

Integrating STEM-Oriented Inquiry-Based Learning to Improve Scientific Literacy and Problem-Solving Skills in Secondary Science Education

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ABSTRAK

Penelitian ini bertujuan untuk menganalisis efektivitas pembelajaran berbasis inkuiri berorientasi STEM dalam meningkatkan literasi sains dan keterampilan pemecahan masalah siswa pada pembelajaran IPA di tingkat sekolah menengah. 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 berorientasi STEM dan kelompok kontrol yang menggunakan metode pembelajaran konvensional. Data dikumpulkan melalui tes literasi sains dan tes keterampilan pemecahan masalah. 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 berorientasi STEM terbukti meningkatkan kemampuan siswa dalam mengidentifikasi masalah, mengembangkan strategi, serta mengevaluasi solusi. Hasil ini menunjukkan bahwa integrasi pendekatan STEM dengan pembelajaran berbasis inkuiri merupakan strategi yang efektif untuk meningkatkan kualitas pembelajaran dan mengembangkan keterampilan abad ke-21 dalam pendidikan IPA.

Kata Kunci: *pembelajaran STEM, pembelajaran berbasis inkuiri, literasi sains, keterampilan pemecahan masalah, pendidikan IPA.*

ABSTRACT

This study aims to examine the effectiveness of STEM-oriented inquiry-based learning in improving students' scientific literacy and problem-solving skills in secondary 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 STEM-oriented inquiry-based learning and a control group taught using conventional methods. Data were collected through a scientific literacy test and a problem-solving skills test. 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 ($p < 0.05$). Furthermore, STEM-oriented inquiry-based learning was found to enhance students' abilities in problem identification, strategy development, and evaluation of solutions. These findings suggest that integrating STEM approaches with inquiry-based learning is an effective strategy to promote meaningful learning and develop essential 21st-century skills in science education.

Keywords: *STEM-oriented learning, inquiry-based learning, scientific literacy, problem-solving skills, science education.*



INTRODUCTION

Science education in the 21st century is increasingly oriented toward preparing students with competencies that go beyond conceptual understanding, including scientific literacy and problem-solving skills (Öztürk, 2023). Scientific literacy is considered a fundamental outcome of science education, as it enables students to interpret scientific information, make evidence-based decisions, and apply knowledge in real-world contexts (Kumar & Choudhary, 2025). The growing complexity of global challenges, such as environmental issues and technological advancement, requires students to develop not only knowledge but also the ability to think critically and solve problems effectively (Shutaleva, 2023).

Recent educational reforms emphasize the integration of Science, Technology, Engineering, and Mathematics (STEM) approaches into science learning to support the development of these competencies (Ortiz-Revilla et al., 2022). STEM-oriented learning encourages interdisciplinary understanding and promotes the application of knowledge in authentic contexts (Yang et al., 2026). In this regard, inquiry-based learning (IBL) has emerged as a key pedagogical strategy that aligns well with STEM principles (Gomez, 2025). Inquiry-based learning emphasizes active student involvement in questioning, investigating, and constructing knowledge through evidence-based reasoning, which is essential for developing scientific thinking skills (Arifin et al., 2025).

A systematic review by Urdanivia Alarcon et al. (2023) highlights that inquiry-based learning plays a significant role in fostering scientific reasoning and knowledge construction. The study found that students engaged in inquiry-based learning demonstrate higher levels of understanding and are better able to connect theoretical concepts with real-world phenomena (Karakoc et al., 2025). Furthermore, the integration of inquiry approaches with technology and STEM-based activities has become increasingly prominent, reflecting the evolving nature of science education in the digital era.

In addition, recent research indicates that integrating digital tools within inquiry-based learning environments can further enhance students' scientific literacy. A systematic review by Ramli and Borhan (2024) found that digital inquiry-based learning supports students in visualizing abstract concepts, engaging in interactive learning, and improving their understanding of scientific processes. The study also emphasizes that combining digital tools with inquiry strategies leads to more effective learning experiences and improved student outcomes (Lee, 2023).

Moreover, empirical evidence shows that digital inquiry-based science learning can improve students' conceptual understanding and engagement. Kamarudin and Mat Noor (2024) found that the implementation of digital inquiry-based learning in science classrooms supports active learning, encourages independent thinking, and enhances students' ability to connect prior knowledge with new concepts. Their findings also highlight the importance of scaffolding and technological support in ensuring the effectiveness of inquiry-based instruction.

Despite these advantages, the implementation of STEM-oriented inquiry-based learning still faces several challenges. These include limited teacher readiness, insufficient integration of interdisciplinary content, and constraints in classroom practices. Additionally, students may experience difficulties in adapting to inquiry-based environments that require active participation and self-directed learning. These challenges indicate the need for more structured and well-designed instructional strategies that effectively integrate STEM and inquiry-based approaches.

Therefore, this study aims to investigate the effectiveness of integrating STEM-oriented inquiry-based learning in improving students' scientific literacy and problem-solving skills in secondary science education. This research is expected to contribute to the development of innovative instructional models that align with the demands of 21st-century education and provide practical insights for educators in implementing effective science teaching strategies.

METHOD

This study employed a quantitative research approach using a quasi-experimental design with a non-equivalent control group to examine the effectiveness of STEM-oriented inquiry-based learning in improving students' scientific literacy and problem-solving skills. This design is appropriate for educational research conducted in natural classroom settings where random assignment is not feasible, allowing researchers to compare learning outcomes between groups while maintaining ecological validity (Creswell & Creswell, 2021).

The study was conducted in a secondary school context, involving two groups of students. The experimental group received instruction through STEM-oriented inquiry-based learning, which integrates science concepts with technology, engineering, and mathematics through structured inquiry activities. These activities included problem identification, design-based investigation, experimentation, data analysis, and solution development. Meanwhile, the control group was taught using conventional teacher-centered approaches focusing on lectures and textbook-based exercises. Participants were selected using purposive sampling to ensure similar academic backgrounds and learning characteristics between groups.

Data collection was carried out using two primary instruments: a scientific literacy test and a problem-solving skills test. The scientific literacy test was adapted from international assessment frameworks to measure students' ability to explain scientific phenomena, interpret data, and evaluate evidence (Organisation for Economic Co-operation and Development, 2023). The problem-solving skills test was designed based on indicators such as problem identification, strategy development, implementation, and evaluation of solutions. Both instruments were validated through expert judgment and pilot testing to ensure their validity and reliability.

The intervention was implemented over several instructional sessions, during which students in the experimental group engaged in STEM-oriented inquiry activities supported by contextual and real-world problems. This approach emphasizes interdisciplinary learning and encourages students to apply scientific knowledge in practical situations. Previous studies have shown that integrating STEM with inquiry-based learning enhances students' reasoning and problem-solving abilities by providing authentic and meaningful learning experiences (Urdanivia Alarcon et al., 2023; Ramli & Borhan, 2024).

Before the main data collection, a pilot study was conducted to test the instruments. Reliability analysis was performed using Cronbach's alpha coefficient to ensure internal consistency. Data analysis included descriptive statistics to summarize students' performance and inferential statistics, such as independent sample t-tests and normalized gain (N-gain), to determine the effectiveness of the intervention. Statistical analysis was conducted using SPSS software with a significance level of 0.05. This methodological approach is consistent with recent research emphasizing the effectiveness of STEM-integrated inquiry-based learning in improving students' higher-order thinking skills and scientific competencies (Kamarudin & Mat Noor, 2024).

RESULTS AND DISCUSSION

The results of this study were analyzed using descriptive statistics, normalized gain (N-gain), and inferential statistical tests to evaluate the effectiveness of STEM-oriented inquiry-based learning in improving students' scientific literacy and problem-solving skills.

Descriptive Analysis

The descriptive findings revealed that both the experimental and control groups showed improvement in post-test scores compared to pre-test results. However, the magnitude of improvement differed significantly between the two groups. The experimental group, which was exposed to STEM-oriented inquiry-based learning, demonstrated a higher increase in mean scores than the control group, which received conventional instruction. The similarity in pre-test scores between the groups indicates that students had comparable initial abilities. After the intervention, the experimental group showed a substantial improvement in both scientific literacy and problem-solving performance. This suggests that the integration of STEM and inquiry-based learning provides a more effective learning environment for developing students' understanding and skills.

Normalized Gain (N-gain) Analysis

The N-gain analysis further supports these findings, showing that the experimental group achieved a medium to high level of improvement, while the control group remained in the low to medium category. This indicates that STEM-oriented inquiry-based learning not only enhances students' learning outcomes but also accelerates their cognitive development and conceptual understanding. The interdisciplinary nature of STEM learning allows students to connect knowledge across domains, while inquiry-based activities encourage active exploration and problem-solving. This combination contributes to more meaningful learning experiences and improved knowledge retention.

Inferential Analysis

The results of the independent sample t-test revealed a statistically significant difference between the experimental and control groups ($p < 0.05$). This confirms that the implementation of STEM-oriented inquiry-based learning has a significant positive effect on students' scientific literacy and problem-solving skills. In addition, effect size analysis indicated a moderate to high impact, suggesting that the intervention had a meaningful practical effect on student learning outcomes. This highlights the effectiveness of integrating STEM and inquiry-based approaches in science education.

Analysis of Scientific Literacy and Problem-Solving Indicators

Further analysis of scientific literacy indicators showed significant improvements in students' ability to explain scientific phenomena, interpret data, and evaluate evidence. Similarly, problem-solving skills improved across all indicators, including problem identification, strategy development, solution implementation, and evaluation. The most significant improvement was observed in strategy development and evaluation, indicating that students became more capable of designing effective solutions and critically assessing their outcomes. This reflects the impact of inquiry-based learning in promoting higher-order thinking skills.

Discussion

The findings of this study demonstrate that STEM-oriented inquiry-based learning significantly enhances students' scientific literacy and problem-solving skills. These results are consistent with constructivist learning theory, which emphasizes that knowledge is actively constructed through experience and interaction with the environment. The significant improvement observed in the experimental group can be

attributed to the integration of STEM and inquiry-based learning, which promotes active engagement and interdisciplinary understanding. Students are not only required to understand scientific concepts but also to apply them in solving real-world problems. This aligns with the findings of Urdanivia Alarcon et al. (2023), who reported that inquiry-based learning enhances students' ability to construct knowledge and connect theoretical concepts with practical applications.

Furthermore, the improvement in problem-solving skills supports previous research indicating that STEM education fosters critical thinking and analytical reasoning. Ramli and Borhan (2024) emphasized that integrating digital tools and inquiry-based strategies in STEM learning environments enhances students' ability to analyze problems, develop solutions, and evaluate outcomes effectively. The results also align with Kamarudin and Mat Noor (2024), who found that inquiry-based science learning encourages active participation and independent thinking. In this study, students in the experimental group demonstrated greater engagement in designing investigations and evaluating solutions, which contributed to the development of their problem-solving abilities.

In addition, the interdisciplinary nature of STEM learning plays a crucial role in enhancing students' cognitive flexibility. By integrating concepts from science, technology, engineering, and mathematics, students are able to approach problems from multiple perspectives. This supports the argument that STEM-oriented learning environments are more effective in preparing students for complex real-world challenges. Despite these positive outcomes, several challenges were identified during the implementation of STEM-oriented inquiry-based learning. One major challenge is the need for adequate instructional time, as inquiry-based and STEM activities require more time for exploration and discussion compared to traditional methods. This finding is consistent with previous studies highlighting time constraints as a common barrier in implementing student-centered learning approaches.

Another challenge relates to teacher readiness. Effective implementation of STEM-oriented inquiry-based learning requires teachers to possess interdisciplinary knowledge and strong facilitation skills. Without proper training and support, teachers may find it difficult to design and implement effective inquiry-based STEM activities. Additionally, some students initially faced difficulties in adapting to inquiry-based learning environments, particularly in terms of independent thinking and problem-solving. This suggests that gradual implementation and continuous scaffolding are necessary to support students in developing these skills.

These findings have important implications for science education. First, they highlight the importance of integrating STEM and inquiry-based learning to improve both cognitive and practical competencies. Second, they emphasize the need for professional development programs to enhance teachers' ability to implement innovative instructional strategies. Third, they suggest that curriculum design should incorporate interdisciplinary and inquiry-based approaches to better align with the demands of 21st-century education. Overall, this study provides strong evidence that STEM-oriented inquiry-based learning is an effective approach for improving students' scientific literacy and problem-solving skills. By promoting active learning, interdisciplinary understanding, and real-world application, this approach contributes significantly to the advancement of science education.

CONCLUSION

This study concludes that the implementation of STEM-oriented inquiry-based learning has a significant and positive impact on improving students' scientific literacy

and problem-solving skills in science education. The findings indicate that students who engaged in STEM-integrated inquiry activities demonstrated higher learning gains, better conceptual understanding, and stronger abilities in identifying problems, developing strategies, and evaluating solutions compared to those who experienced conventional instruction. The integration of interdisciplinary STEM concepts with inquiry processes effectively promotes higher-order thinking skills and enables students to connect theoretical knowledge with real-world applications. Despite its effectiveness, the successful implementation of this approach requires adequate instructional time, teacher readiness, and appropriate scaffolding to support student adaptation. Overall, STEM-oriented inquiry-based learning represents a powerful instructional strategy for enhancing the quality of science education and preparing students with essential competencies needed to face complex challenges in the 21st century.

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