



The Effect of Green Chemistry-Integrated Project-Based Learning on Students' Learning Outcomes in Acid-Base Chemistry

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Abstract

This study aimed to determine whether students taught using the Green Chemistry-Integrated Project-Based Learning (PjBL) model achieved better learning outcomes than students taught using the Direct Instruction (DI) model on acid-base material. This study used a quasi-experimental method with a nonequivalent control group design. The sample consisted of two eleventh-grade classes at SMAN 1 Sei Bingai, with 32 students in each class. The experimental class was taught using Green Chemistry-Integrated PjBL, while the control class was taught using DI. The research instrument was a 20-item multiple-choice test on acid-base material. The data were analyzed using normality test, homogeneity test, independent sample t-test, and Cohen's d effect size analysis. The results showed that the experimental class obtained a higher posttest score (83.91 ± 10.13) than the control class (77.81 ± 11.31), with $p = 0.029 < 0.05$. The effect size was 0.56, which is categorized as a medium effect. These findings indicate that the Green Chemistry-Integrated PjBL model significantly improved students' learning outcomes in acid-base chemistry compared to the Direct Instruction model.

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INTRODUCTION

Chemistry plays an important role in explaining various phenomena encountered in everyday life through scientific principles and concepts (Rahmawan & Ashfarini, 2024). However, chemistry is often perceived as a difficult subject by students due to its abstract and complex nature, which involves macroscopic, microscopic, and symbolic representations (Yu, 2025). One of the topics frequently considered challenging is acid-base chemistry because it requires both conceptual understanding and the ability to apply concepts in real-life contexts. Previous studies have reported that students experience difficulties in understanding acid-base concepts, particularly when learning is dominated by teacher-centered approaches such as direct instruction. These conditions contribute to low student learning outcomes in chemistry (Febriani et al., 2025; Rusmansyah et al., 2024).

Based on interviews with a chemistry teacher at SMAN 1 Sei Bingai, only 40% of students achieved the Minimum Mastery Criteria in acid-base chemistry. The learning process is still dominated by the Direct Instruction model, while Project-Based Learning (PjBL) activities have not yet been optimally implemented.

PjBL is an instructional model that promotes active student participation and real-world problem solving, which contributes to improved learning outcomes (Yuna et al., 2025; Zhang & Ma, 2023). Previous studies have shown that PjBL can significantly enhance students' cognitive achievement and learning engagement (Firdaus et al., 2023). In addition, the integration of green chemistry principles into learning activities supports environmentally responsible science education by encouraging the use of safer, more sustainable, and context-based learning

processes. Studies by Asyhar & Minarni (2024) reported that the integration of green chemistry within PjBL improves students' learning outcomes in chemistry learning.

Although previous studies have examined PjBL and green chemistry separately or general integration, limited research has explicitly integrated green chemistry-based PjBL through yogurt-making projects in acid-base chemistry learning. Yogurt is produced through the fermentation of milk by lactic acid bacteria (LAB), during which the fermentation process leads to a decrease in pH levels (Nazziyah et al., 2025). This change in pH reflects fundamental acid-base concepts, particularly related to acidity and basicity, which are commonly introduced in senior high school chemistry learning. Acid-base learning also involves students' understanding of pH, including its interpretation and basic pH calculations (Herianto & Suryani, 2025; Kurniawati & Aini, 2022). In this context, yogurt production can be utilized as a contextual learning activity that is relevant to real-world situations and aligns with the principles of PjBL. Furthermore, yogurt production involves biological fermentation processes using food-grade materials without hazardous chemical reagents, making it a relatively safe experimental activity in science education. This characteristic is consistent with the principles of green chemistry, which emphasize safer, more environmentally friendly, and sustainable practices in chemical and scientific processes (Miladinović, 2025; Pertiwi & Wahyuningrum, 2024).

Based on this background, this study aims to investigate whether students taught using the green chemistry-integrated PjBL model achieve better learning outcomes than those taught using the Direct Instruction model in acid-base chemistry, and to determine the effect size of the implementation of the learning model. Additionally, this study addresses the following hypothesis: there is a significant difference in learning outcomes between students taught using green chemistry-integrated PjBL and those taught using Direct Instruction.

METHOD

Research Design

This study employed a quantitative approach using a quasi-experimental design with a nonequivalent control group design. Two existing

intact classes were used without random assignment; instead, class selection was based on the similarity of initial abilities as confirmed by pretest scores. The class with slightly higher prior knowledge balance was designated as the experimental class ($n = 32$), and the remaining class was designated as the control class ($n = 32$). The pretest results confirmed that both groups had comparable baseline achievement prior to treatment, supporting the suitability of this design for causal inference in a naturalistic school setting. The research design is presented in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O ₁	X ₁	O ₂
Control	O ₃	X ₂	O ₄

Description:

O₁ = Administration of the pretest for the experimental class before the treatment was administered

O₂ = Administration of the posttest for the experimental class after the treatment was administered

X₁ = Learning treatment using the Project-Based Learning model integrated with green chemistry

X₂ = Learning treatment using the Direct Instruction model

O₃ = Administration of the pretest for the control class before the treatment was administered

O₄ = Administration of the posttest for the control class after the treatment was administered

The population consisted of all eleventh-grade students enrolled in Chemistry classes at SMAN 1 Sei Bingai in the 2025/2026 academic year, comprising two intact classes with 32 students in each class, resulting in a total of 64 students. Total sampling was applied, meaning that all members of the population were included as the research sample. The participants consisted of both male and female students. Therefore, the findings of this study are limited to this specific school context.

The experimental class received instruction through the PjBL model integrated with green chemistry, while the control class received instruction through the Direct Instruction model. The intervention was conducted over four meetings, each lasting 2×45 minutes. In the experimental class, the learning process followed the six syntactic stages of PjBL: (1) problem orientation, (2) project planning, (3) project scheduling, (4) project implementation and monitoring, (5) product testing and evaluation, and (6) reflection (Ariyana et al., 2018). Students

completed a yogurt-making project using safe, natural, and environmentally friendly materials, consistent with the green chemistry principles of waste prevention, use of safer substances, and design for reduced environmental impact, to explore acid–base concepts. In the control class,

instruction followed the DI sequence consisting of learning orientation, teacher instruction and demonstration, guided practice, independent practice, and reinforcement (Hunaepi et al., 2019). The detailed treatment procedure for each meeting is presented in Table 2.

Table 2. Treatment Procedure

Meeting	Experimental Class	Control Class
1	Problem orientation: introduction of acid–base concepts (Arrhenius, Brønsted–Lowry, and Lewis theories), contextualized through the yogurt fermentation scenario as a real-world acid–base application	Orientation: explanation of learning objectives, review of prerequisite knowledge, and motivational introduction to acid–base concepts
2	Project planning and scheduling: designing yogurt production procedure and selecting safe and non-hazardous materials suitable for food-related experiments consistent with green chemistry principles of waste prevention and use of safer substances	Instruction and demonstration: teacher explanation of acid–base theories, pH concept, H^+/OH^- calculation, and indicator color changes, followed by worked examples
3	Project implementation and monitoring: conducting fermentation process, observing pH changes, and collected data on acid–base properties of the yogurt product	Guided practice: structured exercises on pH calculation and indicator interpretation completed under teacher supervision, with corrective feedback provided immediately
4	Product testing and evaluation: students presented their yogurt products, analyzed pH data, and evaluated outcomes against acid–base theory and reflection	Independent practice and reinforcement: students completed application exercises independently; teacher reviewed answers and provided reinforcement and corrective feedback

The research instrument consisted of a 20-item multiple-choice test designed to measure students' learning outcomes in acid–base chemistry, covering cognitive domains of understanding (C2), applying (C3), analyzing (C4), and evaluating (C5) based on Bloom's taxonomy. Content validity was established through expert judgment conducted by two chemistry education lecturers. Empirical validity was subsequently assessed through a tryout administered to 34 grade XII students who had previously studied acid–base material.

Item analysis included the assessment of difficulty index, discrimination index, distractor effectiveness, and construct validity using the point-biserial correlation coefficient (rpbis). Items were retained if they met all of the following criteria: difficulty index between 0.20 and 0.80, discrimination index ≥ 0.20 , at least one distractor selected by $\geq 5\%$ of examinees, and rpbis $> r$ -table (0.339 at $\alpha = 0.05$, $N = 34$). Of the original 40 items, 20 items met all criteria and were selected for use in the pretest and posttest. Reliability analysis was conducted using the Kuder–Richardson Formula 20 (KR-20), yielding a reliability

coefficient (r_{11}) of 0.875, which falls within the very high category (Asri et al., 2024).

Data were collected through pretest and posttest administrations in both classes, with the intervention delivered between these two assessments. Prior to hypothesis testing, the data were subjected to normality testing using the Shapiro–Wilk test and homogeneity testing using Levene's test, both at a significance level of $\alpha = 0.05$, using SPSS Version 26 for Windows. Since both assumptions were satisfied, hypothesis testing was conducted using a one-tailed independent samples t-test. The practical significance of the treatment effect was subsequently quantified using Cohen's d effect size, calculated according to the following formula (Baidowi et al., 2024; Funder & Ozer, 2019):

$$d = \frac{\bar{x}_1 - \bar{x}_2}{sd}$$

Description:

d = effect size

$\bar{x}_1$ = mean score of the experimental group

$\bar{x}_2$ = mean score of the control group

sd = pooled standard deviation

Cohen's d values were interpreted according to Cohen's (1988) criteria of effect: small ($0.2 \leq d < 0.5$), medium ($0.5 \leq d < 0.8$), and large ($d \geq 0.8$). The research procedure is summarized in Figure 1.

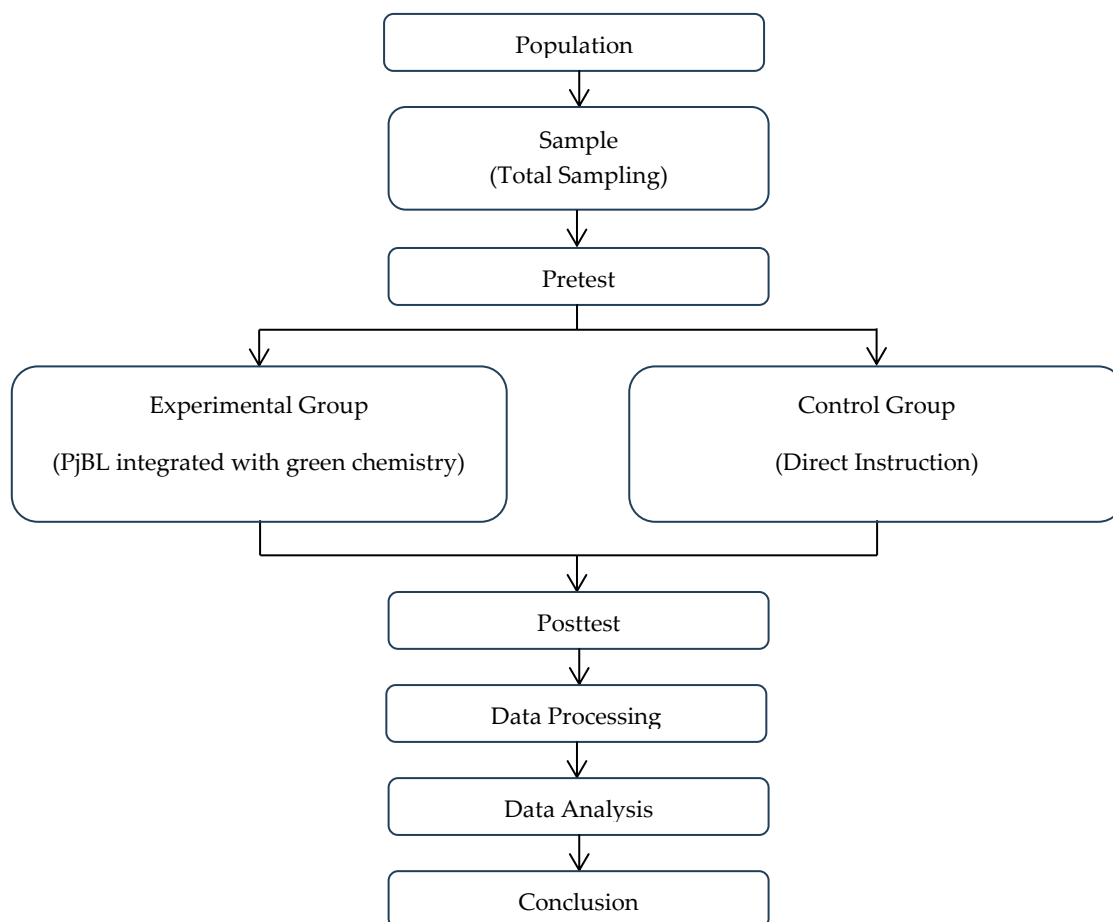


Figure 1. Flow of the research procedure

RESULTS AND DISCUSSION

Results

Prior to the main data collection, the 40-item instrument was administered to 34 grade XII students for pilot testing. Item analysis indicated that 26 items met the difficulty index criterion ($0.20-0.80$). In addition, 27 items demonstrated acceptable discrimination ($D \geq 0.20$), and 27 items were confirmed as valid based on the point-biserial correlation coefficient. Based on the combined criteria of difficulty index, discrimination index, item validity, and distractor effectiveness, a final set of 20 items was selected for use in the pretest and posttest. The reliability analysis using the Kuder–Richardson Formula 20 (KR-20) yielded a coefficient of 0.875, indicating very high internal consistency.

Learning outcome data were collected from both classes through pretest and posttest assessments. The mean pretest scores of the experimental class (35.47 ± 8.87) and the control class (36.56 ± 10.64) were comparable, indicating

that both groups had equivalent baseline knowledge prior to the intervention. Following the instructional treatment, the experimental class achieved a mean posttest score of 83.91 ± 10.13 , while the control class obtained a mean posttest score of 77.81 ± 11.31 . The descriptive statistics for both classes are summarized in Table 3.

Table 3. Descriptive Statistics of Learning Outcomes

Statistic	Experimental Class	Control Class
N	32	32
Mean Pretest ($\pm$ SD)	35.47 ± 8.87	36.56 ± 10.64
Mean Posttest ($\pm$ SD)	83.91 ± 10.13	77.81 ± 11.31
Minimum Posttest	60.00	50.00
Maximum Posttest	100.00	95.00
Students Meeting KKTP (%)	78.13%	56.25%

As illustrated in Table 3, the experimental class outperformed the control class on the posttest. The percentage of students meeting the Learning

Objective Attainment Criteria (KKTP) was substantially higher in the experimental class (78.13%) than in the control class (56.25%), indicating that PjBL integrated with green chemistry was more effective in helping students attain the required competency threshold.

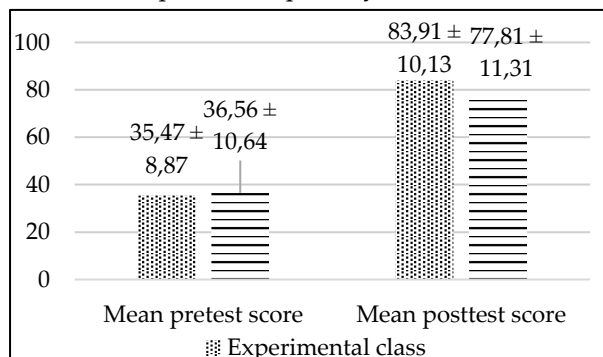


Figure 2. Comparison of Mean Pretest and Posttest Scores in Experimental and Control Classes

In addition to overall scores, the attainment of each of the five learning indicators was analyzed for both classes. The pretest and posttest indicator attainment results for the experimental class are presented in Tables 4 and 5, respectively.

Table 4. Pretest Indicator Attainment in the Experimental Class

No.	Learning Indicator	Item Numbers	Attainment (%)
1	Acid-base concepts and theories (Arrhenius, Bronsted-Lowry, and Lewis)	1-8	33.59
2	Properties of acidic, basic, and neutral solutions based on pH and indicator data	9	56.25
3	Calculating pH or H^+/OH^- ion concentration of acid and base solutions	10-13	31.25
4	Analysis of pH data and indicator color changes	14-18	31.25
5	Application of acid-base concepts in daily life	19-20	51.56

All five indicators in the experimental class exceeded the 80% attainment threshold following the intervention. The highest attainment was recorded for the application of acid-base concepts

in daily life (89.06%), reflecting the effectiveness of the green chemistry context in making scientific concepts relevant to students' lived experiences.

Table 5. Posttest Indicator Attainment in the Experimental Class

No.	Learning Indicator	Item Numbers	Attainment (%)
1	Acid-base concepts and theories (Arrhenius, Bronsted-Lowry, and Lewis)	1-8	83.98
2	Properties of acidic, basic, and neutral solutions based on pH and indicator data	9	84.38
3	Calculating pH or H^+/OH^- ion concentration of acid and base solutions	10-13	85.94
4	Analysis of pH data and indicator color changes	14-18	80.00
5	Application of acid-base concepts in daily life	19-20	89.06

The lowest attainment was on the indicator for pH data analysis and interpretation of indicator color changes (80.00%), suggesting that students still require additional practice and scaffolding in this area, as it demands higher-order analytical thinking skills. The pretest and posttest indicator attainment results for the control class are presented in Tables 6 and 7, respectively.

Table 6. Pretest Indicator Attainment of Control Class

No.	Learning Indicator	Item Numbers	Attainment (%)
1	Acid-base concepts and theories (Arrhenius, Bronsted-Lowry, and Lewis)	1-8	36.72
2	Properties of acidic, basic, and neutral solutions based on pH and indicator data	9	43.75

No.	Learning Indicator	Item Numbers	Attainment (%)
3	Calculating pH or H^+/OH^- ion concentration of acid and base solutions	10–13	31.25
4	Analysis of pH data and indicator color changes	14–18	31.88
5	Application of acid–base concepts in daily life	19–20	54.69

Table 7. Posttest Indicator Attainment of Control Class

No.	Learning Indicator	Item Numbers	Attainment (%)
1	Acid–base concepts and theories (Arrhenius, Bronsted–Lowry, and Lewis)	1–8	82.03
2	Properties of acidic, basic, and neutral solutions based on pH and indicator data	9	75.00
3	Calculating pH or H^+/OH^- ion concentration of	10–13	71.09

Table 8. Results of Normality and Homogeneity Tests

Variable	Class	Statistic	df	Sig.	Category
Shapiro-Wilk Normality Test	Experimental (Pretest)	.957	32	.232	Normal
	Experimental (Posttest)	.948	32	.124	Normal
	Control (Pretest)	.965	32	.378	Normal
	Control (Posttest)	.939	32	.072	Normal
Levene's Homogeneity Test	Both classes	.545	1, 62	.463	Homogeneous

All Shapiro–Wilk significance values exceeded $\alpha = 0.05$, confirming that the data were normally distributed. The Levene's test yielded a significance value of 0.463 (> 0.05), confirming homogeneity of variance. These results satisfied the parametric assumptions required for the independent samples t-test.

A one-tailed independent samples t-test was conducted to determine whether the mean posttest score of the experimental class was significantly greater than that of the control class. The results are presented in Table 9.

Table 9. Results of Hypothesis Testing and Effect Size Analysis

Variable	t _{test}	t _{table}	df	Sig. (1-tailed)	Cohen's d	Category
Learning Outcomes	2.234	1.671	62	0.0145	0.56	Medium effect

No.	Learning Indicator	Item Numbers	Attainment (%)
	acid and base solutions		
4	Analysis of pH data and indicator color changes	14–18	73.75
5	Application of acid–base concepts in daily life	19–20	85.94

In the control class, posttest indicator attainment was more variable, with three indicators falling below 80%. The lowest attainment was recorded for the calculation of pH and H^+/OH^- ion concentration (71.09%), indicating persistent difficulty with procedural, calculation-based tasks under a teacher-centered instructional approach. Without sufficient opportunities for repeated, hands-on practice, students in the control class struggled particularly with tasks requiring both conceptual understanding and procedural fluency.

Before conducting the hypothesis test, the assumption of normality was verified using the Shapiro–Wilk test and the assumption of homogeneity of variance was verified using Levene's test, both at $\alpha = 0.05$. The results are summarized in Table 8.

The independent samples t-test showed a significant difference in learning outcomes, $t(62) = 2.234$, which exceeded the critical value of $t\text{-table} = 1.671$. The one-tailed significance value was 0.0145, which is below the alpha level of 0.05. Based on these results, the null hypothesis (H_0) was rejected and the alternative hypothesis (H_a) was accepted. This indicates that students who were taught using the Green Chemistry-integrated PjBL model achieved higher learning outcomes in acid-base chemistry than those who received Direct Instruction.

The effect size analysis showed a Cohen's d value of 0.56. This value is classified as a medium effect according to Cohen's (1988) criteria. This suggests that the instructional model had a meaningful practical impact on student learning outcomes. The effect size indicates a moderate improvement, showing that the intervention contributed to better performance. However, further improvement may be needed to strengthen learning support for lower-performing students and to improve students' ability in data analysis.

Discussion

The results of this study demonstrate that the Green Chemistry-Integrated PjBL model produced significantly better learning outcomes in acid-base chemistry than the Direct Instruction model, as evidenced by the higher mean posttest score, a significant t -test result, and a medium effect size. These findings are consistent with and extend the existing literature on PjBL in chemistry education.

The higher achievement of the experimental class can be attributed to the implementation of Project-Based Learning integrated with Green Chemistry principles, which promotes active and contextual learning (Mitarlis et al., 2023; Said et al., 2025; Sari & Atun, 2023). In this model, students were actively involved in problem identification, project design, implementation, data collection, product evaluation, and reflection. These learning processes required students to apply acid-base concepts in meaningful real-world situations, thereby strengthening their conceptual understanding beyond memorization. This immersive engagement aligns with constructivist learning theory, which posits that meaningful learning occurs when students actively construct knowledge through direct experience (Chand, 2023). These findings are consistent with those of Yulizah et al. (2025), who reported that PjBL enhances conceptual understanding in acid-base chemistry by shifting the instructional focus from passive theory reception to active practical application, and with those of Bangun et al. (2024), who demonstrated that PjBL produces better learning outcomes on acid-base material than teacher-centered instruction.

The integration of green chemistry principles through the yogurt-making project played a particularly important role in contextualizing

abstract acid-base concepts. By observing measurable pH decreases during the fermentation of milk by lactic acid bacteria, students gained direct empirical experience of acid-base phenomena within a familiar, safe, and environmentally responsible setting. This contextual relevance is reflected in the highest indicator attainment score, which was recorded for the application of acid-base concepts in daily life (89.06%), suggesting that students who engaged with real-world, sustainable applications developed stronger connections between scientific theory and practice. This finding is consistent with Asyhar & Minarni (2024), who demonstrated that integrating green chemistry into project-based activities strengthens students' contextual understanding of chemistry concepts, and with Pertiwi & Wahyuningrum (2024), who emphasized that green chemistry promotes environmentally conscious and meaningful science education.

Despite the overall positive outcomes, the indicator related to pH data analysis and interpretation of indicator color changes recorded the lowest attainment in the experimental class (80.00%). This suggests that higher-order analytical skills, which require students to integrate observational data with theoretical concepts, remain challenging even within a PjBL environment. This finding aligns with Salame et al. (2022), who reported that students tend to prioritize memorization over genuine conceptual understanding of acid-base properties and pH interpretation, making analytical tasks particularly demanding even within active learning environments. This result indicates the need for stronger instructional support.

The difference between the experimental and control classes was also evident in the KKTP attainment rates. In the experimental class, 78.13% of students achieved the minimum competency criteria, compared to 56.25% in the control class. This difference shows that the Green Chemistry-integrated PjBL model not only improved average learning outcomes but also increased the proportion of students who met the required competency threshold. These findings align with Chintya et al. (2023) and Suradika et al. (2023), who reported that PjBL enhances student learning outcomes across various instructional contexts.

The effect size (Cohen's $d = 0.56$) falls within the medium category, consistent with Kalla &

Nurwijaya (2019), suggesting that the practical impact of PjBL tends to remain stable across different educational settings. This finding is further supported by Zhang & Ma (2023), whose meta-analysis of 66 PjBL studies demonstrated that the effectiveness of PjBL varies according to moderating variables such as class size, instructional duration, and academic level, indicating that a medium effect size is a plausible outcome in high school chemistry contexts with limited instructional sessions.

This study has several limitations. The sample was limited to two intact classes from SMAN 1 Sei Bingai, which reduces the generalizability of the findings. In addition, the study focused only on cognitive learning outcomes. Future research should include affective and psychomotor domains, such as scientific attitudes, critical thinking skills, and environmental awareness, to provide a more comprehensive evaluation of the instructional model.

CONCLUSION

This study concludes that the Green Chemistry-Integrated Project-Based Learning (PjBL) model significantly improved students' learning outcomes in acid-base chemistry compared with the Direct Instruction model. The experimental class achieved a significantly higher mean posttest score (83.91 ± 10.13) than the control class (77.81 ± 11.31), with $t(62) = 2.234$, $p = 0.029 < 0.05$, leading to the acceptance of the alternative hypothesis. The effect size analysis yielded Cohen's $d = 0.56$, indicating a medium practical effect. These findings, which are limited to the sample and school context of this study, demonstrate that the integration of green chemistry principles within a PjBL framework constitutes an effective instructional approach for improving student achievement in acid-base chemistry.

RECOMMENDATION

Based on the findings of this study, several recommendations are proposed. First, chemistry teachers and pre-service chemistry educators are encouraged to adopt the Green Chemistry-integrated PjBL model as an evidence-based instructional alternative for teaching acid-base chemistry, given its demonstrated effectiveness in improving student learning outcomes. Second, since the lowest indicator attainment was found in pH data analysis and interpretation of indicator

color changes, future implementations should include more structured worksheets, guided data interpretation activities, and repeated practice specifically targeting this competency. Third, future research is recommended to examine the effects of this instructional model on additional outcome variables, such as critical thinking skills, scientific attitudes, and environmental awareness, using larger and more diverse samples, randomized experimental designs where possible, and delayed posttest measures to assess learning retention.

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