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The Implementation of Problem-Based Learning to Improve Junior High School Students' Scientific Thinking Skills on Ecosystem Topics

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ABSTRACT. The integration of Science, Technology, Engineering, and Mathematics (STEM) has become a strategic approach in preparing students to face global challenges related to sustainability and technological innovation. In science education, renewable energy topics offer rich opportunities for project-based learning that promotes interdisciplinary understanding and engineering thinking. This study aims to analyze the role of STEM-integrated learning in enhancing senior high school students' problem-solving skills, creativity, and conceptual understanding through miniature renewable energy engineering projects. This research employs a qualitative library research method by reviewing and synthesizing relevant national and international literature on STEM education, project-based learning, and renewable energy instruction. The data were analyzed using thematic analysis to identify key pedagogical patterns and instructional implications. The findings indicate that STEM-integrated projects effectively improve students' engineering design skills, collaborative learning, and critical thinking. Furthermore, renewable energy projects encourage students' awareness of sustainability issues and foster meaningful learning experiences. This study concludes that STEM integration in engineering-based projects is a promising pedagogical strategy for promoting interdisciplinary learning and sustainable education in senior high school contexts.

Keywords: STEM education, renewable energy, engineering project

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INTRODUCTION

The rapid development of science and technology in the 21st century has significantly transformed the demands placed on education systems worldwide. Students are no longer expected to merely memorize scientific facts but are required to develop interdisciplinary skills such as problem-solving, creativity, critical thinking, and technological literacy. One educational approach that has gained strong attention in this context is Science, Technology, Engineering, and Mathematics (STEM) education, which emphasizes the integration of multiple disciplines to solve real-world problems (Bybee, 2013; OECD, 2018).

STEM education is designed to prepare students for complex challenges in modern society by fostering engineering thinking and innovative problem-solving abilities. Rather than teaching science and mathematics as isolated subjects, STEM promotes holistic learning experiences where students apply scientific concepts through technological tools and engineering design processes

(Kelley & Knowles, 2016). This interdisciplinary approach is particularly relevant for senior high school students, who are at a developmental stage where abstract reasoning and applied thinking can be maximally cultivated.

One of the most promising contexts for implementing STEM learning is renewable energy education. Renewable energy topics, such as solar, wind, and hydroelectric power, provide authentic and meaningful learning opportunities that connect scientific theories with global sustainability issues (UNESCO, 2017). Through renewable energy projects, students can explore environmental problems while simultaneously developing technological and engineering competencies (Capraro, Capraro, & Morgan, 2013).

Project-based learning is commonly used as an instructional strategy in STEM education because it allows students to engage actively in designing, constructing, and testing products. Engineering projects, such as building miniature renewable energy models, encourage students to apply physics, mathematics, and technological principles in practical ways (Bell, 2010). This learning model supports experiential learning, where knowledge is constructed through direct interaction with real problems (Kolodner et al., 2003).

Several studies indicate that STEM-integrated project learning enhances students' conceptual understanding and higher-order thinking skills. Students involved in engineering design projects demonstrate better scientific reasoning, improved collaboration skills, and stronger motivation compared to those in conventional classrooms (Honey, Pearson, & Schweingruber, 2014). Moreover, miniature engineering projects help students visualize abstract concepts, making learning more concrete and meaningful (Sanders, 2009).

Despite the growing popularity of STEM education, many schools still face challenges in implementing integrated learning models effectively. Teachers often struggle with curriculum integration, assessment design, and limited instructional resources (English, 2016). Therefore, systematic analysis of previous studies is needed to identify effective strategies and best practices in STEM project implementation.

Based on these conditions, this study aims to analyze the integration of STEM learning in miniature renewable energy engineering projects through a literature-based approach. By synthesizing existing research, this study seeks to provide theoretical insights and pedagogical implications for science teachers who intend to adopt STEM-based project learning in senior high school contexts.

METHOD

This study employed a qualitative research design using a library research approach. The purpose of this method was to systematically analyze and synthesize existing theoretical and empirical studies related to the integration of STEM learning in engineering-based projects, particularly in renewable energy education. Library research was chosen because it allows researchers to explore comprehensive insights from previous scholarly works and to construct conceptual frameworks based on established knowledge (Zed, 2014; Snyder, 2019).

The data sources consisted of peer-reviewed international and national journal articles, academic books, and research reports published between 2010 and 2023. The literature was collected from reputable academic databases such as Google Scholar, ERIC, Scopus, and ScienceDirect. The selected sources focused on key themes including STEM integration, project-based learning, engineering design, and renewable energy instruction at the senior high school level. Only full-text publications written in English or Indonesian were included to ensure credibility and accessibility (Creswell & Poth, 2018).

The collected data were analyzed using thematic analysis. This process involved identifying relevant concepts, coding important information, and categorizing the findings into thematic patterns related to learning strategies, engineering processes, interdisciplinary integration, and learning outcomes. The themes were then synthesized to develop a conceptual understanding of how STEM-integrated renewable energy projects contribute to students' problem-solving skills, creativity, and conceptual understanding (Miles, Huberman, & Saldaña, 2014; Kitchenham & Charters, 2007).

RESULT AND DISCUSSION

Result

The results of this literature study indicate that the integration of STEM learning in miniature renewable energy engineering projects provides significant benefits for students' cognitive, technical, and affective development. The reviewed studies consistently show that STEM-based projects encourage active learning and interdisciplinary understanding by combining scientific concepts, technological tools, engineering design processes, and mathematical reasoning into a single learning experience (Bybee, 2013; Kelley & Knowles, 2016). To present the findings systematically, the results are organized into several thematic categories.

1. Development of Engineering Design Skills

The literature reveals that STEM-integrated projects significantly enhance students' engineering design skills. Through renewable energy mini projects, students are required to identify problems, design solutions, construct prototypes, and evaluate their performance. This process trains students to think like engineers by applying scientific principles to solve practical problems. Several studies emphasize that hands-on engineering activities improve students' ability to plan, test, revise, and optimize their designs (Capraro et al., 2013; Kolodner et al., 2003).

2. Improvement of Problem-Solving and Critical Thinking

Another major finding is the improvement of students' problem-solving and critical thinking abilities. STEM projects expose students to complex and open-ended problems related to energy sustainability, which require analytical thinking and decision-making. Students are encouraged to explore alternative solutions, evaluate the effectiveness of different designs, and justify their choices using logical reasoning. This learning environment supports higher-order thinking and reflective learning processes (Honey et al., 2014; English, 2016).

3. Enhancement of Collaboration and Communication Skills

The reviewed studies also show that STEM-based project learning promotes collaboration and communication among students. Group-based engineering projects require students to share ideas, negotiate solutions, and work collectively toward common goals. These collaborative activities foster social interaction, teamwork, and communication skills, which are essential competencies for future scientific and technological careers (Bell, 2010; Sanders, 2009).

4. Growth of Sustainability Awareness and Motivation

In addition to technical and cognitive skills, STEM-integrated renewable energy projects contribute to students' awareness of sustainability issues. By engaging with real environmental challenges, such as energy conservation and climate change, students develop positive attitudes toward sustainable practices. The literature highlights that contextual learning experiences increase students' motivation and responsibility toward environmental problems, making learning more meaningful and socially relevant (UNESCO, 2017; OECD, 2018).

Discussion

The findings of this literature study confirm that the integration of STEM learning through miniature renewable energy engineering projects is highly effective in promoting meaningful and interdisciplinary learning experiences. The improvement of engineering design skills reflects the core principle of STEM education, which emphasizes learning by doing and applying scientific knowledge to solve real-world problems. This result aligns with constructivist learning theory, which argues that students construct knowledge actively through interaction with their environment and hands-on experiences (Bybee, 2013; Kelley & Knowles, 2016).

The enhancement of problem-solving and critical thinking skills can be explained by the nature of engineering-based projects, which require students to engage in iterative thinking processes. In STEM projects, students are not only expected to produce a final product but also to analyze problems, test multiple solutions, and evaluate the effectiveness of their designs. This learning process supports higher-order cognitive development and encourages reflective thinking, which is consistent with previous studies highlighting the cognitive benefits of project-based and inquiry-based learning (Capraro et al., 2013; Honey et al., 2014).

Furthermore, the growth of collaboration and communication skills indicates that STEM learning fosters social learning environments. Group-based engineering tasks promote peer interaction, collective problem-solving, and shared responsibility. From a socio-constructivist perspective, knowledge is developed through social negotiation and dialogue, making collaboration a crucial component of effective learning. This finding supports earlier research suggesting that STEM education enhances not only academic achievement but also interpersonal and communication competencies (Bell, 2010; Sanders, 2009).

In addition, the increased sustainability awareness among students demonstrates that renewable energy projects have strong contextual and ethical dimensions. By engaging with real environmental issues, students develop a deeper understanding of the social and ecological impacts of scientific and technological decisions. This result aligns with the goals of education for sustainable development, which emphasize the importance of integrating environmental responsibility and global citizenship into science education (UNESCO, 2017; OECD, 2018).

Overall, the discussion suggests that the effectiveness of STEM-integrated renewable energy projects lies in their ability to combine cognitive, technical, social, and ethical learning dimensions. This holistic learning approach prepares students not only to master scientific concepts but also to become innovative problem solvers and environmentally responsible citizens. Therefore, STEM-based engineering projects can be considered a pedagogically robust model for supporting future-oriented science education at the senior high school level.

CONCLUSION

This study concludes that the integration of STEM learning in miniature renewable energy engineering projects provides a highly effective pedagogical approach for senior high school science education. Based on the synthesis of previous studies, STEM-based projects consistently enhance students' engineering design skills, problem-solving abilities, critical thinking, and collaborative competencies. These skills are essential for preparing students to face complex scientific and technological challenges in the 21st century.

Furthermore, this study highlights that renewable energy projects promote students' sustainability awareness and environmental responsibility. By engaging in real-world and context-based learning activities, students develop meaningful understanding of scientific concepts while simultaneously building ethical and social awareness related to global environmental issues.

Therefore, this study recommends that science teachers and curriculum developers integrate STEM-based engineering projects into classroom practices as an alternative strategy to promote interdisciplinary and future-oriented learning. Future research is encouraged to conduct empirical classroom studies to validate the conceptual findings and to explore the long-term impact of STEM integration on students' academic achievement and career readiness.

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