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Effect of Problem Based Learning E-Book with Deep Learning Approach on Junior High School Students' Problem Solving Skills and Environmental Care Attitudes

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ABSTRACT

The development of students' problem-solving skills and environmental care attitudes remains an important concern in science education. This study investigated the effect of a Problem-Based Learning (PBL)–Deep Learning Approach e-book on seventh-grade students' problem-solving skills and environmental care attitudes in ecology and biodiversity learning in Yogyakarta, Indonesia. A quasi-experimental pretest–posttest control group design was employed involving 63 students, with 31 in the experimental group and 32 in the control group. The intervention was implemented over six learning sessions. The experimental group learned using the PBL–Deep Learning Approach e-book, while the control group received conventional learning. Data were collected using a problem-solving skills test and an environmental care attitude questionnaire. Group differences were analyzed using an independent-samples t-test and the Mann–Whitney U test, according to the data distribution. Effect sizes were calculated to determine the magnitude of the intervention effects. The results showed a significant difference in problem-solving skills between the groups ($p < 0.001$), with a large effect size (Cohen's $d = 1.107$). Environmental care attitudes also differed significantly ($p = 0.004$), with a moderate effect size ($r = 0.37$). These findings suggest that the PBL–Deep Learning Approach e-book supports students' problem-solving skills and environmental care attitudes through contextual problem analysis, evidence-based investigation, and reflection. The findings highlight the contribution of integrating PBL and the Deep Learning Approach into digital science learning resources to support problem-solving and environmentally responsible learning in junior high schools.

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1. INTRODUCTION

Students' problem-solving skills and environmental care attitudes remain important challenges in junior high school science education. Students need to be able to identify problems, formulate strategies, evaluate alternatives, and make appropriate decisions when addressing scientific and real-world issues (Istiana et al., 2024; Yolanda et al., 2024). In science learning, these skills enable students not only to understand scientific concepts but also to apply scientific knowledge to solve complex and contextual problems in everyday life (Budianto, 2021). However, the development of these skills remains challenging. A preliminary study conducted among junior high school students in Yogyakarta revealed an average problem-solving score of 46.6, indicating that students' problem-solving skills require further improvement. This finding highlights the need for science learning that provides students with opportunities to identify problems, analyze information, formulate solution strategies, and evaluate solutions based on scientific evidence. However, developing these competencies remains challenging, particularly when learning activities and resources do not adequately support scientific inquiry, problem analysis, and the application of knowledge to real-world situations.

Beyond problem-solving skills, environmental care attitudes are another important outcome of science education. Environmental challenges require students not only to understand scientific concepts but also to develop the awareness, dispositions, and behaviors necessary to act responsibly toward their surroundings (OECD, 2022). Kollmuss and Agyeman (2002) explained that pro-environmental behavior is influenced by the interaction of environmental knowledge, attitudes, values, and other internal and external factors. This perspective highlights that possessing environmental knowledge alone does not necessarily lead to responsible environmental behavior. Environmental literacy frameworks, such as that developed by the North American Association for Environmental Education (NAAEE), likewise emphasize the interconnected roles of environmental knowledge, dispositions, competencies, and responsible environmental behavior. Accordingly, environmental care in science education should be examined through multiple dimensions rather than knowledge alone.

The need to strengthen environmental care is also evident in the Indonesian school context. Preliminary observations and teacher interviews conducted at junior high schools in Yogyakarta Special Region, Indonesia, revealed behaviors that may indicate a need to strengthen students' environmental responsibility, including littering, inefficient energy use, and insufficient attention to school cleanliness. These findings, based on teachers' accounts of students' daily habits, suggest that environmental care remains an important aspect to address in science education. In this study, environmental care was examined through three dimensions: environmental knowledge, environmental attitudes, and environmental actions. These dimensions provide a basis for investigating whether science learning can support not only students' understanding of environmental issues but also their attitudes and actions toward environmental protection. The preliminary qualitative findings highlight the need for an instructional intervention that integrates environmental knowledge with opportunities to develop responsible attitudes and environmentally conscious behaviors.

The topic of ecology and biodiversity is particularly relevant for developing both problem-solving skills and environmental care attitudes. This topic is an essential component of junior high school science because learning is not limited to understanding ecological concepts but also involves students' responses and responsibility toward the environment (Rohmawati & Sumiri, 2025). Ecology and biodiversity provide opportunities for students to examine environmental problems, understand interactions within ecosystems, and recognize the importance of maintaining environmental

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sustainability (Noviana et al., 2023). Nevertheless, previous studies have reported that learning outcomes in ecology remain suboptimal and that learning activities have not always been integrated with environmental care attitudes (Hanikah et al., 2022). Therefore, ecology and biodiversity learning requires learning experiences that not only strengthen students' conceptual understanding but also engage them in solving contextual environmental problems and developing responsible attitudes toward their environment.

These conditions highlight the need for learning resources that can simultaneously facilitate problem-solving skills and environmental care. An e-book can serve as an interactive and flexible learning resource by integrating multimedia features, such as videos, animations, interactive quizzes, and other digital activities. These features can provide varied learning experiences and support students' engagement with science content. Although Hanikah et al. (2022) examined interactive e-books in elementary education, their findings provide general support for the use of digital books as diversified learning resources; however, evidence from secondary education is more directly relevant to the present study. For example, Ningsih et al. (2023) found that an environment-oriented e-book based on Problem-Based Learning (PBL) was effective in improving high school students' problem-solving skills. Similarly, Fahlevi et al. (2024) investigated a PBL-based science e-book integrated with local environmental potential to foster students' environmental literacy. These studies support the potential of environment-oriented e-books to connect science learning with contextual environmental issues, while also highlighting the need to investigate learning resources that address both problem-solving skills and environmental care attitudes among junior high school students.

Problem-Based Learning (PBL) offers a pedagogical framework for addressing these needs. PBL engages students in learning through complex, authentic problems that require them to identify knowledge gaps, investigate relevant information, collaborate with others, develop potential solutions, and reflect on their learning (Hmelo-Silver, 2004; Savery, 2006). Research syntheses have also reported advantages of PBL in developing skills and supporting long-term knowledge retention, although its effects may vary depending on the learning outcome and assessment method (Strobel & van Barneveld, 2009). In science education, this approach provides opportunities for students to apply scientific concepts to real-world environmental problems and consider the consequences of alternative solutions. Nevertheless, the effectiveness of PBL depends on appropriate instructional design and facilitation, including support for reflection, meaningful application of knowledge, and productive collaboration.

Despite its potential, PBL requires instructional support to ensure that students engage meaningfully with problems, connect scientific concepts with their experiences, and reflect on the reasoning behind their proposed solutions. In this study, the Deep Learning approach is integrated with PBL to strengthen these aspects of learning. The term *Deep Learning* in this study refers to the educational approach promoted in the Indonesian curriculum, rather than deep learning as a machine-learning technique or the deep approach to learning discussed in earlier educational psychology literature. The approach emphasizes meaningful, mindful, and joyful learning experiences that encourage students to construct relevant understanding, engage consciously in the learning process, and participate in an engaging learning environment (Suyanto et al., 2025). This orientation is also consistent with broader educational perspectives on deeper learning, which emphasize authentic problem solving, the transfer of knowledge to real-world contexts, and the development of competencies for meaningful

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participation in society (Fullan et al., 2018). By combining PBL with these principles, the e-book is intended to support students in investigating contextual environmental problems, evaluating evidence, developing solutions, and reflecting on their decisions, while also encouraging environmental knowledge, attitudes, and actions. The effectiveness of this integrated learning resource therefore needs to be examined in relation to both problem-solving skills and environmental care attitudes among junior high school students.

Therefore, integrating PBL and Deep Learning into an interactive e-book offers a potential approach to creating meaningful, contextual, and technology-supported science learning. In this design, the e-book serves as a digital medium for organizing the PBL learning process, while the principles of meaningful, mindful, and joyful learning are incorporated into learning activities to support students' engagement, understanding, application, and reflection. This integration is intended to help students investigate and solve contextual environmental problems, connect scientific knowledge with their everyday experiences, and reflect on the consequences of their decisions.

Previous studies have explored the potential of PBL-based and interactive e-books to support science learning outcomes, including problem-solving skills and environmental-related learning outcomes (Asi et al., 2021; Ningsih et al., 2023; Lieung et al., 2023; Fahlevi et al., 2024). However, the specific contribution of these studies differs in terms of instructional design, learning outcomes, and educational context. The present study addresses this research gap by developing an e-book that systematically integrates the principles of Deep Learning, meaningful, mindful, and joyful learning into each stage of the PBL process. Unlike studies that focus on individual learning outcomes or examine digital learning resources without this specific integration, the present study evaluates two complementary outcomes simultaneously: students' problem-solving skills and environmental care attitudes. The e-book is designed for ecology and biodiversity learning at the junior high school level, connecting scientific problem solving with the development of environmental knowledge, attitudes, and actions.

Accordingly, this study aims to examine the effectiveness of a PBL–Deep Learning e-book in improving junior high school students' problem-solving skills and environmental care attitudes in ecology and biodiversity learning. Specifically, the study investigates whether the use of the e-book leads to improvements in these outcomes compared with the learning resources used in the control group.

The research questions are as follows:

(1) Is there a significant difference in students' problem-solving skills between those who learn using the PBL–Deep Learning e-book and those who learn through conventional learning?
(2) Is there a significant difference in students' environmental care attitudes between those who learn using the PBL–Deep Learning e-book and those who learn through conventional learning?

Statistical hypotheses

Based on the research questions, the statistical hypotheses are formulated as follows:

Problem-solving skills

H0: There is no significant difference in students' problem-solving skills between the group that learns using the PBL–Deep Learning e-book and the group that learns through conventional learning.
H1: There is a significant difference in students' problem-solving skills between the group that learns using the PBL–Deep Learning e-book and the group that learns through conventional learning.

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Environmental care attitudes

H0: There is no significant difference in students' environmental care attitudes between the group that learns using the PBL–Deep Learning e-book and the group that learns through conventional learning.

H1: There is a significant difference in students' environmental care attitudes between the group that learns using the PBL–Deep Learning e-book and the group that learns through conventional learning.

2. METHODS

2.1. Research Design and Participants

This study employed a quasi-experimental pretest–posttest control group design involving 63 seventh-grade students from two junior high schools in Yogyakarta, Indonesia. The participants were assigned to an experimental group comprising 31 students and a control group comprising 32 students. The study focused on ecology and biodiversity in junior high school science education. The study used cluster random sampling. Random sampling was employed to minimize selection bias and provide an equal opportunity for members of the target population to be selected. The experimental and control groups completed pretests before the intervention to assess their initial problem-solving skills and environmental care attitudes. The baseline scores were compared to examine the initial comparability of the two groups. After the intervention, posttests were administered to assess changes in both outcome variables. The data were analyzed using appropriate statistical tests based on the distribution of the data, with a significance level of 0.05. Effect sizes were also calculated to determine the magnitude of the intervention's effects on students' problem-solving skills and environmental care attitudes.

2.2. Intervention Procedures

The intervention was conducted over six learning sessions. The experimental group learned ecology and biodiversity using a PBL–Deep Learning Approach e-book, which integrated the stages of Problem-Based Learning with the principles of meaningful, mindful, and joyful learning. Learning activities involved contextual environmental problems, information analysis, problem-solving, presentation of proposed solutions, and reflection. The intervention was implemented by researcher in accordance with the planned lesson activities. The control group learned using the student textbook and Problem-Based Learning (PBL)-based student worksheets (LKPD). Learning activities followed the PBL stages, including problem orientation, student organization, investigation, presentation of solutions, and reflection. Students worked on problems and completed learning activities using the textbook and LKPD, without the additional digital features provided by the PBL–Deep Learning Approach e-book.

2.3. E-book Development and Validation

The PBL–Deep Learning Approach e-book was developed using Heyzine. The e-book presented ecology and biodiversity content through multimedia, interactive activities, and quizzes. Students accessed the e-book using smartphones or personal computers (PCs). The e-book and research instruments were evaluated through expert judgment involving two validators: a subject-matter expert and a media expert. The validation process assessed content, presentation, language, and media quality.

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2.4. Research Instruments and Data Collection

Data were collected using a problem-solving skills test and an environmental care attitude questionnaire. The problem-solving test assessed students' abilities to understand problems, develop solution plans, implement the plans, and evaluate the results. Environmental care attitudes were measured using a four-point Likert-scale questionnaire. Both instruments were administered before and after the intervention to evaluate changes in the two outcome variables. The research instruments underwent expert validation before use.

2.5. Data Analysis

The data were analyzed using descriptive and inferential statistics. Normality and homogeneity tests were conducted to determine the suitability of the data for parametric analysis. Independent-samples t-tests were used for comparisons when the relevant assumptions were satisfied, whereas Mann–Whitney U tests were used when the normality assumption was not met. The significance level was set at 0.05. Effect sizes were calculated to estimate the magnitude of the differences between groups in problem-solving skills and environmental care attitudes. Effect sizes were calculated to estimate the magnitude of the differences between groups. Cohen's *d*, obtained from the SPSS output, was used for independent-samples *t*-tests, whereas effect size *r* was calculated for the Mann–Whitney U, where *Z* represents the standardized test statistic and *N* represents the total sample size across both groups. The analyses were conducted using gain scores, calculated as the difference between posttest and pretest scores.

3. RESULTS AND DISCUSSION

3.1. Effectiveness of the PBL–*Deep Learning* E-Book on Problem-Solving Skills

The prerequisite tests consisted of normality and the baseline equivalence test. The results are presented in Tables 1 and 2

Table 1. Normality test results for problem-solving skills.

Class	N	df	Shapiro–Wilk Sig.	Interpretation
Experimental	31	63	0.214	Normal
Control	32	63	0.298	Normal

The normality test results for the gain scores obtained from the pretest and posttest showed that the data in both the experimental and control groups were normally distributed. The experimental group had a significance value of 0.214, while the control group had a significance value of 0.298.

Table 2. Baseline equivalence test.

Test	Sig.	Decision
Independent Sample t-test	0,429	Retain the null hypothesis

The results of the independent-samples t-test showed a significance value of 0.429, which was greater than 0.05. Therefore, the null hypothesis was retained, indicating that there was no statistically significant difference in the students' baseline abilities between the experimental and control groups. This result suggests that the two groups had statistically equivalent initial abilities before the intervention.

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Table 3. Homogeneity test results for problem-solving skills.

Test	Sig. (Levene's Test)	Interpretation
Homogeneity	0.018	Not homogeneous

The Levene's test resulted in a significance value of 0.018, indicating that the variances of the gain scores between the two groups were not homogeneous. The hypothesis was tested using a Welch's *t*-Test Results with SPSS 30 at a significance level of 0.05. The results are presented in Table 4.

Table 4. Welch's *t*-test results for problem-solving skills mean gain.

Statistic	Experimental Group	Control Group
N	31	32
Mean Gain	26.81	15.50
SD	6.9	12.5
t	4.40	
df	48.61	
p	< .001	
Mean Difference	11.31	
95% CI [LL, UL]	[6.18, 16.43]	

Welch's independent-samples t-test revealed a statistically significant difference in problem-solving skill gains between the experimental and control groups, $t(48.61) = 4.40$, $p < .001$. The experimental group showed a higher mean gain ($M = 26.81$, $SD = 6.9$) than the control group ($M = 15.50$, $SD = 12.5$), with a mean difference of 11.31 (95% CI [6.18, 16.43]). These results indicate greater improvement in problem-solving skills in the experimental group.

3.2. Effectiveness of the PBL–*Deep Learning* E-Book on Environmental Care Attitudes

The prerequisite tests consisted of normality and homogeneity tests. The results are presented in Tables 5 and 6.

Table 5. Normality test results for environmental care attitudes.

Class	N	Shapiro–Wilk Sig.	Interpretation
Experimental	31	0.272	Normal
Control	31	<0.001	Not normal

Data on environmental care attitudes were available for only 31 students because one student was absent during data collection, resulting in incomplete data for this variable. The normality test results for the gain scores showed that the experimental group was normally distributed, with a significance value of 0.272, whereas the control group was not normally distributed, with a significance value of <0.001.

Table 6. Homogeneity test results for environmental care attitudes.

Test	Sig. (Levene's Test)	Interpretation
Homogeneity	0.131	Homogeneous

The Levene's test resulted in a significance value of 0.131, indicating that the gain score variances between the two groups were homogeneous. The prerequisite test results showed that the data did not meet the normality assumption. Therefore, the

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assumption for the *Independent Samples t-Test* was not fulfilled, and the Mann–Whitney U test was used as a non-parametric alternative. The results are presented in Table 7.

Table 7. Hypothesis test results for environmental care attitudes.

Group	N	Mean Rank	Sig. (2-tailed)	Interpretation
Experimental	31	38.15	0.004	Significant difference
Control	31	24.85		

The Mann–Whitney U test produced a significance value of 0.004, which is lower than 0.05. Therefore, H0 was rejected and Ha was accepted. This result indicates a significant difference in environmental care attitudes between the experimental and control groups after the intervention.

3.3. Effect Size Analysis

Effect size analysis was conducted to determine the magnitude of the effect of the PBL–*Deep Learning* e-book on students' problem-solving skills and environmental care attitudes. The results are presented in Table 8.

Table 8. Effect size analysis results.

Variable	Statistical Test	Effect Size	Category
Problem-solving skills	Independent Samples t-Test	Cohen'd (1.107)	Large
Environmental care attitudes	Mann–Whitney U test	Nilai r (0.37)	Moderate

The effect size analysis showed that problem-solving skills had an effect size of 1.107, categorized as large, whereas environmental care attitudes had an effect size of 0.308, categorized as moderate. These findings indicate that the PBL–*Deep Learning* e-book had a larger effect on students' problem-solving skills than on their environmental care attitudes.

3.4. Problem-Solving Skills

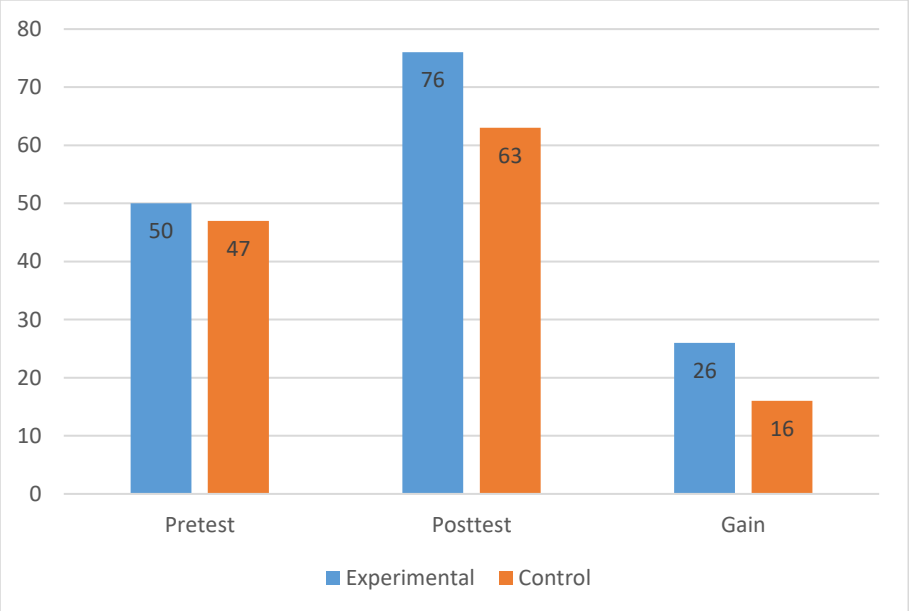


Figure 1. Increase in students' mean scores.

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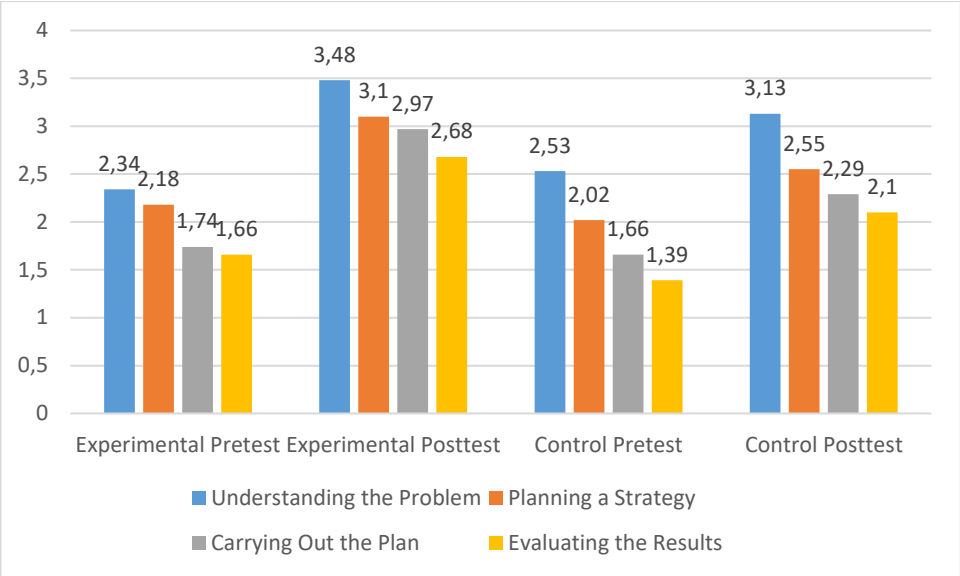


Figure 2. Improvement in scores for each indicator.

The experimental group demonstrated improvements across all four problem-solving indicators: understanding the problem, planning a strategy, carrying out the plan, and evaluating the results. The mean scores increased from 2.3 to 3.5 for understanding the problem, from 2.1 to 3.1 for planning a strategy, from 1.5 to 2.9 for carrying out the plan, and from 1.7 to 2.7 for evaluating the results. Descriptively, carrying out the plan showed the greatest increase (1.4 points), followed by understanding the problem (1.2 points), planning a strategy (1.0 point), and evaluating the results (1.0 point). However, these differences should be interpreted descriptively, as no statistical tests were conducted to determine whether the improvements differed significantly across indicators. The overall improvement suggests that Problem-Based Learning (PBL) may support the development of problem-solving skills by providing students with opportunities to investigate problems, process information, discuss findings, formulate and implement solution strategies, and evaluate the solutions obtained. This interpretation is consistent with the characteristics of PBL, which engages students in identifying problems, understanding relevant information, determining appropriate strategies, conducting investigations, and evaluating proposed solutions (Inayah et al., 2024). These activities align with Polya's four stages of problem-solving and suggest that PBL can facilitate students' engagement in the systematic process of solving problems.

The improvement in students' problem-solving skills may be associated with the integration of Problem-Based Learning (PBL), Deep Learning principles, and e-book media in the experimental learning intervention. The Deep Learning approach emphasizes mindful, meaningful, and joyful learning, which encourages students to engage actively in the learning process (Rosiyati et al., 2025). Mindful learning emphasizes awareness and understanding of problems before determining possible solutions (Kovač et al., 2025), while meaningful learning connects learning materials with contexts relevant to students' everyday lives (Hermes & Rimanoczy, 2018). Joyful learning, meanwhile, aims to create an engaging learning environment through varied learning activities and media. These principles may have complemented the PBL activities by encouraging students to understand contextual problems, explore possible solutions, and participate actively in learning. This interpretation is consistent with Nur Akmal and Maelasari (2025), who reported that the Deep Learning approach can promote student engagement through social and emotional interactions and support the development of problem-solving, innovation, and collaboration skills. However, because

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the intervention combined PBL, Deep Learning principles, and e-book media, while the control group received conventional instruction, the effects of these components cannot be isolated within the present research design. Therefore, the observed improvement should be interpreted as an outcome associated with the integrated intervention rather than as evidence of the independent contribution of Deep Learning principles. Future research could examine the contributions of individual components by using a design that separates their effects and by incorporating classroom observation data or student perception questionnaires to assess the implementation and experience of mindful, meaningful, and joyful learning.

The improvement in students' problem-solving scores suggests that the integrated learning intervention may have helped students engage more effectively with contextual problems. In particular, the increase in the mean score for understanding the problem, from 2.3 to 3.5, indicates a descriptive improvement in students' ability to identify relevant information, determine what a problem requires, and recognize relationships among the information provided. The contextual problems presented in the e-book may have helped students relate learning materials to familiar situations and identify the main issues before attempting to develop solutions (Andriyani & Suniasih, 2021). Such contextualization is consistent with the meaningful learning principle and the problem-oriented activities of PBL. Nevertheless, without direct observational evidence or student perception data, the extent to which contextual presentation contributed to the observed improvement remains uncertain. Accordingly, this result provides evidence of a change in the indicator score but does not establish the specific mechanism responsible for that change.

The indicator of planning a strategy increased from 2.1 to 3.1. The relatively smaller increase of 1.0 point may be related to the greater cognitive demands involved in this stage. Students are required to determine appropriate steps, select relevant information, consider alternative solutions, and connect the problem with previously learned concepts (Maisyaroh Agsya et al., 2019). Thus, planning a strategy requires more complex cognitive processing than simply understanding the information provided.

The largest improvement occurred in carrying out the plan, which increased from 1.5 to 2.9, representing an increase of 1.4 points. This result may be attributed to the PBL activities that provided students with opportunities to directly implement solutions. After understanding the problem and developing a strategy, students were directed to conduct investigations, collect and process information, discuss findings, and formulate solutions. These activities provided concrete learning experiences and repeated opportunities to practice the problem-solving process. This finding corresponds with the third stage of Polya (1945) problem-solving process, carrying out the plan, in which students apply the strategy that has been developed and monitor each step of the solution process. Thus, the PBL activities provided students with meaningful opportunities to translate their planned strategies into concrete actions, thereby strengthening their ability to carry out solutions systematically.

The high improvement in carrying out the plan can also be associated with the meaningful learning principle of Deep Learning. When students solve problems related to real-life situations, they do not merely receive solution procedures from the teacher but use the knowledge and information they have acquired to develop solutions. This process enables students to connect scientific concepts with their experiences and the problems they are addressing.

The indicator of evaluating the results increased from 1.7 to 2.7, representing a gain of 1.0 point. This improvement indicates a descriptive increase in students' ability to review their problem-solving processes and assess the appropriateness of their

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solutions. According to Polya (1945), the looking back stage involves checking the solution, reviewing the problem-solving process, and considering whether the strategy can be applied to other problems. From the perspective of the revised Bloom's taxonomy, evaluating involves making judgments based on criteria and standards, which requires students to examine information and justify their decisions (Anderson & Krathwohl, 2001). These cognitive demands highlight the importance of providing students with opportunities to review their solutions and explain the reasoning behind their decisions. In the present study, the increase in the evaluation score suggests that students demonstrated progress in this aspect of problem-solving following the integrated learning intervention. However, because the gains across indicators were not statistically compared, the differences in their improvement should be interpreted descriptively rather than as evidence of significantly different levels of progress.

Overall, the pattern of improvement indicates that the PBL–*Deep Learning* e-book provided learning experiences that supported the development of problem-solving skills at each stage. The largest improvement in carrying out the plan suggests that students obtained strong opportunities to practice problem-solving directly, whereas the relatively smaller improvements in planning strategies and evaluating results indicate that these stages may require more intensive practice and habituation because of their higher cognitive demands.

In the control group, improvement was observed across all four problem-solving indicators. Understanding the problem increased from 2.5 to 3.1, planning a strategy from 2.0 to 2.6, carrying out the plan from 1.6 to 2.3, and evaluating the results from 1.4 to 2.1. Although both groups demonstrated improvement, the experimental group showed greater gains across all four indicators. However, the initial difference in the understanding-the-problem indicator should be considered when interpreting these findings, as the control group had a higher pretest score (2.5) than the experimental group (2.3). This difference suggests that the two groups did not have identical baseline performance on this indicator, although the magnitude of the difference alone is insufficient to determine whether the groups were statistically equivalent before the intervention. Therefore, the greater improvement in the experimental group should be interpreted in relation to both the initial scores and the changes observed after the intervention. The improvement in the control group may be attributed to regular classroom instruction, students' continued exposure to the learning material, and familiarity with the assessment format gained through the pretest, which may have helped them perform better on the posttest. Nevertheless, the greater gains in the experimental group suggest that Problem-Based Learning (PBL) may have provided additional opportunities for students to engage in the problem-solving process through problem identification, strategy development, implementation, and evaluation. These findings highlight the potential contribution of PBL to enhancing students' problem-solving skills beyond the improvement associated with regular instruction.

The e-book also supported problem-solving skills by presenting learning materials, problems, investigative activities, and evaluations in a structured manner. Students obtained opportunities to learn independently and collaboratively in understanding problems and developing alternative solutions (Kusuma et al., 2022). Thus, the e-book functioned not only as a source of information but also as a guide for learning activities that directed students through the problem-solving process.

The magnitude of the effect was further supported by the effect size of 1.107, which is categorized as large, indicating that the difference in problem-solving improvement between the experimental and control groups was not only statistically significant but

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also practically meaningful. These findings suggest that integrating Problem-Based Learning (PBL) and Deep Learning into an e-book has the potential to support students' problem-solving skills through contextual problems, investigation activities, and reflection on solutions (Istiana et al., 2024).

3.5. Environmental Care Attitudes

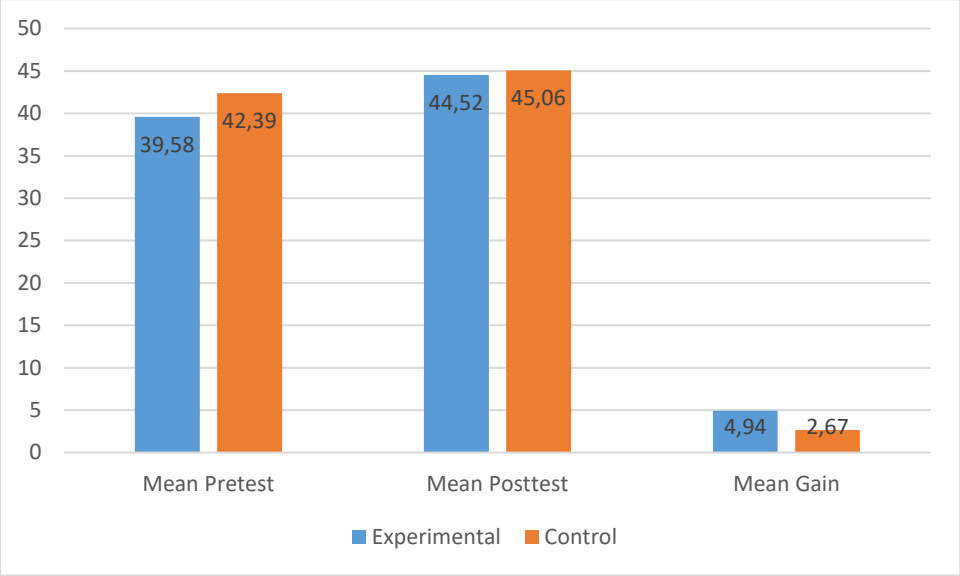


Figure 3. Improvement in questionnaire scores.

The PBL–Deep Learning e-book also significantly affected students' environmental care attitudes. The experimental group's mean score increased from 39.58 in the pretest to 44.52 in the posttest, yielding a mean gain of 4.94, while the control group's mean score increased from 42.39 to 45.06, with a mean gain of 2.67. The Mann–Whitney U test indicated a statistically significant difference between the groups ($p = 0.004$), with an effect size of 0.37, indicating a moderate effect. However, the control group had a higher pretest score than the experimental group, suggesting that the groups differed in their initial levels of environmental care attitudes. This baseline difference should be considered when interpreting the results, as the control group's higher initial scores may have limited its potential for further improvement. If scores on individual indicators were already close to the maximum of 4, a ceiling effect may also have contributed to the smaller gain in the control group. controlling for baseline differences.

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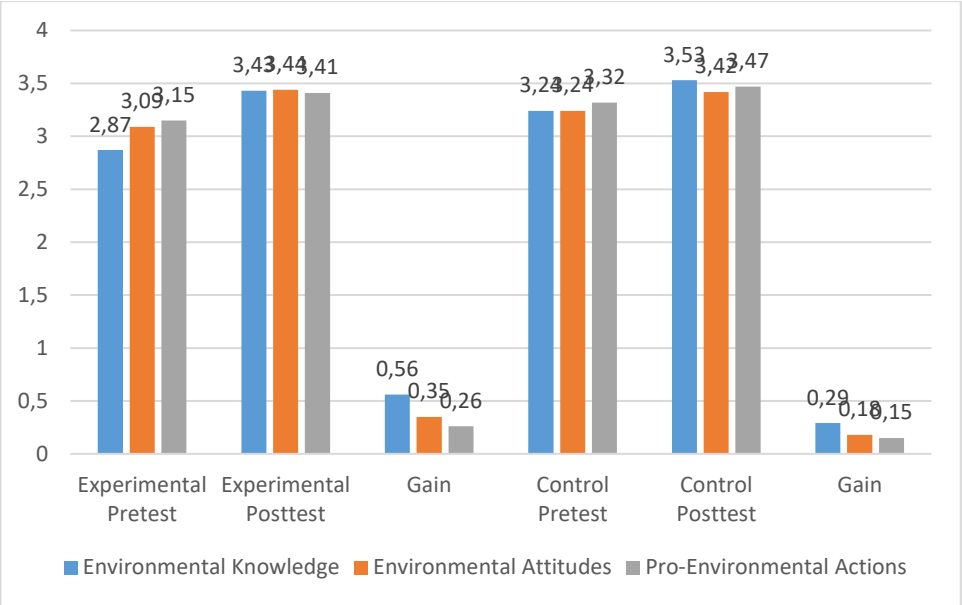


Figure 4. Improvement in scores for each indicator.

The experimental group showed improvement across all three environmental care indicators: environmental knowledge increased from 2.87 to 3.43 (gain = 0.56), environmental attitudes increased from 3.09 to 3.44 (gain = 0.35), and self-reported pro-environmental actions increased from 3.15 to 3.41 (gain = 0.26). The greatest improvement was observed in environmental knowledge, followed by environmental attitudes and self-reported pro-environmental actions. These findings suggest that the PBL–Deep Learning e-book may contribute to improvements in multiple dimensions of environmental care. However, because the study employed a pretest–posttest design with only two measurement points, the results do not establish that environmental care develops sequentially from knowledge to attitudes and then to actions. The observed differences in gains should therefore be interpreted as variations in the extent of improvement across the three indicators rather than evidence of a developmental sequence. The improvements may be associated with the contextual environmental problems presented in the e-book. Through PBL activities, students were encouraged to identify environmental problems, analyze their causes and impacts, and develop possible solutions. These activities may have helped students connect scientific knowledge with environmental conditions in their surroundings, potentially strengthening their environmental awareness and sense of responsibility (Okta Aninda & Suryadarma, 2017).

In addition, the implementation of PBL in the e-book provided student-centered learning experiences. Students were confronted with environmental problems relevant to everyday life, making the learning process more meaningful. Direct involvement in identifying and solving environmental problems may encourage the development of attitudes related to environmental responsibility (Purwati, 2017). Thus, the e-book provided contextual learning experiences that supported the development of environmental care attitudes.

The largest improvement in the experimental group occurred in environmental knowledge, with a gain of 0.56. This improvement can be associated with the characteristics of the e-book, which provided information and learning experiences concerning environmental problems in contextual situations. Through PBL, students were not merely presented with information but were directed to understand problems, identify causes, analyze impacts, and develop alternative solutions (Mahagia et al., 2023).

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According to constructivist theory, knowledge is actively constructed by students through experience and involvement in the learning process (Wahab et al., 2021). Therefore, learning that exposes students to real environmental problems can support the construction of environmental knowledge in a more meaningful manner.

The environmental attitude indicator increased by 0.35. This improvement suggests that students' experiences in learning about environmental problems may have contributed to greater environmental awareness and more positive evaluations of environmental protection. According to the Theory of Planned Behavior, attitudes toward a behavior, subjective norms, and perceived behavioral control influence behavioral intentions, which, together with perceived behavioral control, help explain actual behavior (Ajzen, 1991). Therefore, increased knowledge and understanding of environmental problems may support the development of more positive environmental attitudes, although this does not necessarily guarantee corresponding behavioral changes.

The pro-environmental action indicator increased by 0.26, which was lower than the gains in environmental knowledge and attitudes. This difference may reflect the knowledge–action gap, whereby possessing environmental knowledge and expressing positive attitudes do not automatically translate into pro-environmental behavior (Kollmuss & Agyeman, 2002). The translation of environmental concern into action may depend on additional factors, including behavioral intentions, personal habits, available opportunities, and contextual support. Thus, the relatively smaller increase in self-reported pro-environmental actions suggests that further opportunities for practice and habituation may be beneficial in encouraging students to apply their environmental knowledge and attitudes in everyday life. However, because this indicator was measured using a self-report questionnaire, the findings reflect students' reported actions rather than verified changes in their actual behavior.

The control group also showed improvements across all three indicators, with the largest gain observed in environmental knowledge (0.29), followed by environmental attitudes (0.18) and self-reported pro-environmental actions (0.15). The experimental group showed numerically greater gains across all three indicators. These findings suggest that the PBL–*Deep Learning* e-book may have contributed to improvements in environmental knowledge, attitudes, and reported pro-environmental actions. However, because the differences in gains across individual indicators were not statistically tested, the results do not establish that the intervention had significantly different effects on each dimension of environmental care.

The findings also suggest that improvements in environmental knowledge and attitudes do not necessarily translate into behavioral changes of the same magnitude. Although the experimental group showed a larger gain in self-reported pro-environmental actions than the control group (0.26 versus 0.15), the relatively small gains in both groups indicate that translating environmental knowledge and positive attitudes into everyday practices may require additional support. Therefore, environmental learning could be strengthened by providing authentic environmental experiences, repeated opportunities for action, and sustained habituation. Further research is needed to determine whether these improvements lead to consistent changes in students' actual environmental behavior over time.

3.6. Limitations and Future Research

This study has several limitations. The relatively small sample from a single geographical area and the use of intact classes may limit the generalizability of the findings and the ability to establish causal effects. The short intervention period also

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limits conclusions about the long-term retention of learning outcomes. Furthermore, the combined implementation of PBL, Deep Learning, and e-book media makes it difficult to isolate the contribution of each component. Environmental attitudes and pro-environmental actions were measured using self-report questionnaires, which may be subject to social desirability bias and may not fully reflect actual behavior. Additionally, the novelty of digital media may have temporarily influenced student engagement. Future research should involve larger and more diverse samples, longer interventions, delayed posttests, behavioral observations, and research designs that distinguish the effects of individual intervention components.

Practically, teachers are encouraged to integrate contextual environmental problems, investigation, reflection, and repeated environmental activities into learning. Educational media developers should incorporate interactive problem-solving tasks and opportunities for students to practice and document pro-environmental actions.

4. CONCLUSION

The findings indicate that the PBL–*Deep Learning* e-book significantly improved students' problem-solving skills and environmental care attitudes. The effect size was large for problem-solving skills (d = 1.107) and moderate for environmental care attitudes (d = 0.37). These results suggest that the integration of Problem-Based Learning (PBL) and Deep Learning in a contextual digital learning resource has potential as an alternative approach to supporting cognitive skill development and environmental awareness in science education.

In practice, science teachers are encouraged to integrate contextual problem-solving activities, environmental investigations, and reflection into digital learning. Educational media developers may use these findings to design e-books that connect scientific concepts with real-world environmental issues. Future research should involve larger and more diverse samples, longer intervention periods, delayed posttests, and behavioral observations to examine the sustainability of learning outcomes and changes in students' environmental practices.

5. AUTHORS' NOTE

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