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Impact of Project-Based Learning Implementation on Students' Achievement in Green Chemistry Concepts

Febriani[1], Muhammad Hasan[2]*, Ibnu Khaldun[2], Wipavadee Khwaengmek[3]

[1]Science Education Study Program, The Gradute School, Universitas Syiah Kuala, Banda Aceh, Indonesia.
[2]Chemistry Education Study Program, Teacher Training and Education, Universitas Syiah Kuala, Banda Aceh, Indonesia
[3]Science Education, Valaya Alongkorn Rajabhat University, Khlong Luang, Thailand

*Corresponding author's email: muhammadhasan.kimia@usk.ac.id.

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Abstract. This study is grounded in the fact that students' learning outcomes in green chemistry are relatively low, which are attributed to conventional teaching methods that involve students only minimally. This study aims to investigate the effect of project-based learning implementation on enhancing students' learning outcomes in the topic of green chemistry. A quasi-experimental design with a pretest–posttest control group was employed. The participants were tenth-grade students at MAS Darul Ihsan, assigned to an experimental class using PjBL and a control class applying traditional instruction. Data were collected through cognitive achievement tests and student activity observation sheets. The data were analyzed using an independent t-test, yielding a significance level of 0.000. Findings revealed a significant difference in learning outcomes between the two groups, with the experimental class achieving an N-Gain score of 0.73 (high category), while the control class obtained 0.37 (medium category). These results demonstrate that the implementation of PjBL effectively enhances student engagement and conceptual mastery and awareness of the importance of green chemistry principles. Therefore, PjBL can be recommended as an effective instructional model to optimize learning outcomes and foster environmentally conscious attitudes among students.
Keywords: Project based learning, learning outcomes, green chemistry

Introduction

The swift advancement of science and technology in the 21st century necessitates the education sector to produce human resources with critical thinking, creativity, teamwork proficiency and problem-solving ability in real-world contexts (Rehman et al., 2024). In chemistry education, particularly in the concept of green chemistry, students are expected not only to understand theoretical concepts but also to apply them in daily life to support sustainable development (Sharma et al., 2025). The green chemistry concept emphasizes environmentally friendly chemical principles, such as the use of safe materials, energy efficiency, and waste reduction, making it highly relevant for fostering students' environmental awareness and enhancing learning outcomes through the resolution of authentic problems (Ciriminna et al., 2024). However, in practice, students' learning outcomes in chemistry particularly in green chemistry topics remain relatively low. This is partly because chemistry is often perceived as a difficult subject due to its abstract concepts (Febriani et al., 2024). Ratnasari & Nugraheni, (2024) reported that Indonesian students ranked 68th out of 81 countries in PISA assessments, reflecting their relatively low cognitive skills. This condition is largely attributed to the dominance of conventional teaching methods, such as lectures and drill exercises, which render students passive, less motivated, and minimally engaged. Consequently, learning achievement has yet to reach its optimal level. One potential solution to address these issues is the implementation of project-based learning (PjBL).

PjBL is an instructional model that places projects at the core of the learning process, where students actively design, implement, and evaluate projects to solve real-world problems either independently or through teamwork (Ismaini et al., 2025). Through PjBL, students are provided with opportunities to explore, collaborate, and develop higher-order thinking skills (Usmeldi & Amini, 2022; Habibati et al., 2024). In the context of green chemistry, PjBL can be directed towards the creation of environmentally friendly products or the simulation of chemical processes that minimize negative environmental impacts.

Based on preliminary observations at MAS Darul Ihsan, located in Gampong Siem, Darussalam District, Aceh Besar Regency, it was found that students' chemistry learning outcomes were still categorized as low, as indicated by an average daily test score of 60.23 below the minimum mastery criterion (MMC) of 70. In addition, interviews with the chemistry teacher at MAS Darul Ihsan revealed that the teaching process still employed the direct instruction model and had never utilized the laboratory for practical activities. Vitoria et al., (2024) stated that teachers are one of the key factors influencing students' learning outcomes, both in terms of pedagogical knowledge and teaching methods applied. Furthermore, the interview results also indicated that the PjBL model had never been implemented in teaching, particularly in the green chemistry topic. This lack of student participation and collaboration in the learning process has resulted in students having limited skills in communicating ideas and concepts, which may negatively affect their learning outcomes. The current merdeka curriculum emphasizes a learning approach that places students at the core of the process, intended to improve instructional quality and promote higher levels of student participation (Syukri et al., 2025).

Earlier research has demonstrated that applying PjBL can enhance students' learning motivation, conceptual understanding, and problem-solving skills (Rahmawati & Wafiqni, 2022). Research by (Wu, 2024; Zen et al., 2022) demonstrated that PjBL has a positive impact on students' academic achievement, fosters intrinsic motivation, and plays a significant role in sustaining lifelong learning capacity. In addition, Isa & Azid (2021) reported that the PjBL approach is highly effective because it creates an enjoyable learning atmosphere, which influences students' behavior and has a positive effect on the learning process, ultimately improving their learning outcomes. Therefore, it is important to investigate the effect of PjBL implementation on improving student learning outcomes in the context of green chemistry. The purpose of this study is to determine the extent to which the PjBL model can improve student learning outcomes, so that it can serve as a reference in developing more effective, contextual, and 21st-century-oriented chemistry teaching strategies.

Methods

The research utilized a quasi-experimental method with a pretest–posttest control group design. The purpose of the research was to examine the effect of the PjBL model in improving students' learning outcomes on the concept of green chemistry. The subjects of this study were Grade X-D and X-E students at MAS Darul Ihsan in the 2024/2025 academic year. Class X-D served as the control group, receiving conventional instruction, while Class

X-E was the experimental group, receiving PjBL treatment. Each class consisted of 33 students. The research instrument used was an essay test that had been validated by three expert validators.

Data were collected through pre-tests and post-tests, as well as observations and interviews to obtain qualitative information regarding students' experiences. The data analysis was carried out in several stages: (a) instrument validity and reliability testing, (b) field trials, (c) analysis of learning outcome improvement, (d) project assessment analysis, and (e) t-test analysis.

The validity test of the test instrument was conducted by calculating Aiken's V index and determining its reliability through the intraclass correlation coefficient (ICC). The formula for Aiken's V index is as follows:

$$V = \frac{\sum s}{n\,(c-1)} \qquad (1)$$

Description:

V = Index of agreement among validators regarding item validation

S = Score assigned by each validator minus the lowest possible score

n = Number of validators

c = Number of categories available for selection by validators

The decision criteria were determined based on (Retnawati, 2016). Meanwhile, the determination of reliability using the ICC followed the procedures described by (Ismunarti et al., 2020). After being declared feasible by the validators, the test instrument will first be piloted before being implemented on the research sample. The item analysis of the trial results refers to Kadir (2015), which includes tests of validity, reliability, difficulty level, and discriminating power.

Results and Discussion

Instrument Validity and Reliability

The instrument used to assess learning outcomes consisted of 10 essay questions. Its validation process involved an analysis of the test blueprint, which included learning indicators, test items, and corresponding answer keys. Instruments considered suitable for use were refined based on feedback from three validators and subsequently administered in a trial test to evaluate their quality with respondents. A comprehensive analysis of the validity test results is provided in Table 1.

Table 1. Results of validity and reliability calculations by 3 validators

Category	Aiken index	Validity standard	ICC	Reliability standard
Essay question	0.88	High	0.526	*Fair to good*

Based on Table 1, the validation results show that the test items achieved an Aiken's V index of 0.88, which falls into the high category. The experts' agreement on the test items, measured using the ICC, was 0.526, indicating a moderately good level of agreement. The validators' consensus in assessing the alignment of the test items with the learning indicators can serve as a benchmark for determining the feasibility of the instrument. This finding is consistent with Cruz et al. (2024), who stated that item validity is related to the degree of alignment between the test items and the assessment indicators. Furthermore, Purwandari et al. (2024) reported that a high level of validity is achieved when the Aiken's V index exceeds 0.8. Therefore, the instrument developed in this study can be considered suitable for use in the learning process.

Field Testing

After the item validity process by experts was completed, the next stage was field testing of the test items to evaluate the quality of the instrument with respondents who would not be part of the main study. The items tested were those deemed valid by the validators, totaling 10 questions. The respondents for the instrument trial were Grade XI-D students of MAS Darul Ihsan. The selection was based on the consideration that green chemistry, the material employed in this study, is included in the second-semester curriculum of Grade X; thus, the instrument was administered to students at least one grade higher who had previously studied the topic.

a. Instrument Validity and Reliability

Item validity indicates the degree to which a test item is suitable for use, which is assessed by comparing the obtained r-value with the r-table as the validity benchmark. When the calculated r (the correlation coefficient between the item and the variable) exceeds the r-table value, the item is regarded as valid. Furthermore, item reliability reflects the consistency of the items in generating stable measurement results. The outcomes of the validity analyses are displayed in Table 2.

Table 2. Validity of respondent questions

No. Item	Calculated r value	Table r value	Validity
1.	0.725	0.471	Valid
2.	0.725	0.471	Valid
3.	0.609	0.471	Valid
4.	0.704	0.471	Valid
5.	0.741	0.471	Valid
6.	0.587	0.471	Valid
7.	0.811	0.471	Valid
8.	0.672	0.471	Valid
9.	0.000	0.471	Invalid
10.	0.588	0.471	Valid

Drawing on the findings of the empirical validity test for the 10 items displayed in Table 2, it was found that most of the items met the validity criteria, while item number 9 was categorized as invalid because its correlation coefficient (r-calculated) was lower than the r-table value, and therefore needed to be eliminated from the instrument. This finding is consistent with Riyani et al. (2017), who stated that an item is considered valid if the calculated r value is greater than the r-table value. The high validity of most items indicates that the instrument is generally capable of measuring aspects of critical thinking skills and is suitable for use in the study (Rodríguez-Rojas et al., 2024).

The reliability test was conducted on all items (1–10) using the Cronbach's Alpha reliability formula. The calculation results showed a reliability coefficient of 0.844, which falls into the "very high" category. This value indicates that the instrument has excellent internal consistency, meaning that each item tends to measure the same construct consistently. This finding is in line with Rashwan et al. (2024), who explained that when the r value approaches one, the instrument's reliability approaches perfection. The high reliability supports the previous validity results, confirming that the instrument is suitable for use.

b. Item Difficulty Level

The item difficulty level aims to measure how easy or difficult a test item is for students to answer. Items that are too easy or too difficult may provide invalid information about students' abilities. The difficulty level of an item can influence both the test results and its validity. Items that are too easy or too difficult may yield inaccurate assessments of test-takers' abilities. The level of difficulty for each item is shown in Table 3.

Table 3. Level of difficulty of questions

No. Item	Difficulty index	Criteria
1.	0.37	Currently
2.	0.35	Currently
3.	0.28	Difficult
4.	0.70	Easy
5.	0.38	Currently
6.	0.48	Currently
7.	0.23	Difficult
8.	0.43	Currently
9.	0.00	Difficult
10.	0.72	Easy

Based on the difficulty index values presented in the table above, items 4 and 10 fall into the "easy" category; items 1, 2, 5, 6, and 8 are classified as "moderate"; and items 3 and 7 are categorized as "difficult," as determined according to the difficulty level classification in Table 3.7. The larger the difficulty index obtained from the calculation, the easier the item is (Kunjappagounder et al., 2021). Generally, the difficulty index of an item should fall within the range of 0.3–0.7. Within this range, information about students' abilities can be obtained optimally, and items in this range are highly recommended because they are neither too difficult nor too easy (Rashwan et al., 2024).

c. Item Discrimination Index

The item discrimination index measures the extent to which a test item can distinguish between students with high and low abilities. In general, the item discrimination results indicate a reasonably adequate quality in assessing differences in students' abilities. The item discrimination results are presented in Table 4.

Table 4. Item Discrimination Index

No. Item	Discrimination index	Criteria
1.	0.333	Enough
2.	0.333	Enough
3.	0.238	Enough
4.	0.286	Enough
5.	0.524	Good
6.	0.286	Enough

7.	0.524	Good
8.	0.333	Enough
9.	0.000	Not enough
10.	0.143	Not enough

Based on Table 4, items 1, 2, 3, 4, 6, and 8 have discrimination index values ranging from 0.238 to 0.333, categorized as "fair." These items can still be used to distinguish between students who have mastered the material and those who have not. Items 5 and 7 have discrimination index values of 0.524, which fall into the "good" category. This indicates that both items can effectively differentiate between students with strong mastery of the material and those with weaker understanding. In contrast, items 9 and 10 fall into the "poor" category, with discrimination index values of 0.000 and 0.143, respectively. This suggests that these items cannot distinguish between students who have mastered the material and those who have not. The poor discrimination is due to item 9 being too difficult and item 10 being too easy, resulting in no students being able to answer these items correctly. The acceptable range for item discrimination is greater than 0.2 (Rashwan et al., 2024). Zubairi et al. (2025) stated that a good test item is one that can still distinguish between students who have mastered the material and those who have not. A higher item discrimination index indicates that the test item is more effective in distinguishing between students who have mastered the material and those who have not (Kunjappagounder et al., 2021).

Based on the results of the instrument quality testing, five items were selected according to their difficulty levels to be implemented with the research sample. The selected items were numbers 1, 2, 5, 6, and 8.

Analysis of Learning Outcome Improvement

Student learning outcomes serve as a benchmark for evaluating the effectiveness of the approaches, strategies, and models employed in instructional activities (Chaudhary & Singh, 2022). In the context of this study, learning outcomes were analyzed through quantitative measurements involving pre-test and post-test scores from two distinct groups, namely the experimental and control classes. The pre-test instrument was administered to obtain an initial overview of students' understanding prior to the intervention, whereas the post-test was conducted to measure changes after the instructional treatment was applied. The comparison between the two classes served as the basis for evaluating the effectiveness of the given intervention, in this case, the Project-Based Learning model. The experimental group was taught through the PjBL approach, whereas the control group received instruction using traditional methods. By comparing the pre-test and post-test scores and calculating the normalized gain (N-gain) for each group, the researchers were able to determine the extent to which Project-Based Learning significantly enhanced students' academic performance.

The results of this research offer not only a quantitative depiction of changes in learning outcomes but also reinforce the premise that experiential learning and active student engagement hold substantial potential for enhancing conceptual understanding (Baskoro et al., 2024; Fadhilah et al., 2023; Zhang & Ma, 2023). Accordingly, learning outcomes are not merely an end product, but rather a reflection of the quality of cognitive processes that are effectively facilitated throughout the learning activities. The students' learning outcomes are presented in Table 5.

Table 5. Results of analysis of improvements in student learning outcomes

Class	Average Value		N-Gain	Category
	Pretest	Posttest		
Experiment	36	83	0.73	High
Control	39	63	0.37	Currently

Based on the data presented in Table 5, it can be observed that the students' learning test results, as measured through pretest, posttest, and N-Gain scores, revealed a substantial difference between the experimental and control classes. The pretest scores in both classes were relatively equivalent and classified as very low, averaging 36 in the experimental class and 39 in the control class. This finding indicates that students' initial understanding of green chemistry concepts was still highly limited, possibly due to insufficient exposure to environmentally friendly chemistry concepts in prior learning experiences (Juanjuan & Shengli, 2020). Following the instructional intervention, there was a notable increase in posttest scores, particularly in the experimental class. The average posttest score in the experimental class rose to 83, whereas the control class only achieved 63. The greater improvement observed in the experimental class suggests that the Project-Based Learning model had a positive impact on students' academic achievement. The PjBL approach proved effective in enhancing students' cognitive engagement through authentic, collaborative, and contextual project-based activities, which are particularly well-suited for exploring environmental issues such as green chemistry (Burhanuddin et al., 2025). The experimental group obtained an N-Gain score of 0.73, which is categorized as a high level of improvement, while the control group achieved an N-Gain score of 0.37, indicating a moderate category. These results indicate that the implementation of the PjBL model was more effective in improving students' learning outcomes compared to conventional instructional approaches. This finding aligns with previous studies (Zhang & Ma, 2023), which demonstrated that the application of PjBL in science education contexts significantly enhances students' conceptual understanding compared to traditional methods. The consistency of results across studies strengthens the argument that PjBL is an effective strategy for improving instructional quality, particularly in contextual and multidisciplinary themes such as green chemistry.

Analysis Results of the Project Assessment

Project assessment is a form of authentic evaluation designed to measure collaboration skills, creativity, and the utilization of knowledge to solve real-life problems (Hernáiz-Pérez et al., 2021). The assessment process begins with students planning the topic of their respective projects. The results of the project assessment are presented in Table 6.

Table 6. Project assessment

No	Assessment aspects	Score/Group					
		1	2	3	4	5	6
1	Project Topic	4	4	4	4	4	4
2	Practical Tools and Materials	3	4	4	3	4	4
3	Project procedures	4	4	4	4	4	4
4	How to write down observation data	3	3	3	3	4	2
5	Clarity of presentation	2	3	3	2	3	3
6	Knowledge	3	4	3	3	2	2

7	Product appearance	4	4	4	4	1	1
	score total	23	26	25	23	22	20
	Value	82.1	92.9	89.3	82.1	78.6	71.4

Based on Table 6, it can be observed that Group 2 achieved the highest score, 92.9, indicating that this group demonstrated optimal performance across all aspects, from planning and implementation to the presentation of project outcomes. This finding aligns with Paristiowati et al. (2022), who assert that success in PjBL is strongly influenced by team effectiveness, which enhances communication and understanding of assigned tasks. Engaging in teamwork and addressing real-world problems enables project-based learning to foster a stronger sense of responsibility and self-confidence among learners (Hernáiz-Pérez et al., 2021). Furthermore, Singh-Pillay (2020) explains that the PjBL approach also promotes social learning and real-world contextual skills such as communication and collaboration which are highly valuable in the workplace and everyday life. Conversely, group 6 obtained the lowest score, 71.4, suggesting the presence of challenges in the project execution process, including collaboration, time management, and conceptual understanding. This indicates the need for teachers to provide additional guidance and support.

t-Test Analysis

The purpose of the t-test analysis is to identify whether a statistically significant difference exists between two time conditions across the two groups. When the significance value (p-value) obtained is below 0.05, it indicates that the treatment given produces a significant effect (Afla et al., 2024). The comprehensive results of the independent sample t-test are displayed in Table 7.

Table 7. t-test

Class	Average Value		Sig	Category
	Pretest	Posttest		
Experiment	36	83	0.000	H_0 rejected
Control	39	63		

Based on the analysis presented in Table 7, the significance (p) value obtained from the independent sample t-test was 0.000, which is far below the threshold of 0.05. These results demonstrate a statistically significant difference in the posttest scores between students in the experimental group and those in the control group. Hence, it can be inferred that the implementation of the PjBL model had a meaningful impact on enhancing student learning outcomes. Accordingly, the null hypothesis (H_0) is rejected, while the alternative hypothesis (H_1) is accepted. These results are consistent with the findings of Zen et al. (2022), who reported that the implementation of the PjBL model effectively enhances cognitive engagement and academic achievement, particularly in PjBL contexts that emphasize problem-solving and collaboration. With the acceptance of H_1, it can be concluded that the application of the PjBL model has a significant positive impact on improving student learning outcomes at MAS Darul Ihsan. This reinforces the importance of innovative, experience-based instructional designs in fostering 21st-century competencies (Paristiowati et al., 2022).

Conclusion

Based on the findings, the implementation of PjBL has been shown to exert a positive influence on improving students' learning outcomes in the context of green chemistry. Through PjBL, students became more actively engaged in the learning process, demonstrated the ability to connect theoretical content to real-life contexts, and developed critical, creative, and collaborative thinking skills. Project activities designed in alignment with the principles of green chemistry enabled students to gain a deeper conceptual understanding, enhanced their learning motivation, and fostered awareness of the importance of applying environmentally friendly chemical practices. Improvements in learning outcomes were evident in the cognitive domain, as indicated by a statistically noteworthy disparity between pre-intervention and post-intervention results. Therefore, the PjBL model can be recommended as an effective instructional strategy for teaching green chemistry concepts while simultaneously cultivating students' environmental awareness and responsibility.

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