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Pembelajaran Berbasis Proyek Kolaboratif dengan Tema Produk Ramah Lingkungan: Meningkatkan Pemahaman Konseptual Siswa tentang Hukum Dasar Kimia

(Collaborative Project-Based Learning with Eco-Friendly Product Theme: Improving Students' Conceptual Understanding of Basic Chemical Laws)

Devita Marlina Venessa[a*], Ariyatun[a], Vida Zenitha Sudariasri[a], Fera Kuraysia[b], Dira Ayu Annisa[c]

[a]*Chemistry Education, Faculty of Teacher Training and Education, Universitas Negeri Jakarta, Jakarta, Indonesia, 13220*
[b]*Community Education, Faculty of Teacher Training and Education, Universitas Negeri Jakarta, Jakarta, Indonesia, 13220*
[3]*Chemistry Education, Faculty of Teacher Training and Education Universitas Khairun, Ternate, Indonesia, 97719*

[*]*Corresponding author:* devita.marlina@unj.ac.id

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ABSTRACT. A strong understanding of basic chemistry concepts is essential in science education, but students often struggle because of the material's abstract nature and a tendency to memorize rather than understand. Conventional teaching methods often fail to connect these concepts to real-world phenomena, ultimately leading to persistent misconceptions. To overcome this, an integrated approach is needed that can bridge theoretical knowledge with practical contexts across disciplines. This study aims to analyze the effectiveness of a collaborative interdisciplinary physics-chemistry Project-Based Learning (PjBL) model with the theme of Eco-Friendly Products to improve understanding of basic chemistry concepts. The method employed a quasi-experiment with a one-group pretest-posttest design involving 55 tenth-grade students at a private high school in Jakarta. Quantitative data in the form of pretest and posttest scores were analyzed using descriptive statistics, paired t-tests, Pearson correlations, and N-Gain, while qualitative data were collected through observation, project reports, video documentation, and presentations. The results showed an increase in the average score from 66.36 on the pretest to 85.55 on the posttest, with the percentage of mastery increasing from 45.45% to 90.91%. The decrease in standard deviation indicates that the distribution of scores became more even. Statistical analysis shows a statistically significant increase ($p<0.001$) and a moderate positive correlation between initial and final scores. Holistic assessment of project reports and presentations further indicates that students effectively integrated chemistry concepts into real-world designs. In conclusion, the collaborative PjBL model significantly improved conceptual understanding and encouraged a more even distribution of student performance. This model effectively bridges theoretical knowledge with practical skills and fosters critical thinking and collaboration in high school chemistry education.

INTRODUCTION

A strong conceptual understanding of the basic laws of chemistry is an essential foundation of science education, especially at the high school level. Mastering this fundamental material is crucial but often presents a significant challenge for students. Several studies have shown that students generally experience learning difficulties in topics related to the basic laws of chemistry, such as stoichiometry, which are highly dependent on understanding basic concepts[1], [2] This learning barrier arises because of students' tendency to memorize the steps for solving problems without understanding the basic concepts [3]. Furthermore, the abstract nature of chemistry, which involves representations at the invisible particle level, directly impacts students' low ability to understand the relationship between the macroscopic and submicroscopic levels, which seriously impacts their understanding of chemical concepts [1], [4].

The conventional teaching methods also pose a major challenge because they rarely link basic chemical laws to real-world phenomena. Conventional teaching often focuses on symbolic and submicroscopic aspects without establishing strong connections between conceptual levels, making it difficult for students to connect the macroscopic, submicroscopic, and symbolic levels, leading to misconceptions in chemical concepts [5], [6]. Inappropriate teaching methods without building proper scientific meaning for students can lead to misconceptions, especially in the aspect of submicroscopic representation [7], [8]. The use of a learning approach that integrates all levels of chemical representation, integrated with real-world contexts, can connect chemical concepts with real-life situations, phenomena, and increase students' chemical interest and literacy [9].

One learning approach that integrates real-world contexts and has been shown to improve student learning outcomes is Project-Based Learning (PjBL). Based on several studies, the implementation of the project-based learning (PjBL) model effectively develops students' critical thinking, creativity, communication, and collaboration skills by engaging them in authentic, real-world projects[10]. In the process, students actively ask essential questions, design schedules, and manage science-related projects, thereby encouraging deeper engagement and conceptual understanding. Experimental studies have shown that PjBL not only significantly improves science learning outcomes but also positively impacts motivation and creativity. Furthermore, when integrated with the STEM approach (PjBL-STEM), this model has been shown to be superior at improving conceptual mastery and critical thinking [11]. The main advantage of PjBL is its ability to facilitate deep learning by completing authentic tasks that directly train essential competencies, such as problem-solving and collaboration [12].

The effectiveness of PjBL in one field of study has been widely demonstrated, but its application in interdisciplinary collaboration, such as chemistry and physics, remains very limited. A systematic review of the literature on PjBL in high school chemistry over the past decade (2013-2023) indicates a significant increase in publications. Overall, PjBL is an effective and promising approach in high school chemistry learning, but research design and evaluation still need to be strengthened to increase empirical evidence of its impact, because most of these studies are still limited to qualitative evidence, so the validity of its learning impact is not always strong[13]. In addition, although PjBL is recognized for successfully connecting chemistry concepts to real-world contexts, many of the projects produced remain interdisciplinary or broad STEM initiatives, lacking a sustainable, specific curriculum design to integrate physics concepts into introductory chemistry materials. A bibliometric study covering the period 2015-2022 also shows that PjBL research generally still focuses on developing 21st-century skills in a single discipline and rarely connects the basic laws of chemistry with the law of conservation of energy[14]. This has led to “epistemic fragmentation,” in which students regard the phenomena of matter and energy change as two separate entities, even though in nature they are inseparable.

In response to prior research recommendations to deepen content and enhance interdisciplinarity [13], this study implements a collaborative Project-Based Learning (PjBL) model on the topic of Eco-Friendly Products. This topic is part of the context of effective STEM learning as an integrative cross-disciplinary context (physics-chemistry) in promoting scientific concept understanding, creativity, and science literacy[15], [16], [17]. The Eco-Friendly Product topic was chosen as the context for the PjBL project because it is well-suited to integrating chemistry concepts (material formation reactions and fundamental laws of chemistry) with physics concepts (energy conservation, isolated systems, and energy). This interdisciplinary integration allows students to understand the interaction between energy, technology, and the environment comprehensively, thereby building social awareness of sustainable energy issues[17], [18]. Unlike previous studies that typically used only one type of learning outcome or were purely qualitative, this study employed a more comprehensive evaluation approach, encompassing dynamic learning outcomes (tests, presentations, and prototypes) and static learning outcomes (project reports) to enhance the validity of student learning outcome data. Through this systematic interdisciplinary collaborative approach, students' conceptual understanding is expected to improve holistically. Therefore, this study analyzes the effectiveness of the PjBL model on Eco-Friendly Products in improving students' conceptual understanding, particularly of basic chemistry concepts, which are often considered abstract and difficult to grasp.

RESEARCH METHOD

This study employs a quasi-experimental one-group pretest-posttest design using a collaborative interdisciplinary Physics-Chemistry Project-Based Learning (PjBL) model. A quantitative approach will be used to analyze learning outcome data (pre-test and post-test), and quantitative performance assessment data, based on five predetermined criteria, will be presented to provide an overview of the implementation of PjBL related to the topic of Eco-Friendly Products, carried out collaboratively across the disciplines of chemistry and physics.

This study involved 55 tenth-grade students from a private high school in West Jakarta. The research subjects were selected through purposive sampling from two specific classes (XA and XB) with the following criteria: (1) initial assessment results showed that students in both classes had difficulty understanding the basic laws of chemistry, (2) recommendations from physics teachers because students faced similar obstacles in learning the law of conservation of energy, and (3) the relevance between the basic laws of chemistry and the law of conservation of energy being studied. Through this cross-subject collaboration, it is hoped that students' conceptual understanding can be improved not only through conventional tests but also through project-based learning (PjBL).

This study used a one-group pretest-posttest design carried out in three stages: preparation, implementation, and evaluation [19].

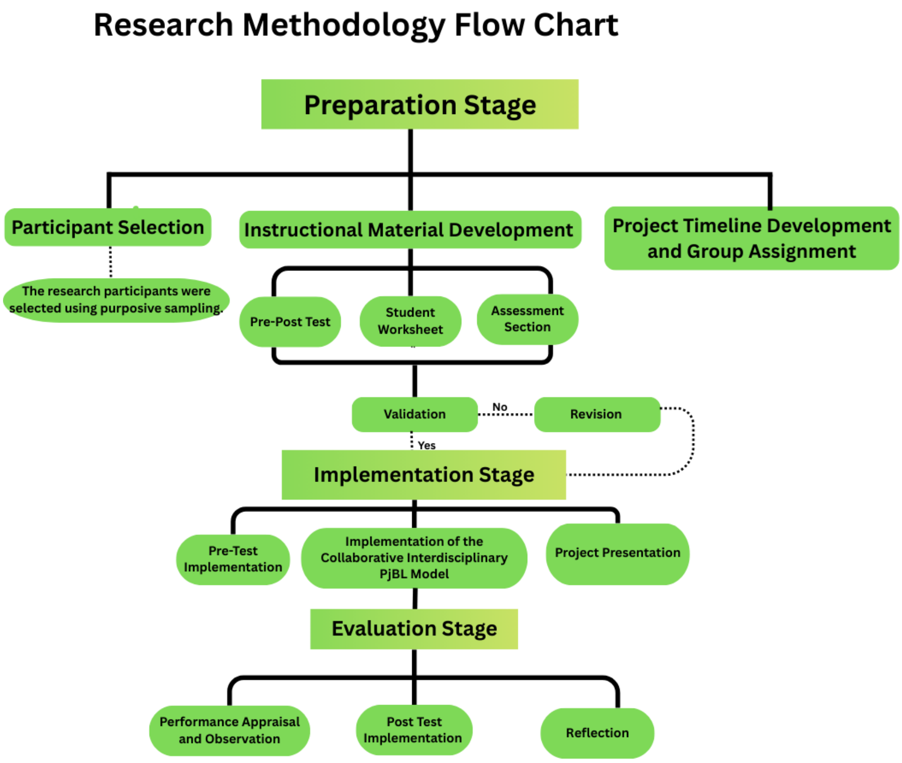

Figure 1. Collaborative interdisciplinary PjBL research flowchart

Preparation Stage

At this stage, researchers developed test instruments and student worksheets containing project identities, project instructions, project timelines, themes for 10 groups, assessment rubrics, and guiding questions. These student worksheets served as guidelines for students in designing, implementing, presenting, and collecting final products in the form of prototypes, video documentation, and project reports. Multiple-choice and essay tests are used to assess students' understanding of basic chemistry and energy concepts before and after the learning intervention. Questions are compiled based on learning indicators drawn from the high school chemistry curriculum and the literature. The test instruments cover topics such as stoichiometry, basic chemistry, energy changes, gases, and their application in the context of eco-friendly products. The questions were designed with varying levels of difficulty to measure knowledge and application of concepts. All questions were gradually revised based on validator feedback, particularly regarding language, contextual clarity, and distractor quality, to better distinguish between students who understood the concepts and those who did not.

An instrument for analyzing group performance holistically using a performance assessment rubric. This instrument is designed to observe final outputs in the form of (1) video documentation of the experiment process, (2) written reports on project results, and (3) presentations by each group in class. The assessment rubric shows quantitative data used to assess group performance based on assessment parameters that have been determined through the rubric, namely:

1. Project Planning and Design: the ability to identify problems, formulate hypotheses, and design experiments.
2. Experiment Implementation and Collaboration: laboratory skills, ability to work together in groups, adaptability, and problem-solving.
3. Integration of Chemical Concepts: understanding and application of chemical concepts and their integration across disciplines, e.g., with physics in renewable energy projects.
4. Data Collection and Analysis: quality of data acquisition (e.g., electrical power data, product volume, etc.), ability to analyze and interpret experimental results.

5. Communication and Documentation: quality of video documentation, ability to present in class, and ability to reflect on and summarize results.

Implementation and Evaluation Stage

The research began with a diagnostic test (pre-test). The pre-test data were used to calculate the increase in average score, standard deviation, minimum score, maximum score, and the percentage of students achieving the minimum passing standard. The quantitative data obtained were further analyzed using descriptive statistics. Following the implementation of PjBL, a final test is administered to assess students' understanding upon project completion. The final test (post-test) will be compared with the initial test (pre-test) to assess the effectiveness of the PjBL model using normalized gain (N-Gain) analysis, Pearson's correlation, and a paired-samples t-test.

The implementation of collaborative Project-Based Learning (PjBL) across the chemistry and physics disciplines occurred in several systematic stages. The implementation of this learning model was carried out in accordance with the PjBL syntax shown in Figure 2, emphasizing active collaboration between teachers and students. Quantitative data were obtained using a performance assessment rubric to provide an objective picture of the implementation of the collaborative PjBL model across chemistry and physics disciplines.

Figure 2. Stages of implementing Collaborative Project-Based Learning (PjBL) across the disciplines of chemistry and physics

RESULTS AND DISCUSSION

Quantitative Analysis of Students' Increased Understanding of Basic Chemistry Concepts

Pre-test and post-test data obtained before and after the implementation of the collaborative interdisciplinary physics-chemistry Project-Based Learning (PjBL) model were analyzed using descriptive statistics. Based on pretest results from 55 students, the average pretest score was 66.36%, with a maximum of 100 and a minimum of 25. The number of students who achieved the minimum passing standard of 75 was 45.46%. The standard deviation was 15.75. In contrast, post-test scores following the implementation of PjBL averaged 85.55, with a maximum of 100 and a minimum of 70. In addition, the percentage of students who achieved the minimum passing standard increased from 45.45% to 90.91%, while the standard deviation changed from 15.75 to 6.89. These data are presented in Table 1.

Table 1. Statistical analysis results from student pre-tests and post-tests.

Value Range	Pretest			Post Test			N-Gain
	Number of Students	Percentage	Standard Deviation	Number of Students	Percentage	Standard Deviation	
0-40	1	1,81%	15,75	0	0,00%	6,89	0,51
41-60	16	29,09%		0	0,00%		
61-80	29	52,73%		12	21,82%		
81-100	7	12,73%		40	72,73%		
Average	66,36			86,55			
Std. Error Mean	2,124			0,914			
Percentage completion	45,45%			90,91%			

Based on pretest scores, students' abilities varied greatly, and there was a significant gap in understanding between high-ability and low-ability students prior to the implementation of collaborative interdisciplinary PjBL in Physics-Chemistry. Similar studies also show a significant gap in understanding between high- and low-ability students, especially in abstract concepts such as the law of constant proportion, the law of multiple proportions, and the law of conservation of mass [18], [20], [21]. This is due to the material's abstract nature and the lack of contextual application of concepts and of minimal interdisciplinary collaboration. Therefore, this interdisciplinary collaborative PjBL learning model is expected to accommodate highly heterogeneous classes to encourage low-ability students to collaborate with higher-ability students.

The post-test results show a change in students' conceptual understanding after the implementation of the collaborative Project-Based Learning (PJBL) model in physics and chemistry. The average class score increased from 66.36 to 85.55. This shows that the majority of students have gained a better understanding of the concepts and successfully met the learning objectives after participating in the learning process. In addition, the minimum standard completion rate increased from 45.45% to 90.91%. Through the implementation of collaborative PJBL across the disciplines of physics and chemistry, the learning mastery targets were achieved, and students' conceptual understanding increased significantly. This finding is in line with several studies showing that PJBL can increase student motivation, engagement, and conceptual understanding[22], [23], [24], [25] .

Based on the data distribution analysis, the average pre-test score of 66.36 (SD = 15.75) indicates substantial variability in participants' initial understanding prior to the learning intervention. Conversely, the average post-test score increased to 85.55, with a lower standard deviation (6.78), indicating that collaborative interdisciplinary PjBL learning not only increased cognitive averages but also improved understanding among students, with understanding becoming more evenly distributed and relatively consistent across students. The decrease in standard deviation indicates that the differences in ability among students became smaller, such that the collaborative process succeeded in evening out learning outcomes. The smaller standard error of the mean (SEM) in the post-test (0.91 vs. 2.12) indicates greater precision of the mean estimate following the intervention.

Statistical analysis also showed a Pearson correlation of 0.511 ($p < 0.001$) between pre-test and post-test scores. This indicates a statistically significant moderate positive relationship. This implies that participants with higher initial scores also tended to obtain higher final scores, although the increase in scores was general across all groups. This correlation also supports the assumption that the data were obtained from the same subjects (within-subjects design), thereby making the use of the paired-samples t-test methodologically appropriate.

Table 2. Data Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	PreTest - Posttest	-19.18182	13.60023	1.83386	-22.85848	-15.50516	-10.460	54	.000

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The paired-samples t-test indicates a statistically significant decrease in the pre-test-post-test difference (average difference = –19.18). This negative value is conventionally interpreted as an average increase of 19.18 points from the pre-test to the post-test. The standard deviation of the difference of 13.60 reflects individual variation in the magnitude of the score increase. The calculated t-value of –10.46 with degrees of freedom (df) = 54 resulted in a two-tailed significance value of $p < 0.001$, which is well below the threshold of $\alpha = 0.05$. Thus, the null hypothesis (that there is no difference in mean between the pre-test and post-test) was rejected. This indicates that the application of the tested learning method has a substantial impact on participants' learning outcomes. In addition, the 95% confidence interval for the mean difference ranges from –22.86 to –15.51, which does not include zero, supporting the conclusion that the increase was not due to chance but was a real effect of the learning intervention.

An N-Gain of 0.51 indicates that it falls within the moderate category. Based on this analysis, the application of the collaborative PjBL model across the disciplines of Physics and Chemistry effectively improves students' conceptual understanding, although there remains room for improvement to achieve optimal results. Thus, the application of the collaborative PjBL model significantly improves students' conceptual understanding. Several studies also show that PjBL can improve learning outcomes, creativity, motivation, and students' collaboration and critical thinking skills[10], [26], [27] Collaborative PjBL has a significant effect on improving students' conceptual understanding, especially of basic chemistry concepts.

Descriptive Analysis of Collaborative Project-Based Learning Implementation

In the implementation of collaborative PjBL in chemistry and physics, researchers collaborated with teachers of both subjects, starting with the design of worksheets as a guide for eco-friendly projects consisting of learning objectives, work instructions, project themes, timelines, and assessment criteria, while students were given the freedom to design procedures independently based on valid sources. Learning begins with essential questions about how to apply chemistry and physics concepts to design energy-efficient and environmentally friendly products, and how to communicate the design results in clear and polite language. This question encourages students to conduct more in-depth investigations and is expected to increase student engagement, improve conceptual understanding, foster critical thinking, strengthen collaboration, and prepare students to solve real-world problems, especially in technological development [28], [29].

During the implementation stage of collaborative PjBL, 55 students were divided into 10 groups, with each group assigned a different theme determined by a random draw. The 10 eco-friendly project themes were: (1) Solar-powered lamps (DIY solar panels), (2) Energy storage using homemade batteries, (3) Water heaters using chemical reactions (exothermic), (4) Making ice cubes using endothermic reactions, (5) Making mini wind turbines from recycled plastic, (6) Photosynthesis reactions in a closed ecosystem, (7) Simple evaporative refrigerator, (8) Making soap from used oil (saponification reaction), (9) Water filter with activated carbon (adsorption), (10) Mini electric vehicle based on recycled materials. Each group member collaborated to develop a timeline, analyze the literature, prepare procedures and project requirements, create work products, and present them. At each stage of this PJBL implementation, each group was enthusiastic in preparing their project plans.

The project was conducted over two weeks outside of class, with teacher guidance to ensure the accuracy of the concepts and procedures used to create the prototypes. Of the ten groups, nine produced prototypes aligned with the theme, whereas one group created a prototype that did not match the expected theme, although the principles of their prototype were still consistent with the basic laws of chemistry and the law of conservation of energy. In general, each member of the group was actively involved, creative, and critical in integrating concepts and in creating their group's prototype.

The activity then continued with presentations, demonstrations, and holistic assessments through reports, videos, observations, and presentation media to provide a comprehensive picture of the quality of interdisciplinary PjBL implementation. At each stage of PjBL implementation, the holistic assessment process focused on observing group work, project products (final reports, project documentation videos, and prototype results), and prototype presentations. Holistic assessment aimed to comprehensively evaluate group performance and generate quantitative data aligned with predetermined assessment parameters. Holistic assessment is conducted by converting qualitative observational results into quantitative data using assessment parameters defined in a rubric. The rubric uses a multi-level Likert scale and performance rubric descriptions to ensure objectivity and increase the reliability of the assessment. This approach refers to project-based authentic assessment standards that emphasize the integration of scientific skills, conceptual understanding, and soft skills, as recommended in various Project-Based Learning literature that has been analyzed[30], [31], [32]. The criteria for the group performance observation assessment are presented in Table 3.

Tabel 3. Description of Subcriteria for PjBL Group Performance Observation Assessment

Criteria	Sub criteria	Score	Description
Project Planning and Design	Problem Identification	(4) Very Good	The problem is clearly identified, relevant to everyday life, and demonstrates the interrelationship of complex physics and chemistry concepts.
		(3) Good	The problem is well identified and demonstrates the interrelationship of physics and chemistry concepts.
		(2) Fair	The problem is identified, but the interrelationships among the concepts remain unclear.
		(1) Poor	The problem is unclear or does not demonstrate the interrelationship of concepts.
	Hypothesis Formulation	(4) Very Good	Logical, measurable hypothesis that accurately combines physical and chemical principles
		(3) Good	Logical hypothesis that demonstrates understanding of basic concepts
		(2) Fair	A hypothesis exists, but it is inaccurate
		(1) Poor	The hypothesis is illogical or does not exist
	Experimental Design.	(4) Very Good	Systematic design, clear variable control, and measurement methods
		(3) Good	Good design with adequate variable control
		(2) Fair	Adequate design but with deficiencies in variable control
		(1) Poor	Unsystematic or unclear design
Experimentation and Collaboration	Laboratory Skills	(4) Very Good	Proper use of tools and materials, safety procedures followed, and skilled experimental techniques
		(3) Good	Proper use of tools, safety observed
		(2) Fair	Fair use of tools, but minor errors
		(1) Poor	Improper use of tools or disregard for safety
	Team Collaboration	(4) Very Good	Clear division of tasks, effective communication, mutual support, and conflicts resolved well
		(3) Good	Good collaboration with effective communication
		(2) Fair	Adequate collaboration, but communication issues
		(1) Poor	Poor collaboration or dominated by one member
	Adaptation and Problem Solving	(4) Very Good	Able to solve technical problems creatively and scientifically
		(3) Good	Able to solve problems with minimal assistance
		(2) Fair	Able to solve problems but requires guidance
		(1) Poor	Unable to solve problems that arise
Integration of Chemistry Concepts and Interdisciplinary Approaches	Understanding Chemical Concepts	(4) Very Good	Demonstrates a deep understanding of relevant chemistry concepts
		(3) Good	Good and accurate understanding of chemistry concepts
		(2) Fair	Sufficient understanding of chemistry concepts, but with errors
		(1) Poor	Weak or incorrect understanding of chemistry concepts
	Cross-Disciplinary Integration	(4) Very Good	Demonstrates the complex relationship between physics and chemistry concepts very clearly
		(3) Good	Demonstrates the relationship between concepts well
		(2) Fair	Demonstrates the relationship but lacks depth
		(1) Poor	Does not demonstrate integration or misunderstands the concept
Data Collection and Analysis	Data Quality	(4) Very Good	Complete, accurate, and systematically collected data
		(3) Good	Good and complete data
		(2) Fair	Fairly complete data, but with some deficiencies
		(1) Poor	Incomplete or inaccurate data
	Interpretation	(4) Very Good	In-depth analysis with accurate and critical interpretation
		(3) Good	Good analysis with accurate interpretation
		(2) Fair	Adequate analysis, but interpretation lacks depth
		(1) Poor	Weak analysis or incorrect interpretation
Communication and Documentation	Video Documentation Quality	(4) Very Good	Clear video, good audio, professional editing, appropriate length
		(3) Good	Good video with adequate technical quality
		(2) Fair	The video is clear, but there are minor technical issues
		(1) Poor	The video is unclear or of poor technical quality
	Presentation of Results	(4) Very Good	Systematic, clear, interesting, and easy to understand presentation
		(3) Good	Good and easy to follow presentation

Criteria	Sub criteria	Score	Description
		(2) Fair	Adequate but not systematic presentation
		(1) Poor	Unclear or difficult to understand presentation
	Reflection and Conclusion	(4) Very Good	In-depth reflection, accurate conclusions, constructive suggestions for development
		(3) Good	Good reflection with accurate conclusions
		(2) Fair	Adequate reflection, but the conclusions lack depth
		(1) Poor	Weak reflection or inaccurate conclusions

Based on the holistic assessment rubric in Table 3, the holistic assessment results for the implementation of the Chemistry-Physics collaborative learning-based project (PjBL) are presented in Table 4.

Table 4. Performance Assessment Results for 10 Groups Based on 5 Criteria.

Groups	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	Total Nilai
1	18,75	23,25	15	9,50	16,75	83,25
2	16,25	25,00	20	9,50	16,75	87,5
3	18,75	18,75	20	7,50	16,25	81,25
4	18,75	18,75	15	7,50	16,75	76,75
5	18,75	23,25	12,5	7,50	18,00	80
6	12,50	14,50	20	7,50	17,00	71,5
7	16,25	18,75	17,5	7,50	18,00	78
8	16,25	23,00	15	9,50	18,00	81,75
9	18,75	21,25	20	7,50	18,00	85,5
10	18,75	25,00	12,5	9,38	18,75	84,5

* **Criteria 1**: Project Planning and Design
Criteria 2: Experimentation and Collaboration
Criteria 3: Integration of Chemistry Concepts and Interdisciplinary Approaches
Criteria 4: Data Collection and Analysis
Criteria 5: Communication and Documentation

A descriptive analysis and evaluation of the overall implementation of PjBL for ten Eco-Friendly projects indicate adequate understanding in both the presentation of materials and the demonstration of the products produced. Each group successfully presented their products, although improvements were needed in their reports and in the application of basic chemical laws and the law of conservation of energy that they integrated into the ten projects. Some documentation of the collaborative PjBL implementation is shown in Figure 3.

Figure 3. Three examples of student projects: a. Exothermic reaction water heater, b. Soap from used cooking oil, and c. Energy storage with homemade batteries.

Observational analysis and evaluation indicate that the overall implementation of PjBL in ten Eco Friendly Product projects was successful, as evidenced by students' ability to explain concepts and demonstrate the prototypes they developed. Almost all groups were able to relate the project to the basic laws of chemistry and the law of conservation of energy, although some still needed improvement in theoretical accuracy and report writing. Descriptively, this project activity helped students build a deeper conceptual and applied understanding than memorization, mainly due to feedback from physics and chemistry teachers that reinforced the accuracy of concepts[10]. In addition to improving science comprehension, PjBL also develops students' technical skills in designing, testing, and modifying prototypes, in line with previous research findings stating that PjBL is effective in improving conceptual understanding, higher-order thinking skills, and practical skills [26], [33], [34], [35].

In terms of collaboration, PjBL plays an important role in building cooperation, empathy, communication, and a culture of mutual support within the group [36]. Student reflections indicate positive changes in collaboration, clear role division, the ability to overcome team members' weaknesses, and a positive, enjoyable work environment despite time pressure. Each group member will assume their assigned role and work together to produce an effective prototype. Each member plays a role and contributes to a healthy and collaborative work culture.

Similarly, in this study, each group member acknowledged that PjBL had a very positive effect on improving teamwork. Some of the students' reflections quoted from the reflection form are as follows:

Student A: *"I feel very grateful because my friends are united and willing to work together. Everyone works and helps each other. I think this group is quite united."*

Student B: *"My role in the group is as an important person in the group because I can work independently and together. We are not selfish toward one another. Everyone contributes to the project. All individuals possess distinct skill sets. However, there are some weaknesses. We can overcome the weaknesses in our respective skill sets by developing ourselves."*

Student C: I was responsible for gathering information and related tasks. I did my best, even though there was still much I needed to correct in the information I found. Therefore, the group helped one another to complement and cover one another's weaknesses and mistakes.

Student D: We were pressed for time, but we managed to complete the collaborative project by finishing our video. We managed to complete it while having fun and not getting bored or sleepy.

Student E: My experience in working on collaborative projects is that we are experienced in establishing cooperation and solidarity with one another.

Project-based learning also strengthens students' social and emotional skills, increases active participation, and creates a dynamic and participatory learning atmosphere [36], [37]. Overall, PjBL not only strengthens interdisciplinary understanding in physics and chemistry, but also develops innovation, communication, collaboration, and project supervision skills that form the basis for successful final product creation and student readiness to face future challenges [38].

CONCLUSIONS

The application of the collaborative interdisciplinary PJBL learning model in physics and chemistry significantly improved students' understanding of basic chemistry concepts. The pretest results indicated an initial average score of 66.36% and a mastery rate of approximately 45.46%. After the implementation of PjBL, the average post-test score increased to 85.55 with a mastery rate of 90.91%. The decrease in standard deviation and error indicates that students' understanding became more uniform and consistent after learning. Statistical analysis shows a significant increase in scores and a positive relationship between pretest and posttest scores.

In addition, descriptive analysis of the ten projects shows that PjB can improve conceptual understanding and encourage other skill improvements. Holistic assessment, analyzed from the final products, namely project reports, classroom observations, and prototype presentations, revealed that students were able to integrate chemistry concepts in the design and implementation of real projects, improving their technical and applied skills. PjBL encourages students to think critically, work collaboratively, and develop applied skills in designing experiments and prototypes, while simultaneously strengthening their technical and cognitive abilities.

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