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The Effect of the Problem-Based Learning Model on Integrated Problem-Solving Skills in Physics Education

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Abstract

Mastering integrated problem-solving skills is essential under the scope of 21st-century learning and Education for Sustainable Development (ESD)mastering integrated problem-solving abilities is crucial. Nevertheless, learners often find it difficult to relate theoretical physics principles to actual environmental issues like global warming. Consequently, this research investigates how the Problem-Based Learning (PBL) approach influences these integrated problem-solving abilities in physics classes. Using a quantitative quasi-experimental Nonequivalent Control Group Design, the study involved eleventh-grade students from MAN 5 Bireuen ($N = 44$). Through purposive sampling, two classes were selected: Class XI-1 as the experimental group ($n = 22$, taught via PBL) and Class XI-2 as the control group ($n = 22$, taught via direct instruction). Data were gathered using essay-type pretests and posttests evaluating three operational indicators of integrated problem-solvingTo account for initial baseline pretest differences (experimental mean = 31.4; control mean = 36.8) and address the violation of ANCOVA's homogeneity of regression slopes assumption ($p < 0.05$), hypothesis testing was executed using normalized gain (N-gain) scores and an independent-samples t-test. The analysis revealed a statistically significant difference in N-gain scores between the two cohorts $p = 0{,}013$, with the experimental group achieving a markedly higher mean N-gain (0.57 ± 0.27, medium gain category) than the control group (0.35 ± 0.28, low gain category). The intervention yielded a large practical effect size (Cohen's $d = 0.785$, 95% CI $[4.82\%, 38.09\%]$). Substantial gains were recorded across all three measured indicators: framework application (68.9%), solution formulation (71.0%), and competency application (71.6%). The findings demonstrate that PBL effectively enhances specific integrated problem-solving competencies

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in global warming instruction, though cautious causal interpretation is advised due to the nonrandomized design.

Keywords: Problem-Based Learning; Integrated Problem Solving; Global Warming; Physics Education; Education for Sustainable Development.

1. Introduction

Contemporary education in the 21st century extends beyond mere knowledge acquisition; it demands that learners develop capabilities to tackle increasingly intricate and unpredictable worldwide challenges (Nugraheny et al., 2025). Contemporary society faces pressing concerns including resource depletion, ecological damage, disparities in social welfare, and climatic shifts, all of which necessitate that learners grasp these matters holistically and devise suitable, long-term responses (Septiani, 2020). Within this structure, the Sustainable Development Goals (SDGs), established by the United Nations as a component of the 2030 Agenda, function as an international blueprint to advance sustainable progress, particularly via quality learning opportunities and initiatives addressing climatic concerns (UNESCO, 2017)

Education for Sustainable Development (ESD) embodies an educational approach that promotes the achievement of sustainable development goals. ESD prioritizes cultivating competencies that empower learners to confront sustainability challenges through innovative thinking, problem-resolution capabilities, and informed decision-making (Hoerunnisa et al., 2024). A fundamental competency within ESD is integrated problem-solving, defined as the capacity to employ diverse problem-solving methodologies in a cohesive manner to address multifaceted and interconnected sustainability challenges (Misriani et al., 2023). Sustainability issues are multidimensional, so their resolution requires the integration of various forms of knowledge and the simultaneous consideration of environmental, social, and economic aspects (Amprazis & Papadopoulou, 2025). This competency also requires students to select an appropriate problem-solving framework and generate solutions that are viable, inclusive, and equitable (Bunyan, 2025).

In physics education, integrated problem-solving skills are essential because physics problems involve not only solving mathematical problems but also applying concepts to real-life situations. Tantri et al. (2025) explain that integrated problem-solving in physics education encompasses the ability to connect physics concepts with various domains of knowledge, higher-order thinking skills, and sustainability values when addressing complex problems. Physics plays a strategic role in supporting ESD because various global issues, such as the energy crisis and climate change, are closely linked to physical phenomena (Afifah & Malik, 2025; Badiah et al., 2024).

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However, learning conditions in the field indicate that these skills still need to be developed. Results from interviews with teachers at MAN 5 Bireuen show that students still struggle to connect abstract physics concepts with real-world problems. This situation has resulted in suboptimal critical thinking, data analysis, collaboration, and creativity skills when formulating alternative solutions. Furthermore, specific evaluation instruments designed to assess integrated problem-solving capabilities within physics education remain unavailable. Initial assessments reveal that learners' integrated problem-solving competencies fall within the "below average" range, demonstrating an overall achievement level of 34%. The breakdown across indicators shows: implementing problem-solving frameworks for complex sustainability challenges at 35%; creating viable, inclusive, and fair solutions at 42%; and applying relevant competencies for problem resolution at 25%. These outcomes suggest that more contextually grounded instruction is necessary one that offers learners chances to participate actively in inquiry processes and problem-resolution activities.

Problem-Based Learning (PBL) emerges as an instructional approach aligned with these requirements. PBL employs authentic, real-world challenges as learning entry points, thereby engaging learners in activities such as investigation, dialogue, examination, and solution development, with educators serving as guides and advisors (Ardianti et al., 2021). Given these features, PBL can deliver educational experiences that help learners bridge theoretical concepts with practical situations while fostering critical thinking, analytical reasoning, teamwork, and problem-resolution abilities (Wati, 2023; Wulansari et al., 2025). PBL is also consistent with the characteristics of integrated problem-solving because it allows students to integrate conceptual understanding, process skills, and various perspectives in formulating solutions to complex problems (Mitrayana & Juandi, 2023; Simanjuntak & Purwaningsih, 2024).

Existing literature has predominantly examined general problem-solving abilities, critical thinking dispositions, or academic achievement outcomes. Research specifically designed to assess integrated problem-solving competencies through indicators aligned with sustainable development challenges remains scarce. Furthermore, prior investigations have not thoroughly explored how PBL influences integrated problem-solving capabilities within the specific context of global warming education.As a result, this study was conducted to address this shortcoming by exploring how the Problem-Based Learning method influences combined problem-solving skills within the realm of physics teaching.

2. Methods

This research adopted a quantitative approach, utilizing a quasi-experimental design featuring a nonequivalent control group structure. The study was conducted at MAN 5 Bireuen in the initial term of the 2026/2027 academic session. The focus group comprised all students in the eleventh grade who were registered at MAN 5 Bireuen. Through purposive sampling techniques, a total of 44 students were selected as participants: 22 students from class XI-1 served as the experimental

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group, while 22 students from class XI-2 functioned as the control group. The determination of these classes was guided by teacher recommendations, considering that both classes demonstrated relatively comparable characteristics. The group that participated in the experiment underwent teaching using the PBL method, while the comparison group was taught through traditional direct instruction. Both groups studied content related to global warming. Assessment of integrated problem-solving competencies was conducted using essay-type pretests and posttests. Although the pretest and posttest instruments contained different items, they were constructed with equivalent formats and difficulty levels based on established indicators, content coverage, and complexity, ensuring both could effectively measure integrated problem-solving abilities before and after the instructional intervention. Data were collected through essay-type pretests and posttests designed to assess three operational indicators of integrated problem-solving skill, as detailed in Table 1.

Table 1.
Indicators of Integrated Problem-Solving Ability

No	Indicator
1	Utilize various approaches and frameworks to tackle intricate issues related to sustainable development.
2	Formulate viable, inclusive, and equitable solutions.
3	Apply relevant competencies to address real-world problems.

Source: Longhurst & Kemp (2021)

Data were collected through observations and tests. Observations were used to gather information about the implementation of instruction, although tests were employed to assess integrated problem-solving abilities using pretests and posttests. Prior to deployment in the actual study, all instruments underwent rigorous quality assessment to determine their validity, reliability, item difficulty levels, and discriminant power. Data processing and instrument analysis were performed using Microsoft Excel 2021, while statistical analysis of research data utilized SPSS version 24 for Windows. Given the non-randomized, nonequivalent control group design and the initial baseline discrepancy in pretest scores between the experimental group ($M = 31.4$) and the control group ($M = 36.8$), an Analysis of Covariance (ANCOVA) was initially considered. However, preliminary evaluations revealed a violation of the homogeneity of regression slopes assumption ($p < 0.05$), rendering ANCOVA statistically inappropriate. Consequently, in alignment with established methodological standards for nonequivalent control group designs, hypothesis testing was conducted using Hake (1998) normalized gain (N-gain) score analysis. The N-gain formula was applied as follows:

$$N - gain = \frac{Posttest\ Score\ -\ Pretest\ Score}{Maximum\ Possible\ Score\ -\ Pretest\ Score}$$

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Prior to running inferential statistics, parametric assumptions were systematically evaluated on the N-gain dataset using the Shapiro-Wilk test for normality and Levene's test for homogeneity of variance. An independent-samples t-test was subsequently performed on the N-gain scores to determine whether score improvements differed significantly between the experimental and control groups. Furthermore, to evaluate the practical magnitude and educational meaningfulness of the intervention beyond p-values, Cohen's d effect size was calculated along with its 95% Confidence Interval (CI).

3. Result and Discussion

3.1. Research Instrument Quality Assessment

To ensure empirical validity, both the pretest and posttest instruments underwent a pilot trial consisting of 15 questions administered to a sample of 25 students. An item was classified as valid if its computed r-value exceeded the critical table r-value threshold of 0.396. The outcomes of this validity assessment for both testing instruments are detailed in Table 2.

Table 2.
Results of the Item Validity Analysis

No.	Instrument	Number of Items	Valid Items	Invalid Items	Total Valid
1	Pretest	15	1, 2, 3, 5, 6, 8, 10, 11, 12, 13	4, 7, 9, 14, 15	10
2	Posttest	15	1, 2, 3, 5, 6, 7, 8, 10, 14, 15	4, 9, 11, 12, 13	10

The analysis revealed that out of the 15 initial questions, the pretest yielded 10 valid and 5 invalid items. Similarly, the posttest also resulted in 10 valid and 5 invalid items. Therefore, 10 items from each instrument were deemed to meet the validity criteria and were used in the study.

Table 3.
Outcomes of the Instrument Reliability Assessment

Instrument	Cronbach's Alpha	Category	Reliability Decision
Pretest	0,78972	High	Reliable
Posttest	0,78438	High	Reliable

Reliability testing was conducted on the questionnaire items that had previously been validated through empirical validity testing. Therefore, out of a total of 15 items in each instrument, the reliability analysis focused on the 10 validated items. The pretest and posttest results of the statistical evaluation showed a Cronbach's Alpha coefficient of 0.78972 and 0.78438, respectively. Since both coefficients are classified within the "high" reliability range, it is confirmed that both testing instruments demonstrate strong internal consistency and are dependable for data collection.

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Table 4.
Results of the Difficulty Level Test

Instrument	Number of Valid Questions	Easy	Currently	Difficult
Pretest	10	0	7	3
Posttest	10	0	8	2

For each instrument, ten valid items were assessed for difficulty level. The analysis results showed that in the pretest, there were 7 items categorized as moderate and 3 items categorized as difficult; in the posttest, there were 8 items categorized as moderate and 2 items categorized as difficult. Neither instrument contained any items categorized as easy. Therefore, most of the test items used in the study were classified as having a moderate level of difficulty.

Table 5.
Results of the Discriminant Analysis

Instrument	Number of Validators	Very Good	Good	fair	Poor	Very Poor
Pretest	10	0	4	5	1	0
Posttest	10	0	2	7	1	0

In addition, 10 valid items for each instrument were evaluated for discriminant validity. The analysis results showed that 4 items on the pretest were categorized as good, 5 as adequate, and 1 as poor. On the posttest, 2 items were categorized as good, 7 as adequate, and 1 as poor. No items were classified as outstanding or extremely unsatisfactory. The results indicate that most of the valid test items possess sufficient discriminative power for their respective categories.

3.2. Mean Pretest, Posttest Scores, and N-Gain Scores

To rigorously evaluate integrated problem-solving competencies while accounting for initial group comparability, descriptive statistics including sample size (N), mean (M), standard deviation (SD), and normalized gain (N-gain) were computed for both cohorts across pretest and posttest evaluations, as summarized in Table 6.

Table 6.
Descriptive Statistics for Pretest, Posttest, and Normalized Gain (N-Gain) Scores

Group	N	Pretest Mean (SD)	Posttest Mean (SD)	Mean N-Gain (SD)	N-Gain Category
Experimen (PBL)	22	31.4 (14.9)	70.6 (18.7)	0.57 (0,27)	Medium
Control (Direct Instruction)	22	36.8 (8.60)	59.8 (15.6)	0.35 (0,28)	Low

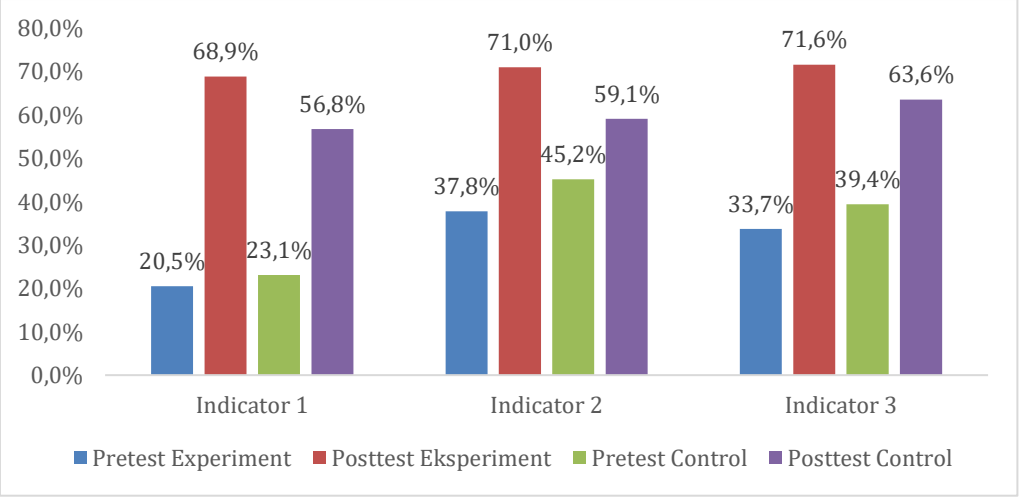
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As illustrated in Table 6, despite entering the intervention with a lower baseline pretest mean (31.4 ± 14.9 vs. 36.8 ± 8.60), the experimental group demonstrated a substantially greater posttest achievement (70.6 ± 18.7) compared to the control group (59.8 ± 15.6). Furthermore, the experimental cohort achieved a mean N-gain of 0.57 ± 0.27, whereas the control group recorded an N-gain of 0.35 ± 0.28, indicating a higher relative skill progression under Problem-Based Learning.

3.3. Achievement of Integrated Problem-Solving Skills Indicators

Further analysis was conducted based on three indicators of integrated problem-solving skills. In the experimental class, the percentage for the first indicator increased from 20.5% to 68.9%, the second indicator from 37.8% to 71.0%, and the third indicator from 33.7% to 71.6%. In the control class, the first indicator increased from 23.1% to 56.8%, the second from 45.2% to 59.1%, and the third from 39.4% to 63.6%.

Figure 1
Integrated Problem-Solving Skills Indicator Diagram



The results show that the third indicator achieved the highest posttest score in the experimental class, at 71.6%. Meanwhile, the first indicator achieved the lowest score, at 68.9%. Nevertheless, all indicators showed improvement following the implementation of PBL. For the first indicator, students demonstrated progress in establishing a problem-solving framework through problem identification and investigation activities. For the second indicator, group meetings provided students with opportunities to reflect on various problem-solving options and different perspectives. With respect to the third indicator, students exhibited enhanced ability to bridge

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physics theories with practical, everyday issues by engaging in inquiry-based learning, critical information examination, and presentation tasks.

3.4. Implementation of Instruction and Student Activities

Observational data revealed that instructional delivery in the experimental group was categorized as "very high". Teacher engagement in the first session reached 91.1%, then increased to 94.2% in the second session, and 95.8% in the third session. On the other hand, student participation reached 79.2% in the first session, increased to 86.5% in the second session, and 88.5% in the third session.

These results show that the PBL learning process was carried out effectively and that there was an increase in student engagement during the learning process. Such observational information acts as corroborative support for the examination results, instead of serving as the principal data source for establishing the treatment's effectiveness.

3.5. Hypothesis Testing and Effect Size Assessment

Prior to inferential hypothesis testing, parametric assumptions were verified for the N-gain dataset. The Shapiro-Wilk test for normality produced significance values of $p = 0.213$ for the eksperimen group and $p = 0.130$ for the control group. Because both values exceed the $\alpha = 0.05$ threshold, the N-gain distributions for both groups satisfy the normality assumption.

Table 7.
Normality Test Results for N-Gain Data (Shapiro-Wilk)

Data	Group	Statistic (W)	df	Sig. (p)	Decision
N-Gain	Eksperimen	0.942	22	0.213	Normally Distributed
N-Gain	Control	0.931	22	0.130	Normally Distributed

Levene's test was subsequently performed to evaluate homogeneity of variance across the N-gain scores, yielding $p = 0.823$. Because $p > 0.05$, variance homogeneity between the two groups was established, fulfilling all parametric requirements for the independent-samples t-test.

Table 8.
Levene's Test for Homogeneity of Variances on N-Gain Scores

Variable	Levene Statistic (F)	$df1$	$df2$	Sig. (p)	Decision
N-Gain Score	0.051	1	42	0.823	Homogeneous

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After confirming statistical assumptions, an independent-samples t-test was executed on the normalized gain ($N-gain$) values. The test revealed a statistically significant outcome $p = 0.013$ (two-tailed). Given that $p < 0.05$, the null hypothesis (H_0) was rejected, confirming a statistically significant difference in integrated problem-solving skill gains between the experimental group and the control group. Beyond mere statistical significance, the practical impact of the instructional treatment was assessed using Cohen's d effect size, accompanied by its 95% Confidence Interval (CI). The resulting effect size was $d = 0.785$ with a 95% CI of [4.82%, 38.09%], indicating a medium effect size according to Cohen's guidelines.

Table 9.
Independent Samples t-Test and Effect Size Analysis on N-Gain Scores

Variable / Comparison	t	df	Sig. (2-tailed)	Mean Difference	Cohen's d	95% Confidence Interval	Decision
N-Gain (Exp vs Control)	2.602	42	0.013	21.45	0.785	[4.82%, 38.09%]	Statistically Significant (H_a Accepted)

3.6. Discussion

The empirical findings demonstrate that the Problem-Based Learning (PBL) approach yields a statistically significant and educationally superior effect compared to conventional direct instruction in developing students' integrated problem-solving skills. Hypothesis testing conducted on normalized gain (N-gain) scores confirmed a statistically significant advantage for the experimental group ($p = 0.013$), with the PBL cohort achieving a mean N-gain of 0.57 ± 0.27 (57% improvement) compared to 0.35 ± 0.28 (35% improvement) in the direct instruction cohort. This represents a net mean difference of 21.45% in relative skill progression. Furthermore, the calculated Cohen's d effect size of 0.785 (95% CI $[4.82\%, 38.09\%]$) underscores that the PBL intervention exerted a large practical impact on student learning. These outcomes align with recent empirical studies by Firmansyah et al. (2022) and Putri et al. (2023), which established that active, problem-centered learning fosters superior problem-solving growth compared to passive instructional models. The current results also corroborate the work of Afzayani et al. (2026), who highlighted that inquiry-driven instructional frameworks effectively scaffold systematic problem decomposition

The significant gain in Indicator 1 (increasing from 20.5% to 68.9% in the PBL group versus 23.1% to 56.8% in the control group) stems from the integration of systems thinking frameworks during the problem orientation phase. Global warming represents a non-linear, complex systemic issue rather than an isolated physical event. During the problem orientation phase of PBL, students were trained using systems thinking principles and the Iceberg Model to move beyond surface events

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(such as local temperature spikes) to analyze structural patterns, systemic drivers (e.g., industrial emissions and land-use changes), and underlying mental models. As articulated by Redman & Wiek (2021), problem-solving frameworks serve as cognitive navigation structures that enable students to organize unstructured environmental data into coherent analytical steps. Furthermore, Kwangmuang et al. (2021) confirmed that structured problem-centered learning effectively cultivates analytical thinking skills required to address multidimensional issues. In contrast, control group students, lacking scaffolding frameworks, tended to address problems piecemeal and struggled to progress beyond superficial descriptions.

Progress in Indicator 2 (increasing from 37.8% to 71.0% in the experimental group compared to 45.2% to 59.1% in the control group) is explained by the Socio-Scientific Issues (SSI) framework and multi-criteria decision-making processes during collaborative group work. Resolving climate change issues requires balancing physical constraints (such as energy conservation and thermal equilibrium) with socio-economic equity. During the group investigation and solution formulation phase, small-group dialogue required students to evaluate technological feasibility, environmental impact, and social equity across divergent stakeholder perspectives. These findings align with studies by López-Fernández et al. (2022) and Suardana et al. (2025), which demonstrated that engaging students in open, controversial socio-scientific issues triggers multi-criteria critical evaluation and prevents students from settling on naive, single-variable answers. The European GreenComp sustainability framework (Bianchi et al., 2022) similarly emphasizes that effective solution formulation must synthesize technical viability with social inclusiveness. Direct instruction, focusing solely on abstract mathematical calculations, failed to provide opportunities for students to evaluate these multidimensional trade-offs.

Indicator 3 recorded the highest posttest achievement in the experimental cohort (71.6% in PBL vs. 63.6% in Control, from baseline scores of 33.7% and 39.4%, respectively), which is strongly supported by Situated Cognition Theory. Situated cognition asserts that knowledge is inherently tied to the activity, context, and culture in which it is acquired. Traditional physics instruction isolates concepts (e.g., thermal equilibrium, Stefan-Boltzmann radiation, and heat transfer mechanisms) as abstract mathematical formulas. In contrast, PBL embeds these physics principles directly into authentic global warming investigations. Empirical research by Fitria et al. (2022) and Bilad et al. (2024) confirms that contextualizing science concepts within actual climate change scenarios enhances context-bound cognitive transfer, enabling students to transform abstract theoretical knowledge into functional competencies for real-world problem resolution. Through inquiry and presentation tasks in PBL, students successfully bridged the gap between abstract physics laws and practical environmental scenarios.

Despite these insights, this study possesses several inherent limitations. First, the investigation was restricted to a single educational institution, MAN 5 Bireuen, and involved only two eleventh-grade classes studying global warming. Second, the quasi-experimental design used nonrandomized groups with different baseline pretest means, so the findings should not be interpreted as definitive

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proof of an unconfounded causal effect. Third, the assessment focused exclusively on three operational indicators of integrated problem-solving: the application of problem-solving frameworks, the formulation of viable, inclusive, and equitable solutions, and the application of relevant competencies to real-world problems. Therefore, the findings do not establish that PBL improves ESD competencies comprehensively, including other dimensions that were not directly measured. Future studies could involve more schools, different physics topics, and additional validated measures of ESD competencies to examine whether the findings extend beyond the three indicators assessed in this study.

4. Conclusion

In conclusion, the application of the Problem-Based Learning (PBL) model demonstrates a statistically significant positive effect on students' integrated problem-solving skills in physics education on global warming. This conclusion is supported by hypothesis testing on normalized gain (N-gain) scores using an independent-samples t-test, which yielded $p = 0.013$ (two-tailed). Because $p < 0.05$, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_a) is accepted. The experimental group achieved a significantly higher mean N-gain (0.57 ± 0.27, medium category) compared to the control group (0.35 ± 0.28, low category), yielding a large practical effect size ($d = 0.785$, 95% CI $[4.82\%, 38.09\%]$).

This positive development was evident across all three measured operational indicators: (1) employing problem-solving frameworks for sustainable development challenges, (2) formulating viable, inclusive, and equitable solutions, and (3) applying relevant competencies to resolve real-world problems. Given the nonrandomized quasi-experimental design, these results demonstrate significant educational improvement in the measured indicators rather than absolute causal proof. Overall, PBL proves to be an effective instructional model for integrating physics concepts with sustainability challenges.

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