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Enhancing Complex Problem Solving (CPS) and Environmental Awareness Through the Development of STEM-Integrated E-Worksheets

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Abstract

One of the key challenges in 21st-century education is students' limited ability to address complex, real-world problems, particularly those related to global environmental issues. Complex Problem Solving (CPS) has been identified as an essential skill for navigating such challenges; however, CPS proficiency among Indonesian students remains relatively low, especially in the context of environmental awareness. This study aims to develop a differentiated STEM-integrated electronic worksheet (e-worksheet) designed to enhance CPS skills and foster environmental awareness among junior high school students. Employing a Research and Development (R&D) approach based on Thiagarajan's 4D model, Define, Design, Develop, and Disseminate, the study began with a needs analysis involving 15 teachers and 200 students from nine schools in Lampung Province. The STEM-based e-worksheet was developed with a focus on CPS indicators and environmental themes. Implementation was conducted with 26 seventh-grade students from SMP Negeri 12 Bandar Lampung. Data were collected through pre-test and post-test instruments and analyzed using normalized gain (n-gain) and effect size metrics. Results showed that the use of the e-worksheet significantly improved students' CPS abilities,

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with an n-gain of 0.56 (moderate) and an effect size of 4.12 (high), indicating substantial progress across all CPS dimensions. These findings highlight the potential of differentiated, STEM-oriented digital learning tools to enhance critical 21st-century skills and support environmental education at the junior secondary level.

Keywords: Differentiated E-Worksheet; STEM Education; Complex Problem Solving; Environmental Awareness; Junior High School

INTRODUCTION

In the 21st century, education faces a significant challenge in preparing the younger generation to address global issues, particularly the increasingly complex environmental problems. Issues such as pollution, climate change, and ecosystem degradation have become more evident and affect both global and local scales. To address these challenges, integrating environmental education into the curriculum is crucial to enhance students' awareness and understanding of these issues (Shabalala et al., 2023). A 2021 report by the World Economic Forum (WEF) highlights that Complex Problem Solving (CPS) is the most critical skill required for the future (Ratnasari et al., 2019; Varghese & Musthafa, 2021). CPS is essential for tackling complex problems that lack straightforward solutions and demand deep understanding and systematic approaches (Diocos, 2023).

In Indonesia, the CPS skills of students remain significantly limited, particularly regarding environmental issues. Research by Ali et al. (2023). Reveals that most sixth-grade students have low CPS abilities, particularly in understanding environmental pollution concepts. Moreover, the increasing environmental pollution in various regions, such as in Lampung Province, underscores the importance of enhancing students' awareness of the need for effective environmental management (Sarkawi et al., 2024). However, the main challenge is developing students' CPS in a context relevant to environmental issues. In this regard, STEM (Science, Technology, Engineering, and Mathematics) emerges as a fitting approach to foster CPS skills among students. STEM not only integrates knowledge from various disciplines but also engages students in problem-solving processes based on real-world issues, including environmental problems (Kocak et al., 2023). STEM encourages students to link scientific concepts, technology, and engineering with local environmental

challenges, which in turn can raise their awareness of environmental issues (Ainin & Asafri, 2023; Modi et al., 2024).

Implementing STEM can significantly impact students' ability to solve complex problems. Studies have shown that STEM-based learning allows students to develop critical thinking skills and solve problems more logically and systematically (Afikah et al., 2022; Kelana et al., 2024). Therefore, STEM education enhances CPS and strengthens students' awareness of the pressing global environmental issues (Istiana et al., 2023; Valdez & Bungihan, 2019). This approach motivates students to connect knowledge from various disciplines and develop innovative solutions to environmental challenges (Mantha et al., 2017; Wildani & Budiyono, 2022). Research suggests that by incorporating environmental issues into STEM learning, students learn about science and technology, social responsibility and active participation in solving global problems (Abdurrahman et al., 2020; Bukian et al., 2024).

However, despite STEM's proven effectiveness in enhancing CPS, its implementation in Indonesia remains limited, particularly in environmental education. A survey conducted among 15 teachers in Lampung Province found that approximately 70.1% of teachers acknowledged the importance of CPS in education, but few implemented it effectively in the classroom. (Pamungkas et al., 2023). Furthermore, 97.2% of teachers reported that they had not used STEM-integrated e-worksheet with a Project-Based Learning (PjBL) approach in teaching about pollution and other environmental issues (Frischkorn et al., 2014). This highlights the gap between teachers' perceptions and actual practices, underscoring the need for better training programs to strengthen the application of CPS and STEM in environmental education. Such efforts will not only improve teachers' professional competence but also positively impact the quality of student learning, preparing them to effectively address complex environmental challenges (Wibowo, 2022).

The Merdeka Curriculum, implemented in Indonesia, provides significant opportunities to expand STEM implementation in learning. The curriculum's learning outcomes encourage students to identify environmental problems and devise solutions. By the end of phase D, students are expected to identify the interactions between living organisms and their environment, as well as design mitigation efforts for environmental pollution and climate change (Rasyid et al., 2023). However, although the Merdeka

Curriculum includes environmental awareness, many educators have yet to fully utilize approaches that optimize students' critical thinking and problem-solving skills through STEM-integrated e-worksheet (Julita et al., 2022). Several studies suggest that the implementation of STEM approaches in learning can enhance students' critical thinking and problem-solving skills, which are essential for addressing environmental challenges (Istiana et al., 2023; Kartini et al., 2021). Therefore, it is crucial to improve training and support for educators to leverage the potential of the Merdeka Curriculum and strengthen the implementation of STEM in environmental education (Rochim et al., 2022).

This study aims to develop STEM-integrated e-worksheet focused on CPS and Environmental Awareness for junior high school students. This e-worksheet is designed using the Project-Based Learning (PjBL) approach, which allows students to learn by solving real-world problems related to environmental pollution. This approach is expected to enhance students' CPS skills in addressing complex environmental problems and strengthen their awareness of the importance of preserving the natural environment. By integrating STEM into learning, students will gain broader knowledge and practical skills to tackle the environmental challenges they face.

As a contribution to the field of education, this research seeks to fill the gap in literature regarding the application of STEM in teaching CPS and Environmental Awareness in Indonesia, particularly at the junior high school level. The results of this study are expected to provide practical guidance for educators in developing e-worksheet that enhance CPS skills and improve students' environmental awareness, which is a critical skill for facing global challenges in the future.

METHODS

This study employed a Research and Development (R&D) design using the 4D model developed by Thiagarajan, which consists of four main stages: Define, Design, Develop, and Disseminate. This model was selected as it is well-suited for the development of educational tools, such as STEM-integrated e-worksheet, with a focus on enhancing Complex Problem Solving (CPS) skills and Environmental Awareness among junior high school students (Eshaq, 2023).

In the Define stage, the study involved 15 teachers and 200 students from 9 schools across Lampung Province, covering regions such as Bandar Lampung, West Lampung,

East Lampung, Metro, North Lampung, Mesuji, Pesawaran, Pringsewu, and South Lampung. Schools were selected based on the geographic diversity of the areas to ensure a representative sample from various backgrounds. In the Implement stage, the intervention was conducted with 26 students from class VII-C at SMP Negeri 12 Bandar Lampung, selected using purposive sampling. These students were chosen for their direct involvement in the e-worksheet trial, which was designed to enhance their CPS and Environmental Awareness.

Data were collected using two primary methods: pre-test and post-test to assess the improvement in students' CPS abilities, and a questionnaire to evaluate their Environmental Awareness. Pre-tests and post-tests were administered before and after the intervention to measure the change in students' CPS skills. The questionnaire used to measure Environmental Awareness consisted of items focusing on students' understanding of environmental issues and their readiness to act in preserving the (Hamid et al., 2017).

Subject matter experts validated the instruments to ensure their relevance and accuracy in measuring the intended constructs (Richardson et al., 2017). Validation is crucial to ensure that the measurement tools provide reliable and accurate results in identifying students' environmental awareness (Ali & Anufriev, 2020). This solid data collection method aims to significantly contribute to understanding the effects of e-worksheet-based learning on students' CPS and environmental awareness (Ruggiano & Perry, 2017).

The e-worksheet-based learning was conducted using a Project-Based Learning (PjBL) approach, enabling students to address real-world problems related to environmental pollution through an interdisciplinary approach involving science, technology, engineering, and mathematics. Each learning session lasted 2 hours (120 minutes) and was conducted over four sessions over two weeks. During these sessions, students were allowed to discuss issues, conduct investigations, and design solutions based on their observations and experiments to enhance their CPS and Environmental Awareness.

The data collected from pre-tests and post-tests were analyzed using n-gain to measure the improvement in students' CPS abilities. The n-gain value was calculated using the following formula:

$$\text{n-gain} = \frac{\text{post-test score} - \text{pre-test score}}{\text{maximum score} - \text{pre-test score}}$$

Effect size was calculated to assess the strength of the impact of e-worksheet-based learning on students' CPS improvement, using Cohen's d formula (Yıldırım et al., 2019). The pre-test and post-test data were also analyzed using paired sample t-test to determine whether the differences between the pre-test and post-test scores were statistically (Mack et al., 2021).

Before implementation, the e-worksheet and other assessment instruments were validated by two subject experts and two instructional design experts to ensure content and instructional alignment. Instrument validation was performed using product-moment correlation analysis, while reliability was measured using Cronbach's alpha to ensure consistency in the measurement tools (Hanel & Mehler, 2019). The use of Cronbach's alpha analysis is essential for evaluating the internal consistency of the instruments used in this study, ensuring the development of highly valid and reliable measurement tools (Ali & Anufriev, 2020). Therefore, this study combines appropriate evaluation and validation methods to ensure the reliability of the results and provide an accurate representation of the effectiveness of the developed learning tool.

RESULTS

Before being used in this study, the instruments and the developed products were validated to ensure their appropriateness and quality. Two subject matter experts and two instructional design experts validated the instruments to ensure that the CPS test and Environmental Awareness questionnaire effectively measured the intended skills. The validation results for the CPS test showed very high validity, with the product-moment correlation for each item reaching 0.89, indicating that the instrument accurately measures students' ability to solve complex problems related to environmental pollution. For the Environmental Awareness questionnaire, which assesses students' understanding of the importance of environmental preservation and environmentally friendly actions, the validation results showed excellent reliability with a Cronbach's alpha of 0.92, demonstrating high consistency in measuring students' environmental awareness.

In addition to instrument validation, the e-worksheet product was also evaluated by subject matter and instructional design experts. The validation results revealed that the e-

worksheet met very high content quality and instructional construction standards. Regarding curriculum alignment, the product received a score of 88.75%, indicating that the developed e-worksheet is relevant to the learning objectives, particularly in enhancing CPS and Environmental Awareness. As for the alignment of the construction or instructional steps, the product scored 97.69%, demonstrating that the structure and sequence of activities in the e-worksheet were excellently organized and easy for students to follow. Furthermore, the product received a score of 93.22% for the usability of the instructional tools, indicating that the e-worksheet can be effectively implemented in the classroom and supports the development of students' CPS skills.

Overall, the validation results show that the instruments used to measure CPS and Environmental Awareness and the developed e-worksheet meet high-quality standards. These validations assure that the measurement tools and learning products used in this study are reliable for achieving the research objectives, which can significantly improve students' CPS and Environmental Awareness.

This research aimed to develop a STEM-integrated e-worksheet with a Problem-Based Learning (PBL) approach to enhance students' Complex Problem Solving (CPS) and Environmental Awareness. Based on the conducted study, the developed e-worksheet proved effective in improving students' CPS abilities in the context of environmental pollution.

Initially, a needs analysis was conducted through a survey completed by 15 teachers from 9 schools in Lampung Province. This analysis indicated that, although most teachers were familiar with the concepts of CPS and Environmental Awareness, implementing teaching methods adequate to enhance these skills was still limited. Therefore, developing a STEM-based e-worksheet focused on CPS and Environmental Awareness is essential.

In the product development stage, the e-worksheet, designed using a PBL-oriented CPS approach, was trialed with students from class VII C at SMP Negeri 12 Bandar Lampung. Based on the trial results, a significant improvement in students' CPS skills was observed. The average pre-test score of the students was 42.79, while the post-test score increased to 79.42 (Figure 1). This indicates that the use of the STEM-integrated e-worksheet successfully enhanced students' CPS abilities in a significant way.

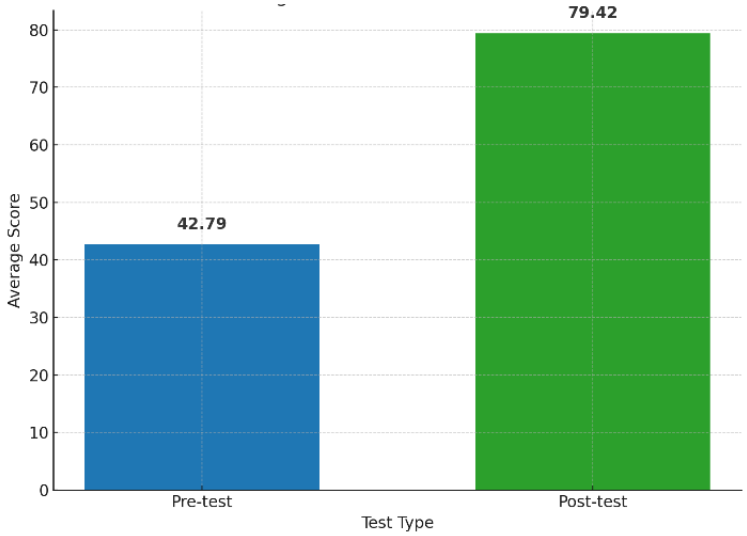


Figure 1: Average Pre-test and Post-test Scores

As further indicators, **Figure 2** presents the results of the n-gain calculation, which yielded a value of 0.56, placing it in the moderate category. This indicates that the improvement in students' CPS abilities is significant. Additionally, the effect size analysis revealed a value of 4.12, which falls into the high category, signifying that the impact of learning through the STEM-integrated e-worksheet substantially enhances students' CPS abilities.

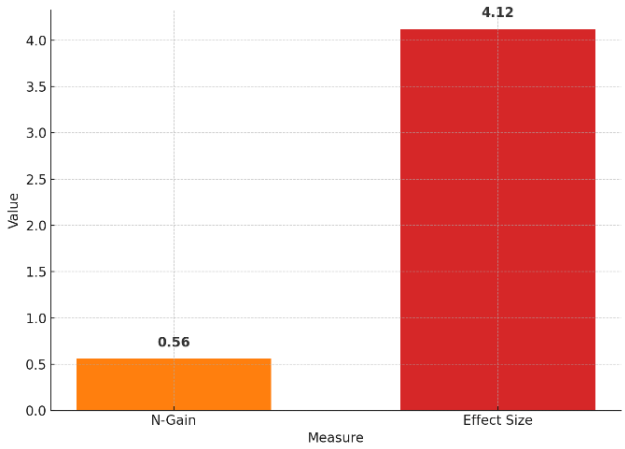


Figure 2: N-Gain and Effect Size Results

Furthermore, observations on the implementation of the learning process showed that the e-worksheet was executed very effectively. The implementation scores for the PBL syntax and the social system were 85% and 100%, respectively, indicating that the e-

worksheet was successfully applied and followed the planned learning framework as intended (Figure 3).

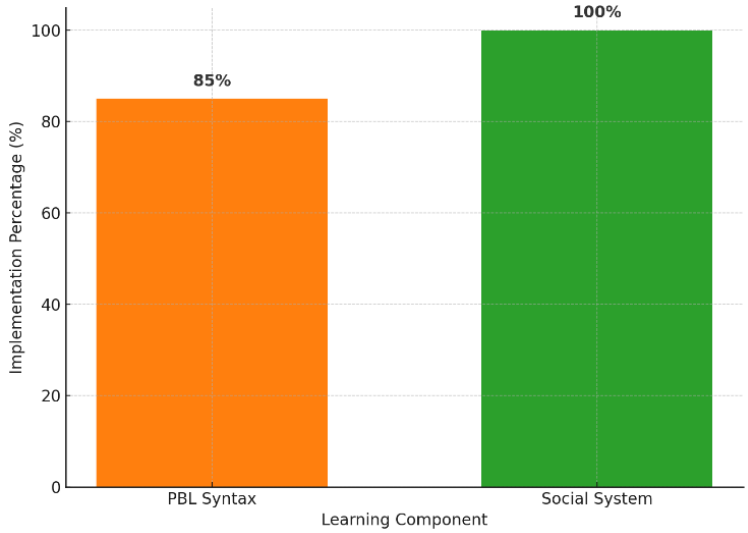


Figure 3: Implementation of Learning Syntax (PBL Syntax and Social System)

This chart illustrates the implementation percentage of the PBL Syntax and Social System components. The PBL Syntax achieved 85% implementation, reflecting strong alignment with the steps of Project-Based Learning, while the Social System reached 100% implementation, indicating complete success in fostering collaborative learning among students.

Additionally, students' Environmental Awareness showed significant improvement after engaging in the e-worksheet-based learning. According to the questionnaire administered to the students, the majority demonstrated high awareness of the importance of environmental preservation and pollution reduction. This improvement included heightened awareness regarding the importance of local environmental cleanliness, waste management, and understanding the impacts of environmental pollution on daily life.

Statistical tests using the paired sample t-test revealed a significant difference between the pre-test and post-test scores, with a p-value of 0.000. This indicates that the e-worksheet-based learning, focused on CPS and Environmental Awareness, effectively enhanced students' abilities.

DISCUSSION

This study aimed to develop a STEM-integrated e-worksheet with a Project-Based Learning (PjBL) approach to enhance students' Complex Problem Solving (CPS) abilities and Environmental Awareness. The results indicated that the e-worksheet improved students' CPS skills and environmental awareness. These findings align with previous research demonstrating the positive impact of STEM education on enhancing students' problem-solving abilities (Reeve & Satria, 2015; Stohlmann & Afriana, 2012) and fostering pro-environmental attitudes (Han et al., 2015). The pre-test scores revealed a low average CPS score of 42.79, indicating that students' ability to address complex environmental issues was underdeveloped. However, following the intervention, the post-test scores increased significantly to an average of 79.42, demonstrating a notable improvement in CPS abilities. This improvement highlights the potential of STEM-integrated learning approaches in developing essential problem-solving skills for addressing environmental challenges.

Further statistical analysis, including the n-gain value of 0.56, placed the improvement in the moderate category, which suggests substantial progress and indicates areas for further enhancement. The effect size of 4.12, which falls into the high category, underscores the significant impact of the e-worksheet intervention on students' CPS abilities. This result corroborates findings from Afriana et al. (2016), who reported significant advancements in problem-solving skills when STEM approaches were integrated into the learning process. Moreover, students' environmental awareness also showed significant improvement. The post-intervention questionnaire revealed that most students demonstrated a deeper understanding of environmental issues, such as maintaining cleanliness and effective waste management. These results reinforce the assertion by Reeve & Satria (2015) that STEM, as an interdisciplinary educational model, enhances cognitive and social awareness of pressing global challenges like environmental pollution.

However, despite these positive outcomes, several areas require further attention. For example, some students did not focus enough on reducing single-use plastics, highlighting the need to emphasize the long-term environmental impact of plastic use. Further studies could incorporate more targeted learning materials that address such specific environmental concerns to enhance students' real-world application of sustainable practices.

The application of the PjBL approach within the e-worksheet was also highly successful. The PjBL syntax achieved an 85% implementation score, while the social system was implemented perfectly with a 100% success rate. This indicates that the e-worksheet was applied effectively, facilitating active student engagement in collaborative problem-solving tasks related to environmental pollution. The results align with Han et al.'s (2015) findings that collaborative learning models like PjBL significantly improve student participation and problem-solving skills.

While this study's findings demonstrate the effectiveness of STEM-integrated e-worksheets in improving CPS and environmental awareness, there remains ample opportunity for further development. Future research could focus on investigating the long-term impact of such interventions on students' behaviors, particularly in terms of adopting sustainable practices, such as reducing plastic use. Additionally, expanding the scope of research to include diverse environmental issues like renewable energy and water conservation would provide a more holistic understanding of how STEM education can contribute to addressing global environmental challenges.

Future studies should also consider adapting this approach for students in diverse educational contexts, such as those from rural or underprivileged areas, where access to resources and the environmental challenges may differ. Moreover, there is a need for further exploration of how teacher professional development programs can better support educators in integrating STEM into their teaching practices. Despite the evident benefits of STEM-based learning, many teachers still face challenges in effectively applying these approaches in the classroom. Enhancing teachers' capacity to implement STEM effectively could significantly improve the quality of education and the extent to which students are equipped to face global environmental issues (Rochim et al., 2022).

In conclusion, this study contributes to the growing body of literature on STEM education by providing evidence of the effectiveness of STEM-integrated e-worksheets in enhancing students' CPS and environmental awareness. The findings suggest that problem-based learning strategies, particularly those integrating STEM, can play a pivotal role in preparing students to tackle the complex environmental challenges of the 21st century.

CONCLUSION

Based on the results of this study, it can be concluded that implementing the STEM-integrated e-worksheet with Project-Based Learning (PjBL) effectively enhances students' Complex Problem Solving (CPS) abilities and Environmental Awareness. The significant improvement observed in students' CPS scores, from pre-test to post-test, indicates that the developed e-worksheet successfully supported students in addressing complex environmental problems. These findings are further validated by the n-gain value categorized as moderate and the high effect size, demonstrating the STEM-integrated e-worksheet's substantial impact in enhancing students' CPS abilities. Moreover, the significant improvement in students' Environmental Awareness highlights the potential of STEM and PjBL-based learning to strengthen students' understanding and commitment to environmental issues.

Overall, the e-worksheet-based learning approach has proven effective in achieving this study's two main objectives: improving students' CPS skills and Environmental Awareness. The results provide strong evidence that problem-based learning, when integrated with STEM, can be a highly effective strategy for preparing students to face the global challenges of the 21st century, particularly in environmental sustainability.

However, despite these positive findings, some areas still require further development. For instance, addressing specific environmental issues, such as reducing single-use plastics, remains an area that needs greater focus within the learning materials. Further research could examine how to integrate more targeted solutions to this issue and other pressing environmental concerns into the curriculum.

This study significantly enriches the STEM and PjBL-based learning models, offering a valuable reference for the future development of e-worksheets. These tools can expand students' CPS and Environmental Awareness skills, extending their applicability from elementary through secondary education. Future research should include larger samples and more diverse contexts to broaden our understanding of the effectiveness of STEM-integrated e-worksheets in educational settings. Such efforts could help refine and scale this approach to reach a wider audience and address global challenges more effectively.

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