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The Effectiveness of Green Chemistry-Integrated PBL Oriented toward SDG 4.7 on Students' Ecoliteracy in Salt Hydrolysis Topic

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Abstract: This study aims to evaluate the effectiveness of a Green Chemistry-integrated Problem-Based Learning (PBL) model oriented toward SDG 4.7 in enhancing students' ecoliteracy in the topic of salt hydrolysis. A quasi-experimental method with a Pretest-Posttest Control Group Design was employed. The research was conducted at SMAN 1 Luhak Nan Duo with Phase F students, comprising an experimental class (n = 31) and a control class (n = 32), selected through a purposive sampling technique. Data were collected using a holistic ecoliteracy measurement instrument that met the criteria for validity and reliability, covering the Head, Heart, Hand, and Action dimensions. The normality test indicated that most of the data were not normally distributed ($p < 0.05$); hence, the hypothesis testing was performed using the non-parametric Mann-Whitney U test. The analysis revealed that the experimental class achieved a Normalized Gain (N-gain) score of 0.70 (high category), which was higher than that of the control class at 0.50 (medium category). The Mann-Whitney U test demonstrated a significant difference in ecoliteracy improvement between the two classes (Asymp. Sig. (2-tailed) = 0.003; $p < 0.05$). Furthermore, the effect size analysis yielded a correlation coefficient of $r = 0.38$, indicating a medium category of effectiveness. These findings suggest that integrating Problem-Based Learning with Green Chemistry principles through authentic environmental problem-solving is effective in improving students' ecoliteracy. Additionally, this learning approach has the potential to support the implementation of Education for Sustainable Development (ESD) as mandated in SDG 4.7 by strengthening knowledge, awareness, skills, and responsible actions toward environmental sustainability

Keywords: Ecoliteracy; Green chemistry; Problem-based learning; Salt hydrolysis; SDGs 4.7

Introduction

21st-century education no longer focuses solely on the transfer of pure academic knowledge, but rather on the development of global competencies and a character that is responsive to environmental degradation (OECD, 2018). This shift aligns with the mandate of SDG 4.7, which emphasizes the integration of sustainable development knowledge and lifestyles in harmony with nature (Giangrande et al., 2019). Consequently, schools are required to transform conventional learning processes into contextual vehicles that not only cultivate students' critical thinking but also foster ecoliteracy to nurture a generation of global citizens responsible for the earth's future (McBride et al., 2013). In this context, solutions to today's various environmental crises must be formulated holistically, drawing on all academic disciplines, with the formal education sector serving as the most fundamental foundation (Aini et al., 2021; Guzmán et al., 2021). In the context of science, chemistry

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education plays a highly strategic role in addressing these ecological challenges, as various concepts in the formal chemistry curriculum—one of which is the hydrolysis of salts—are closely linked, both theoretically and practically, to contemporary phenomena in the surrounding environment (Reyes, 2025; Teplá et al., 2025)

However, empirical evidence indicates that Indonesian students' ecoliteracy generally remains low, with average achievement percentages ranging from 46% to 52% (Paryanti et al., 2021; Ramadhanti et al., 2023; R. T. Sari et al., 2025; Suryanda et al., 2023). This deficient ecoliteracy is further exacerbated by the current state of chemistry education, where students struggle to connect abstract chemical theories with contextual phenomena in daily life (R. M. M. Sari et al., 2019; Vinko et al., 2026). These conceptual barriers linearly impede students' intrinsic learning motivation, ultimately triggering an accumulation of difficulties in comprehensively understanding the essence of chemical science prior to the systematic implementation of any environmentally based learning interventions (Auliah et al., 2025).

The characteristics are clearly evident in the material on salt hydrolysis, which is a very difficult concept for students (Astuti, 2023; Boncel et al., 2017; Gusman et al., 2022; Paputungan et al., 2024) particularly in the areas of solubility, the reaction of ions with water, writing chemical equations, and determining pH (Maryati, 2021). Furthermore, this deficient ecoliteracy is reflected in students' behavioral patterns; they tend to comprehend environmental issues merely as cognitive theories within the classroom, without being balanced by affective awareness or tangible actions to preserve nature (Suharja et al., 2023; Wahyuni et al., 2022).

This limited internalization of environmental values is further compounded by the dominance of conventional classroom approaches, in which salt hydrolysis concepts are delivered partially and focus solely on solving mathematical formulas (Kusumah et al., 2020). Consequently, students fail to construct a comprehensive conceptual understanding and lose the ability to contextualize hydrolysis reaction phenomena—such as agricultural soil acidity dynamics, industrial waste accumulation, or the contamination of water bodies caused by domestic detergents—with the real conditions of their surrounding ecosystems (Klemen et al., 2025). Such learning, which is decontextualized from ecological realities, ultimately creates a misconception among students that chemistry is entirely detached from their moral responsibility to preserve the global environment (Celestino, 2023; Herranen et al., 2021). The green chemistry approach offers a scientific solution that contextualizes abstract chemical concepts within real-world environmental issues through the use of safe natural materials, the reduction of laboratory waste, and energy efficiency (Anastas et al., 2000; Koulougliotis et al., 2024). However, the internalization of these green chemistry principles will not be optimal if they are conveyed solely through linear lecture methods; therefore, the integration of the Problem-Based Learning (PBL) model is necessary to engage students in investigating authentic problems, such as the impact of synthetic substance pollution or the exploitation of hazardous chemicals in the surrounding environment (Arends, 2012), This model facilitates students' independent learning through the exploration of real-world environmental problems, which fosters critical thinking skills in problem-solving (Asda et al., 2025; Hasanti et al., 2025; Safitri et al., 2023; Yerimadesi et al., 2023). Through the synergy of PBL and green chemistry, students do not merely memorize theory but are actively challenged to design green solutions through collaborative problem-solving activities (Herrera-Herrera et al., 2026). This integration directly fulfills SDG 4.7 by transforming the chemistry classroom into a space for reflection on values and effective action that boosts students' ecoliteracy (Rahmawati et al., 2022).

Although numerous prior studies have extensively explored the effectiveness of PBL model in enhancing students' cognitive learning outcomes in the topic of salt hydrolysis (Sartika & Hadi, 2021), as well as the integration of green chemistry approaches to design chemical products and processes that minimize the use of hazardous substances and reduce waste (W. P. P. Sari et al., 2023), these investigations remain fragmented. To date, no empirical study has integrated the PBL syntax with green chemistry principles systematically oriented toward SDG 4.7 targets to comprehensively measure and improve students' holistic ecoliteracy, particularly within the concept of salt hydrolysis.

The novelty of this research lies in the development of an active learning intervention wherein students are confronted with authentic problem-solving based on local environmental issues—such as substituting hazardous synthetic indicators with eco-friendly natural plant extracts—as a concrete means to realize the global mandate of SDG 4.7. Consequently, this study not only fills the research gap regarding the lack of sustainability value integration within formal chemistry education in Indonesia (Putri et al., 2025), but also offers a practical contribution by transforming abstract cognitive chemistry domains into students' affective attitudes and tangible actions toward preserving ecosystem sustainability.

Based on the aforementioned research gap, this study aims to examine the effectiveness of implementing a Green Chemistry-integrated PBL model oriented toward SDG 4.7 targets in enhancing high school students' ecoliteracy skills in the topic of salt hydrolysis. Specifically, this evaluation focuses on analyzing the

extent to which the synergy between the problem-based learning model and the green chemistry approach can boost students' comprehensive ecoliteracy, which encompasses cognitive (environmental knowledge), affective (awareness and caring attitudes), and psychomotor (tangible sustainable actions) dimensions. Through this empirical evidence, this research is expected to provide practical recommendations for chemistry educators regarding innovative learning models that not only successfully overcome misconceptions in abstract salt hydrolysis topics but are also effective in internalizing sustainable development values to nurture a younger generation responsive to global ecosystem sustainability.

Method

The method employed in this study was quasi-experimental research utilizing a Pretest-Posttest Control Group Design. The research was conducted at SMAN 1 Luhak Nan Duo during the even semester of the 2025/2026 academic year. The research population comprised two classes of Phase F students. The sampling was executed using a purposive sampling technique, specifically by selecting classes with relatively equivalent initial ability levels. Based on these criteria, Class XI Chemistry 1 was selected as the experimental group (n = 31), and Class XI Chemistry 2 was designated as the control group (n = 32).

Research Instrument

Data collection on students' ecoliteracy skills in this study was comprehensively conducted using a holistic instrument adapted from the global target indicators of SDG 4.7 and contextualized within the salt hydrolysis topic. In contrast to conventional assessments that tend to be biased solely toward the cognitive domain, the instrument in this study was designed to dissect students' environmental character thoroughly through four main dimensions: Head (cognitive), Heart (affective), Hand (psychomotor), and Action (tangible behavior). Prior to field implementation, the entire set of instruments was declared valid through content validity testing by expert judgment and proven reliable via instrument piloting in Class XII (Advanced Phase F) students who had already studied the salt hydrolysis topic. The distribution of the instrument dimensions is presented in Table 1.

Table 1. Distribution of Ecoliteracy Instrument Dimensions

Dimension	Competency Focus	Specific Indicators (Adapted to Salt Hydrolysis & SDG 4.7)	Instrument Format
HEAD (Cognitive)	Knowledge & Critical Thinking	1. Analyzing the acidity/alkalinity of industrial waste or the surrounding environment based on salt hydrolysis principles 2. Contextualizing green chemistry principles regarding laboratory waste reduction in chemistry practicals.	Multiple-Choice
HEART (Affective)	Attitudes, Values, & Empathy	1. Demonstrating concern regarding the impacts of water pollution caused by the use of hazardous synthetic chemical indicators (e.g., phenolphthalein). 2. Appreciating the importance of local wisdom in utilizing eco-friendly natural materials.	Multiple-Choice
HAND (Psychomotor)	Practical Skills	1. Possessing the skills to design safe salt hydrolysis laboratory procedures (mini-scale lab). 2. Demonstrating proficiency in extracting local flora (surrounding flowers/plants) for use as natural acid-base indicators.	Multiple-Choice
ACTION (Conative/Behavior)	Tangible Actions	1. Managing, neutralizing, and disposing of residual waste from salt hydrolysis practicals responsibly. 2. Encouraging peers or implementing a chemical waste-minimizing lifestyle in daily activities (SDG 4.7 implementation)	Short-Answer

This study was executed through three main phases: the pre-treatment phase, the intervention (treatment) phase, and the post-treatment phase. In the pre-treatment phase, both sample classes were administered a pretest to measure the students' initial ecoliteracy levels. During the intervention phase, the control group was taught utilizing a conventional model, whereas the experimental group received a PBL intervention integrated with green chemistry principles oriented toward SDG 4.7. The learning process in the experimental group was systematically designed to contextualize the abstract topic of salt hydrolysis into real-world environmental issues through five operational phases, which are presented in Table 2.

Table 2. Instructional Syntax of the Experimental Class Using Green Chemistry-Integrated PBL

Syntax Phase	Green Chemistry-Integrated Teacher & Student Activities	Stimulated Ecoliteracy Dimension
Phase 1: Orienting students to the problem	The teacher presents socio-scientific issues regarding the macro-impacts of soil acidity resulting from the use of ammonium sulfate fertilizer waste and water eutrophication caused by phosphate detergent pollution in the surrounding environment.	Head & Heart (Critical Thinking & Environmental Empathy)
Phase 2: Organizing students for study	Students are divided into collaborative groups to define salt hydrolysis problems and plan safe, structured scientific investigations	Head (Collaboration & Solution Planning)
Phase 3: Guiding individual and group investigations	Students conduct salt hydrolysis laboratory experiments by applying green chemistry principles, specifically substituting hazardous synthetic indicators (e.g., phenolphthalein) with eco-friendly natural indicator extracts derived from local flora (e.g., red cabbage, mangosteen peel, or butterfly pea flower).	Hand (Practical Green Chemistry Skills)
Phase 4: Developing and presenting artifacts and exhibits	Students process laboratory data, correlate the pH properties of salt solutions with waste pollution phenomena, and present green solutions for laboratory waste management to the class	Head & Action (Communication & Sustainable Ideas)
Phase 5: Analyzing and evaluating the problem-solving process	The teacher and students reflect on the applied green chemistry principles, identify hydrolysis misconceptions, and commit to taking tangible actions to preserve aquatic and terrestrial ecosystems (SDG 4.7 implementation).	Heart & Action (Value Reflection & Environmental Character)

Quantitative data analysis techniques were utilized to evaluate the effectiveness of the learning model. The improvement in students' ecoliteracy was calculated using the normalized gain factor formula (N-gain). he calculation of the normalized gain score, based on the following formula by Hake (2002), is defined as follows:

$$N - Gain = \frac{posttest\ score - pretest\ score}{100 - pretest\ score} \quad (1)$$

The average N-gain results were interpreted based on the criteria presented in Table 3 below:

Table 3. Classification of N-gain Score Criteria

N-Gain range	Criteria
g ≥ 0.7	High
0.3 < g < 0.7	Medium
g ≤ 0.3	Low

The statistical prerequisite test was performed by conducting a data distribution normality test using the Shapiro-Wilk test at a significance level of α=0.05. If the normality assumption was violated (the data were non-normally distributed), the hypothesis testing was pivoted to the non-parametric Mann-Whitney U statistical test. Furthermore, the effect size was calculated to measure the practical magnitude of the treatment's effectiveness using the correlation coefficient (r) based on the following formula by Cohen (1988):

$$r = \frac{|Z|}{\sqrt{N}} \quad (2)$$

Where:

$|Z|$ = the absolute value of the Z-score obtained from the Mann-Whitney U test results.

N = the total sample size from both groups ($n_{\text{experimental}} + n_{\text{control}}$)

Table 4. Cohen's Effect Size Coefficient Criteria

Cohen's r range	Criteria
r ≥ 0.5	Large effect
0.3 ≤ r < 0.5	Medium effect
0.1 ≤ r < 0.3	Small effect

Result and Discussion

The effectiveness of the Green Chemistry-integrated PBL model, oriented toward SDG 4.7, in enhancing students' ecoliteracy was analyzed based on the calculated Normalized Gain (N-gain) scores from both sample groups. A summary of the mean N-gain scores is presented in Table 5 to illustrate the comparative results.

Based on Table 5, the research results show that both classes began the learning process with relatively

low and comparable initial ecoliteracy levels, as indicated by the average pretest scores of 33.8 for the experimental class and 31.9 for the control class. However, after the intervention, the experimental class—which was taught using the Green Chemistry-integrated PBL model oriented toward SDG 4.7—showed a far more significant increase in ecoliteracy, with a posttest average of 78.4 and an N-gain index of 0.70, which falls into the high category. These results contrast with those of the control class, which used a conventional model; its posttest score reached only 64.8, with an average N-gain of 0.50, which falls into the moderate category. The superior performance of the experimental class empirically demonstrates that integrating real-world environmental issues into the PBL framework effectively transcends the limitations of rote memorization of chemical theory, leading to the development of comprehensive ecoliteracy. A visual comparison of the effectiveness of ecoliteracy improvement between the classes is presented more clearly in Figure 1.

Table 5. Descriptive Recapitulation of Pretest, Posttest, and Mean N-gain Scores

Group	N	Pretest mean	Posttest mean	N-Gain mean	N-Gain criteria
Experimental	31	33.8	78.4	0.70	High
Control	32	31.9	64.8	0.50	Medium

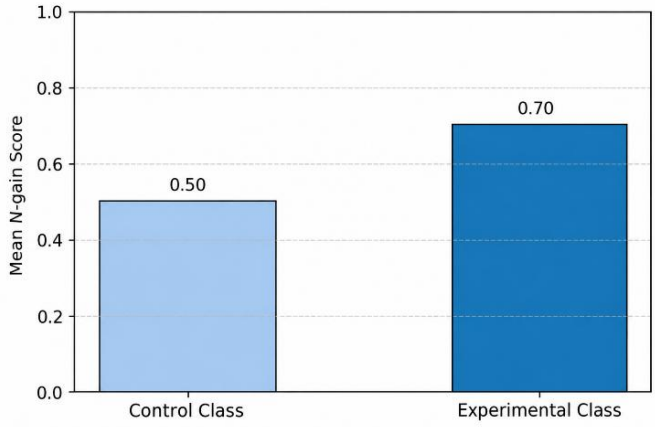


Figure 1. Comparison graph of students' mean ecoliteracy n-gain

Prior to conducting hypothesis testing to evaluate treatment effectiveness, statistical prerequisite analyses were performed by conducting a data distribution normality test on both the pretest and posttest scores of students' ecoliteracy skills. This procedure is essential for validating the assumptions required for inferential statistics in quantitative research.

Based on the data in Table 6, the normality test results indicated that the majority of the data groups were non-normally distributed, as their significance values (Sig.) were below 0.05. Specifically, the experimental group's pretest (p = 0.008), the experimental group's posttest (p = 0.003), and the control group's posttest (p = 0.024) consistently yielded p-values less than 0.05 ($p < 0.05$), thereby rejecting the assumption of normal data distribution. The only data group that demonstrated a normal distribution was the control group's pretest, with a significance value of 0.467 ($p > 0.05$).

Table 6. Normality Test Results of the Data Distribution

Data group	N	Shapiro-wilk Statistic	Sig.	Criteria
Experimental group pretest	31	0.903	0.008	Non-Normally Distributed
Experimental group posttest	31	0.886	0.003	Non-Normally Distributed
Cotrol group pretes	32	0.969	0.467	Normally Distributed
Control group posttest	32	0.922	0.024	Non-Normally Distributed

Because the majority of the data groups were non-normally distributed ($p < 0.05$), the statistical prerequisite assumptions for parametric analysis were not met. Consequently, this study did not proceed to the homogeneity of variance test; instead, the hypothesis testing was directly pivoted to a non-parametric statistical method, specifically the Mann-Whitney U test

Table 7. Results of the Mann-Whitney U Test Analysis

Statistic parameter	Students ecoliteracy
Mann-Whitney U	278.000
Wilcoxon W	806.000
Z	-3.011
Asymp. Sig. (2-tailed)	0.003

The Mann-Whitney U test results (U=278.000, Z=-3.011, p=0.003) indicate a statistically significant difference in ecoliteracy skills between students taught with the Green Chemistry-integrated PBL model (SDG 4.7) and those in the conventional class. Given the p-value is lower than the significance level (0.003 < 0.05), the findings provide empirical evidence rejecting the null hypothesis in favor of the experimental group.

These statistical results provide empirical evidence that there is a significant difference in ecoliteracy skills

between students who received the SDG 4.7-oriented PBL-Green Chemistry model (experimental group) and those who underwent conventional learning (control group).

Based on the Mann-Whitney U test output in Table 7, a Z-score of -3.011 was obtained (Z = -3.011) with a total sample size (N) of 63 students, consisting of 31 students in the experimental group and 32 students in the control group. The mathematical calculation steps to determine the effect size coefficient (r) are defined as follows:

$$r = \frac{|Z|}{\sqrt{N}} \quad (3)$$

$$r = \frac{|-3{,}011|}{\sqrt{63}}$$

$$r = \frac{3{,}011}{7{,}9373} \approx 0{,}38$$

Based on the calculation above, the effect size coefficient (r) is 0.38. According to Cohen's criteria, this value falls within the range of (0.3 ≤ 0.5), indicating that the Green Chemistry-integrated PBL model oriented toward SDG 4.7 has a medium category of effectiveness.

This medium-category effect size reflects that the combination of PBL syntax and green chemistry principles is capable of delivering a tangible and consistent impact on each dimension of students' ecoliteracy (Wardani et al., 2021). The experimental group's achievement of an N-gain score of 0.70 (high category), compared to the control group's score of 0.50 (medium category), stems from the simultaneous stimulation of four primary domains in enhancing students' ecoliteracy at SMAN 1 Luhak Nan Duo.

The Head Dimension (Cognitive): Through the socio-scientific problem orientation phase, students do not merely memorize hydrolysis formulas; instead, they are engaged in analyzing the systemic cause-and-effect relationships between the hydrolysis constants (Kh) of acidic/basic salts and the levels of soil and water contamination (Zoller, 2013).

The Heart Dimension (Affective): The introduction of global SDG 4.7 targets within chemistry learning nurtures students' ecological empathy. They begin to recognize their moral responsibility as global citizens to minimize pollution footprints from their daily activities (Giangrande et al., 2019).

The Hand Dimension (Psychomotor): Independent laboratory investigation activities provide a valuable green lab experience. Students actively execute the substitution of the hazardous synthetic indicator phenolphthalein with natural indicators derived from local plant extracts, such as butterfly pea flower or mangosteen peel. This practical skill demonstrates that chemistry experiments can be redesigned to be environmentally friendly (Koulougliotis et al., 2024).

The Action Dimension (Conative/Behavioral): Reflection at the end of the PBL syntax encourages students in the experimental group to apply waste prevention principles on a household scale, such as practicing responsible disposal of residual detergents or fertilizers (Rahmawati et al., 2022).

Conversely, in the control group, the absence of a global environmental context and green chemistry principles caused students to remain confined to a purely theoretical-algorithmic understanding. While they might be proficient in calculating the pH of salt solutions on paper, they failed to transform this knowledge into tangible actions of environmental concern. Therefore, the achieved effect size (r = 0.38) in this study provides strong legitimacy that the SDG 4.7-oriented, Green Chemistry-integrated PBL model is highly recommended as an effective alternative curriculum strategy for implementing Education for Sustainable Development (ESD) at the secondary school level (UNESCO, 2017; Zidny et al., 2020).

Conclusion

In conclusion, the implementation of the Green Chemistry-integrated Problem-Based Learning (PBL) model oriented toward SDG 4.7 is highly effective in enhancing high school students' ecoliteracy within the topic of salt hydrolysis. Empirical evidence reveals that the experimental group achieved a significantly higher average Normalized Gain (N-gain) score of 0.70 (high category) compared to the control group's score of 0.50 (medium category). This descriptive superiority is robustly validated by the non-parametric Mann-Whitney U test, which confirms a statistically significant difference in ecoliteracy improvement between the two classes (Asymp. Sig. (2-tailed) = 0.003; $p < 0.05$). Furthermore, the effect size analysis yields a correlation coefficient of r = 0.38, emphasizing a medium category of practical effectiveness. These findings indicate that the synergy between a student-centered instructional syntax and green chemistry principles successfully fosters a balanced development across the Head, Heart, Hand, and Action dimensions of ecoliteracy. Based on these outcomes, it is highly recommended that chemistry educators adopt this integrated framework as a viable pedagogical strategy to bridge the gap between abstract chemical theories and the mandate of Education for Sustainable Development (ESD). Future research should broaden the scope by examining the long-term retention of students' environmental behavior and exploring the model's scalability across diverse socioeconomic school environments and alternative chemical topics.

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Conceptualization: D. and An.; Methodology: D. and An.; Validation: An., Al., M.C.M., and R.; Formal Analysis: D., An., Al., and R.; Investigation: D. and M.C.M.; Resources: D. and An.; Data Curation: D. and An.; Writing – Original Draft Preparation: D.; Writing – Review & Editing: An., Al., and R.; Visualization: D. and An. All authors have read and agreed to the published version of the manuscript

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No conflict interest.

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