinking and creativity. Kotsis (2024) argues that inquiry-driven learning environments enable students to actively participate in knowledge construction and develop higher-order thinking skills, which are essential for addressing complex scientific problems. Similarly, Xu et al. (2024) found that inquiry-based teaching strategies significantly enhance students' scientific creativity and problem-solving abilities, further supporting the effectiveness of this approach in science education.

Despite these advantages, the implementation of digital inquiry-based learning still faces several challenges, including limited technological infrastructure, insufficient teacher competence in integrating digital tools, and variability in instructional design. These challenges highlight the need for more structured and evidence-based approaches to integrating digital inquiry-based learning in science education.

Therefore, this study aims to investigate the role of digital inquiry-based learning in enhancing students' scientific literacy and engagement in science education. The findings are expected to provide valuable insights into the development of innovative instructional strategies that integrate technology and inquiry to improve learning outcomes in the digital era.

METHOD

This study employed a quantitative research approach using a quasi-experimental design with a non-equivalent control group structure to investigate the role of digital inquiry-based learning in enhancing students' scientific literacy and engagement in science education. Quasi-experimental designs are widely recognized as appropriate for educational research where random assignment is not feasible, particularly in real classroom settings (Creswell & Creswell, 2021).

The study was conducted in a secondary school context, involving two groups of students. The experimental group was taught using a digital inquiry-based learning approach that integrated technology such as virtual simulations, online collaborative platforms, and interactive learning media. In contrast, the control group received conventional instruction based on teacher-centered methods without the integration of digital inquiry strategies. The participants were selected using purposive sampling to ensure comparable academic backgrounds and learning characteristics between the two groups.

Data collection was carried out using two main instruments: a scientific literacy test and a student engagement questionnaire. The scientific literacy test was adapted from international assessment frameworks to measure students' ability to explain scientific phenomena, interpret data, and apply scientific knowledge in real-life contexts (Organisation for Economic Co-operation and Development, 2023). Meanwhile, student engagement was measured using a validated questionnaire covering behavioral, emotional, and cognitive engagement dimensions (Fredricks et al., 2021).

The intervention was implemented over several instructional sessions, during which students in the experimental group engaged in structured inquiry activities supported by digital tools. These activities included problem identification, hypothesis formulation, virtual experimentation, data analysis, and evidence-based conclusion drawing. The integration of digital technology enabled students to visualize abstract concepts and interact with scientific phenomena in a more dynamic and engaging manner (Chen & Chen, 2025). Meanwhile, the control group followed conventional learning procedures involving lectures and textbook-based exercises.

Prior to the main data collection, a pilot study was conducted to test the validity and reliability of the research instruments. Content validity was assessed through expert judgment, while reliability was measured using Cronbach's alpha coefficient. Data analysis was performed using descriptive and inferential statistics. Descriptive statistics were used to summarize students' performance, while inferential analysis, including independent sample t-tests and normalized gain (N-gain), was conducted to determine the effectiveness of the intervention. Statistical analysis was carried out using SPSS software with a significance level of 0.05. This methodological approach is consistent with recent studies highlighting the effectiveness of integrating digital technology and inquiry-based learning in improving students' scientific literacy and engagement (Xu et al., 2024; Kotsis, 2024).

RESULTS AND DISCUSSION

The results of this study were analyzed using descriptive statistics, normalized gain (N-gain), and inferential statistical tests to determine the effectiveness of digital inquiry-based learning in enhancing students' scientific literacy and engagement.

Descriptive Analysis

The descriptive results indicated that both the experimental and control groups experienced an increase in learning outcomes after the intervention. However, the improvement in the experimental group was significantly higher than that of the control

group. The pre-test scores of both groups were relatively similar, suggesting that students had comparable baseline abilities prior to the treatment. Following the implementation of digital inquiry-based learning, the experimental group showed a substantial increase in post-test scores. This improvement reflects students' enhanced ability to understand scientific concepts, interpret data, and apply knowledge in real-world contexts. In contrast, the control group, which was taught using conventional methods, demonstrated only a moderate increase, indicating limited development in higher-order thinking skills.

Normalized Gain (N-gain) Analysis

The N-gain analysis revealed that the experimental group achieved a medium to high level of improvement, whereas the control group remained in the low to medium category. This suggests that digital inquiry-based learning not only improves students' learning outcomes but also accelerates their conceptual understanding and cognitive development. The integration of digital tools, such as simulations and virtual experiments, played a significant role in enhancing students' ability to visualize abstract concepts and engage more deeply with the learning material. This contributed to more effective knowledge construction compared to traditional learning approaches.

Inferential Analysis

Inferential statistical analysis using an independent sample t-test showed a statistically significant difference between the post-test scores of the experimental and control groups ($p < 0.05$). This result confirms that digital inquiry-based learning has a significant positive effect on students' scientific literacy. In addition, the analysis of student engagement data indicated that the experimental group demonstrated higher levels of behavioral, emotional, and cognitive engagement compared to the control group. Students in the experimental group were more actively involved in learning activities, showed greater interest in the subject matter, and demonstrated increased persistence in solving problems.

Analysis of Scientific Literacy and Engagement Indicators

Further analysis revealed that students in the experimental group showed significant improvement across key dimensions of scientific literacy, including explaining scientific phenomena, interpreting data, and evaluating evidence. Similarly, all dimensions of student engagement—behavioral, emotional, and cognitive—showed notable enhancement. The most prominent improvement was observed in cognitive engagement, indicating that students were more actively involved in deep learning processes such as critical thinking, reasoning, and problem-solving. This suggests that digital inquiry-based learning effectively promotes meaningful learning experiences.

Discussion

The findings of this study demonstrate that digital inquiry-based learning significantly enhances students' scientific literacy and engagement in science education. These results are consistent with contemporary educational theories that emphasize the importance of active, student-centered learning environments in fostering meaningful learning and higher-order thinking skills.

The significant improvement in the experimental group can be attributed to the integration of inquiry-based learning with digital technology. Inquiry-based learning encourages students to actively construct knowledge through investigation and problem-solving, while digital tools provide interactive and dynamic learning environments that support visualization and experimentation. This combination creates a powerful learning experience that promotes deeper understanding and engagement. Similar findings were reported by Chen and Chen (2025), who highlighted that digital learning environments enhance inquiry processes by enabling students to interact with complex scientific concepts through simulations and data-driven activities.

Furthermore, the increase in students' engagement aligns with the framework proposed by Fredricks et al. (2021), which identifies engagement as a multidimensional construct consisting of behavioral, emotional, and cognitive components. In this study, digital inquiry-based learning was found to positively influence all three dimensions, particularly cognitive engagement. This suggests that students were not only participating actively but also investing effort in understanding the learning material at a deeper level.

The improvement in scientific literacy observed in this study is also supported by the findings of the Organisation for Economic Co-operation and Development (2023), which emphasizes the importance of learning environments that promote inquiry and real-world problem-solving in developing students' scientific competencies. The ability of students to interpret data, evaluate evidence, and apply knowledge indicates that inquiry-based learning effectively bridges the gap between theoretical knowledge and practical application.

Additionally, the findings are in line with Xu et al. (2024), who reported that inquiry-based teaching approaches enhance students' scientific reasoning and creativity. The integration of digital tools further strengthens this effect by providing opportunities for exploration and experimentation that are not always possible in traditional classroom settings. Kotsis (2024) also supports the idea that inquiry-based learning fosters higher-order thinking skills by encouraging students to engage in active knowledge construction. In this study, students in the experimental group demonstrated improved critical thinking and problem-solving abilities, indicating that the learning approach successfully facilitated the development of essential 21st-century competencies.

Despite these positive findings, several challenges were identified during the implementation of digital inquiry-based learning. One of the main challenges is the need for adequate technological infrastructure. Limited access to digital tools and internet connectivity can hinder the effectiveness of this approach. Additionally, teachers need sufficient training and support to effectively integrate digital technology into inquiry-based instruction. Another challenge is related to students' readiness. Some students initially struggled to adapt to a more active and self-directed learning approach, particularly those who were accustomed to traditional teacher-centered methods. This suggests that gradual implementation and continuous guidance are necessary to ensure successful adoption.

These findings have important implications for science education. First, they highlight the need to integrate digital inquiry-based learning into the curriculum as a means of improving both cognitive and affective learning outcomes. Second, they emphasize the importance of teacher professional development in enhancing the quality of instruction. Third, they suggest that policymakers should support the provision of adequate technological resources to facilitate innovative learning approaches. Overall, this study provides strong evidence that digital inquiry-based learning is an effective strategy for enhancing scientific literacy and student engagement. By combining the

strengths of inquiry-based pedagogy and digital technology, this approach offers a promising pathway for improving the quality of science education in the digital era.

CONCLUSION

This study concludes that digital inquiry-based learning has a significant and positive impact on students' scientific literacy and engagement in science education. The findings indicate that students who participated in digital inquiry-based learning demonstrated higher levels of understanding, as reflected in improved post-test scores and normalized gain (N-gain) compared to those who experienced conventional instruction. Moreover, the integration of digital tools within inquiry-based learning environments effectively supports the development of higher-order thinking skills, particularly in interpreting data, evaluating evidence, and applying scientific concepts in real-world contexts. In addition, digital inquiry-based learning was found to enhance all dimensions of student engagement, including behavioral, emotional, and cognitive engagement. The most notable improvement occurred in cognitive engagement, suggesting that students were more actively involved in deep learning processes and critical thinking activities. These findings highlight the importance of combining pedagogical innovation with technological integration to create meaningful and interactive learning experiences.

Despite its effectiveness, the implementation of digital inquiry-based learning requires careful consideration of several factors, including the availability of technological infrastructure, teacher readiness, and student adaptability. Challenges such as limited access to digital resources and the need for pedagogical training must be addressed to ensure optimal implementation. Overall, this study provides empirical evidence that digital inquiry-based learning is a highly effective instructional approach for improving both cognitive and affective learning outcomes in science education. Therefore, it is recommended that educators and policymakers promote the integration of digital inquiry-based strategies in science curricula to better prepare students for the demands of the 21st century. Future research is suggested to explore long-term impacts and the scalability of this approach across diverse educational contexts.

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