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Research Article

Efforts to Improve Grade 12 Students' Learning Outcomes on the Topic of Electrolysis Through the Problem-Based Learning Model

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Abstract
This study investigates the implementation of Problem-Based Learning (PBL) to improve the chemistry learning outcomes of 12th-grade students on the topic of electrolysis. Chemistry learning often presents difficulties because many concepts are abstract, especially those involving microscopic processes such as ion movement and redox reactions. Preliminary observations revealed that more than 40% of students in class XII MIPA-1 at SMA Kolese De Britto had not yet reached the Minimum Completion Criteria (KKM = 80) on the topic of electrochemistry, with an average score of 70.57. To address this issue, PBL was applied as it emphasizes contextual problem-solving, student engagement, and the development of 21st-century skills. This research used a Classroom Action Research (CAR) design conducted in two cycles, each including planning, implementation, observation, and reflection. The participants were 30 male students aged 17–18. The instruments consisted of: (1) a learning achievement test with 10 essay items developed according to basic competencies and scored with a rubric, (2) an observation sheet with 10 indicators of participation, collaboration, and discipline, (3) a Likert-scale questionnaire with 20 statements to assess motivation, perception, and problem-solving skills, and (4) documentation of learning activities through photos, field notes, and student products. Data were analyzed both quantitatively (mean scores, mastery percentages) and qualitatively (observations, questionnaires, reflections). The results showed a significant increase in student achievement. The average score rose from 70.57 (33.33% mastery) in the pretest to 79.57 (63.33% mastery) after Cycle I, and 85.16 (80% mastery) after Cycle II. Questionnaire results also indicated improved motivation and collaboration, from 85.07% in Cycle I to 89.59% in Cycle II. Observations confirmed more balanced participation and greater problem-solving engagement. Overall, this study concludes that PBL is effective for improving understanding of electrolysis while fostering critical thinking, collaboration, communication, and creativity. The findings highlight that contextual problem-solving and guided discussions are crucial for bridging abstract chemistry concepts with real-world applications, making PBL a powerful approach for chemistry education.

Keywords: Problem-Based Learning, Electrolysis, Learning Outcomes, Classroom Action Research

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1. INTRODUCTION

Entering the 21st century, education is required to produce human resources with essential competencies, including critical thinking skills, effective communication, creativity, and collaboration (Trilling & Fadel, 2009). Improving the quality of learning needs to focus on developing these skills through approaches that encourage active student engagement, context-based problem-solving, and collaboration. In the context of chemistry learning, the challenges are even greater because many concepts are abstract, involve microscopic processes, and require high-level reasoning skills.

One of the most challenging topics is electrolysis. This topic requires not only an understanding of redox concepts but also skills in reasoning about ionization mechanisms, electron transfer, and the resulting electrochemical products. Without appropriate learning strategies, students often struggle to connect abstract concepts with real-world phenomena, resulting in suboptimal learning outcomes. Initial observations in grade XII MIPA-1 at SMA Kolese De Britto showed that more than 40% of students had not yet achieved the Minimum Completion Criteria (KKM = 80), with a previous average score on the Voltaic Cell topic of only 75.80. Other obstacles identified include low participation in discussions, limited ability to relate concepts to everyday life, and a tendency for teacher-centered learning.

This situation emphasizes the need for innovative learning models that can increase student engagement while deepening conceptual understanding. PBL is a relevant model because it emphasizes real-world problem-solving as the foundation of learning. Through PBL, students are guided to conduct investigations, group discussions, and reflection, thus developing critical thinking, communication, and collaboration skills (Arends, 2012; Hosnan, 2014).

However, research on the application of PBL to electrolysis at the high school level is still relatively limited. This material requires learning strategies that can bridge abstract conceptual understanding with real-life applications. Therefore, this study was conducted in the form of a two-cycle Classroom Action Research (CAR) to improve the learning outcomes of 12th-grade MIPA-1 students at SMA Kolese De Britto in electrolysis through the application of the PBL model.

1.1. Literature Review

To provide a strong theoretical basis for this study, this section reviews key concepts related to learning outcomes and the PBL model. It also highlights previous research that has investigated the effectiveness of PBL in improving student achievement and skills in science learning.

1.1.1. Learning Outcomes

Learning outcomes are changes in student behavior as a result of the learning process. According to Sudjana (2005), they cover cognitive, affective, and psychomotor domains. Suprijono (2018) emphasizes that outcomes should be viewed as holistic behavioral change, not just cognitive achievement. Internal and external factors influence achievement (Sugihartono et al., 2007), and thus the use of appropriate learning models is essential.

1.1.2. Problem-Based Learning (PBL)

PBL is a learning model that uses real-world problems as the starting point for learning. Students are guided to identify problems, gather information, conduct investigations, discuss in groups, and develop solutions collaboratively. The hallmarks of PBL are independent learning, group discussions, and the development of higher-order thinking skills (Arends, 2012).

The general syntax of PBL includes five stages (Hosnan, 2014):

a. Problem orientation: The teacher explains the learning objectives and motivates students to engage in problem-solving.
b. Organizing students: Students are helped to define the problem and formulate the steps of the investigation.
c. Independent and group investigation: Students seek relevant information, conduct experiments, and find solutions.
d. Developing and presenting results: Students prepare a report, presentation, or product based on the problem.
e. Analysis and reflection: Students reflect on the results of the investigation and evaluate the learning process.

The syntax of PBL is shown in Table 1.

Table 1. Syntax of Problem-Based Learning (PBL)

Phase	Learning Stage	Educator Behavior
1	Provide orientation about the problem to students	Educators discuss learning objectives, describe various important logistical needs, and motivate students to engage in problem-solving activities.
2	Organize students to research	Educators help students to define and organize learning tasks related to their problems.
3	Assist in independent and group investigations	Educators motivate students to obtain accurate information, conduct experiments, seek explanations, and solutions.
4	Developing and presenting work	Educators help students plan and prepare appropriate work, such as reports, video recordings, and models, and help them communicate them to others.
5	Analyzing and evaluating the problem-solving process	Educators help students reflect on their investigations and the processes they used.

Existing studies have reported the effectiveness of PBL. For instance, Hmelo-Silver (2004) highlighted its role in building conceptual understanding. Loyens et al. (2015) found that PBL fosters bigger conceptual change. Kirschner et al. (2006) argued that problem-based approaches to complex learning improve knowledge transfer efficiency. Recent research also indicates that PBL effectively enhances learning outcomes, critical thinking skills, and student collaboration in chemistry learning (Sari et al., 2025; Putri, 2022; Haryanto & Kusmiyati, 2021).

Thus, PBL is considered relevant for application in electrolysis learning because it can bridge the understanding of abstract concepts with their real-life application, while simultaneously developing 21st-century competencies such as critical thinking, communication, collaboration, and creativity (Trilling & Fadel, 2009).

2. METHODS

2.1. Research Design

This study is a CAR conducted in two cycles. Each cycle consists of four stages: planning, implementation, observation, and reflection, referring to the spiral model of Kemmis and McTaggart (2010). CAR was chosen because it aligns with the research objectives, namely, to improve learning practices and enhance student learning outcomes sustainably.

2.2. Participants

The research subjects in the study were 30 male students in grade XII MIPA-1 at SMA Kolese De Britto Yogyakarta, aged 17–18. The selection of subjects was based on initial observations that indicated students' low understanding of the topic of electrolysis and low engagement in learning.

2.3. Research Instruments

The research instruments included:

2.3.1. Learning Outcome Test

The test was used to measure students' cognitive achievement after the actions in each cycle. The test consisted of 10 essay questions developed directly by the researcher based on the Basic Competency Framework for Electrolysis. The questions were structured according to the formulated learning indicators, thus effectively representing students' understanding of the concept of electrolysis. This test is administered at the end of each cycle to determine the extent to which students have mastered the material and to identify developments in understanding from cycle to cycle. Each item assessed specific indicators such as understanding ion migration, electrode reactions, and electrochemical products. The test was scored using a rubric on a 0–100 scale.

2.3.2. Observation Sheet

The observation sheet was employed to assess the level of student engagement throughout the learning process. It comprises ten indicators that capture various dimensions of engagement, such as active participation in discussions, willingness to express opinions, collaborative ability, and discipline. Each indicator is rated on a 1–4 scale, representing categories from very poor to very good.

2.3.3. Student Response Questionnaire

This questionnaire was used to determine students' responses, perceptions, and motivations regarding the implementation of the PBL model. The questionnaire was structured on a Likert scale ranging from 1 to 5, ranging from "strongly disagree" to "strongly agree." Questionnaires covered aspects of learning motivation, interest in electrolysis, group collaboration, and perceptions of learning effectiveness. Data from the questionnaire provide a snapshot of students' attitudes and learning experiences, thus complementing the results obtained from tests and observations.

2.3.4. Documentation

Documentation was used to supplement research data through visual recordings and written archives. Documentation includes photographs of learning activities, field notes, student attendance lists, and group work results. These instruments provide tangible evidence of the implementation of actions while supporting data obtained from other instruments. Documentation also serves as evaluation material, reflection, and reinforcement for research reports, making them more objective and accountable.

2.4. Procedures

This research is a CAR study, which aims to continuously improve and enhance the quality of learning practices, thereby enhancing quality, developing educator skills, increasing efficiency, and fostering a culture of research among educators.

The research model used is a CAR design, following the spiral model developed by Kemmis and McTaggart in Kasbolah (2001). Two cycles were implemented in total. If the first cycle did not show the expected improvement, the cycle was continued until the results were satisfactory. The cycles according to this model are shown in Figure 1.

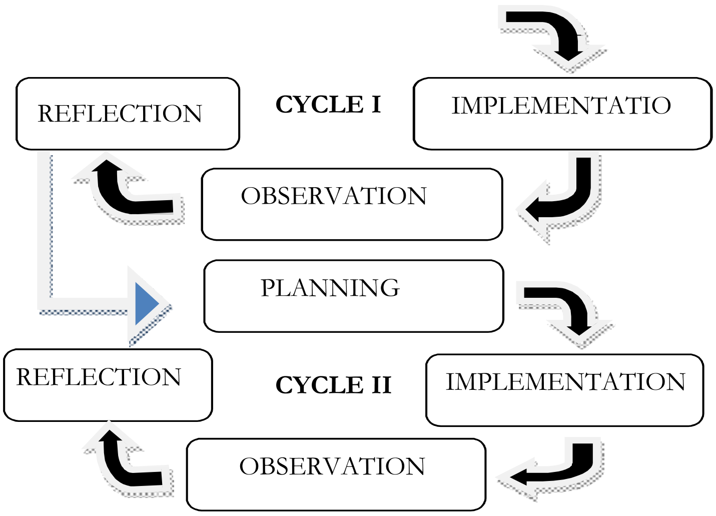

Figure 1. Kemmis & McTaggart Model

This CAR consists of four series of activities typically carried out by educators in a recurring cycle. The four main activities in each cycle are planning, acting, observing, and reflecting. The CAR model used in this study is a spiral model and is implemented in two cycles, as described below:

Cycle I

In the planning stage, lesson plans, student worksheets, test instruments, observation sheets, and questionnaires were developed. The contextual problems selected were related to electrolysis processes in everyday life, such as metal plating. During the implementation stage, the teacher organized students into heterogeneous groups of five to six members, provided an orientation to the problem, and facilitated group discussions to analyze the mechanism of electrolysis. Throughout the process, student activities were monitored using structured observation sheets. In the reflection stage, the outcomes of the group discussions were examined to identify necessary improvements to be implemented in Cycle II.

Cycle II

During Cycle II, the planning stage focused on revising the learning materials based on reflections from Cycle I, including arranging more balanced group divisions to improve collaboration. In the implementation stage, students were presented with more complex problems, such as analyzing electrolysis products in various solutions, while the teacher provided scaffolding through guiding questions to enhance student engagement. Observation activities were carried out by reassessing student participation using established observation instruments. Finally, the reflection stage involved evaluating the effectiveness of the improvements made and determining the extent to which the learning outcomes had been achieved.

2.5. Data Analysis

Data analysis in this study employed both quantitative and qualitative approaches. Quantitative data derived from student learning test results were examined through several procedures. First, the mean score was calculated to determine the progress of students' learning outcomes in each cycle, using the formula:

$$\bar{X} = \frac{\Sigma Xi}{N}$$

where $\bar{X}$ represents the average score, ΣXi the total student scores, and N the number of students. Second, the percentage of learning completion was determined by comparing the number of students who achieved the Minimum Completion Criteria (KKM = 80) with the total number of students, then converted to a percentage using the formula:

$$\text{Completion (\%)} = \frac{\text{number of students who completed}}{\text{total number of students}} \text{ x } 100\ \%$$

Third, improvements across cycles were evaluated by comparing the average scores and completion percentages from Cycle I and Cycle II to assess the effectiveness of the implemented learning model.

Qualitative data were obtained through observations, questionnaires, and documentation, and analyzed descriptively. Observation data were examined to identify changes in student activity based on indicators such as engagement, cooperation, and participation, which were then categorized into predefined criteria (very good, good, sufficient, and poor). Questionnaire data were scored, converted into percentages, and interpreted to reveal shifts in student motivation. Documentation—including photographs, field notes, and recordings—was analyzed narratively to describe classroom dynamics and corroborate findings from observations and questionnaires.

Through the integration of quantitative and qualitative analyses, this study offers a comprehensive understanding of students' learning outcomes, activity levels, and motivational changes throughout the implementation of the learning model.

3. RESULTS

This CAR was conducted in two cycles with the aim of improving the learning outcomes of grade XII MIPA-1 students at SMA Kolese De Britto on electrolysis through the application of the PBL model. The data obtained consisted of quantitative data in the form of student learning test results and qualitative data in the form of observations, student response questionnaires, and reflections on the learning implementation.

3.1. Quantitative Data

3.1.1. Pretest Results

Before the intervention was administered, the pretest results showed that the average score of grade XII MIPA-1 students was 70.57, with only 10 students (33.33%) achieving the Minimum Completion Criteria (KKM) of 80. This indicates that most students did not adequately understand the basic concepts of electrolysis.

3.1.2. Cycle I Test Results

After the implementation of PBL in the first cycle, learning outcomes improved. The average student score increased to 79.57, with the number of students completing the course increasing to 19 (63.33%). However, there were still 11 students who had not achieved completion. These results indicate that the implementation of PBL has begun to have a positive impact, but implementation in Cycle I was not optimal.

3.1.3. Cycle II Test Results

Improved learning strategies in Cycle II, such as dividing students into more heterogeneous groups and providing scaffolding in the form of trigger questions, resulted in improved learning outcomes. The average student score increased to 85.16, with 24 students (80%) achieving the Minimum Competency (KKM), while only 6 students remained incomplete. This indicates that the research target of at least 80% of students achieving learning mastery was achieved.

A summary of student learning outcomes in the pretest, Cycle I, and Cycle II is presented in Table 2.

Table 2. Summary of Student Learning Outcomes

Stage	Number of Students	Average Score	Number of Students Completed	Percentage of Completion (%)
Pretest	30	70,57	10	33,33
Cycle I	30	79,57	19	63,33
Cycle II	30	85,16	24	80,00

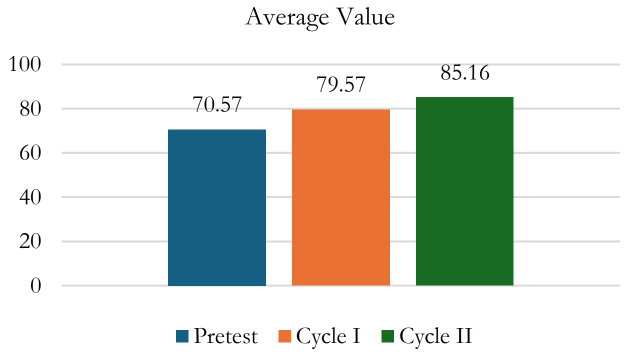

Figure 2. Average Student Scores

Based on the data obtained, the implementation of the learning model evidently had a positive impact on students' cognitive learning outcomes. The improvement in student performance is illustrated through several graphical representations. Figure 2 presents the average student scores across the pretest, Cycle I, and Cycle II, showing a steady increase from 70.57 in the pretest to 79.57 in Cycle I, and further rising to 85.16 in Cycle II. This upward trend reflects significant progress in students' mastery of the material.

Similarly, Figure 3 demonstrates the percentage of students achieving learning completion at each stage. The proportion of students who met the completion criteria increased from 33.33% in the pretest to 63.33% in Cycle I, eventually reaching 80.00% in Cycle II. This improvement indicates that a greater number of students were able to meet the expected competency standards following the intervention.

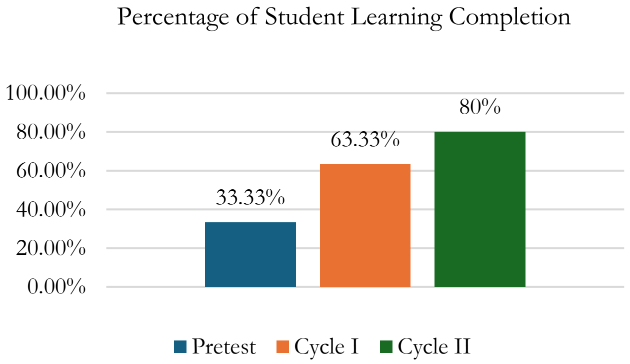

Figure 3. Percentage of Student Learning Completion

Furthermore, Figure 4 illustrates the number of students who achieved learning completion across the three phases. Initially, only 10 students met the completion benchmark during the pretest. After the implementation of the learning model in Cycle I, this number rose to 19. The improvement continued in Cycle II, where 24 students successfully achieved completion. This consistent increase across the stages clearly highlights the effectiveness of the intervention in enhancing student learning outcomes from the initial phase to the conclusion of the learning cycle.

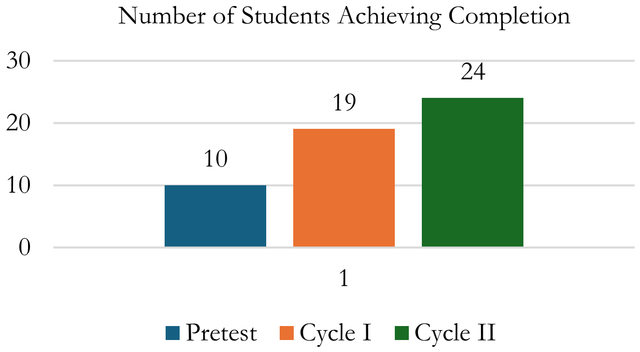

Figure 4. Number of Students Achieving Completion

3.2. Qualitative Data

Qualitative data were collected through activity observations, student response questionnaires, and learning documentation. The questionnaire findings presented in Table 2 indicate an improvement in the quality of student responses, with the average score increasing from 85.07% in Cycle I to 89.59% in Cycle II.

Observations of student activities during the learning process also showed clear progress from Cycle I to Cycle II. In Cycle I, group discussions were still uneven, with certain students dominating while others remained passive. Interaction between groups during presentations was limited, suggesting that collaborative engagement had not yet been fully optimized. In Cycle II, however, students demonstrated greater enthusiasm during discussions, expressed their opinions more confidently, and were more active in responding to other groups' presentations. With the teacher's guidance, encouraging each member to contribute, participation became more evenly distributed across groups.

Student responses to the implementation of PBL were assessed using a Likert-scale questionnaire (1–5). The overall results revealed an increase in positive perceptions across nearly all measured aspects. As shown in Table 3, the average student response rate rose from 85.07% in Cycle I to 89.59% in Cycle II, indicating stronger acceptance and engagement with the PBL approach.

Table 3. Student Responses to Learning

Assessed Aspects	Cycle I (%)	Cycle II (%)
Learning Motivation	78.71	83.87
Understanding of Material	80.65	83.87
Problem-Solving Skills	82.58	92.26
Cooperation in Discussions	87.74	89.68
Interaction with Peers	89.68	95.48
Improved Learning Outcomes	86.45	89.68
Interest and Enjoyment in Learning	89.68	92.26
Overall Average	85.07	89.59

Reflections conducted at the end of each cycle provided insight into the effectiveness of the learning process. In Cycle I, challenges included unequal group composition, limited participation during presentations, and learning outcomes that did not meet the expected targets.

Table 4. Cycle I Reflection Table

Number	Observations	Improvement Plan
1	Group assignments are still uneven in terms of ability.	Differentiate groups to create more engaging discussions and presentations.
2	During presentations, not all members present their discussion material.	Provide direction so that each group member actively participates during presentations
3	During group presentations, other groups provide little feedback.	Provide motivation and incentives for students to respond to other groups' presentations
4	Student interaction during discussions is not even.	The teacher guides the discussion so that all members participate and actively interact.
5	Test scores on the quizzes do not meet the expected assessment.	Strengthen understanding of the material through practice questions and more in-depth discussions.

In Cycle II, improvements were implemented by reorganizing groups, providing clearer instructions, and integrating more contextual problems. These adjustments proved effective, as reflected in the increased student participation and improved learning outcomes.

Table 5. Cycle II Reflection Table

Number	Reflection	Good Things Done
1	Students are more enthusiastic in discussions, more confident when expressing their opinions, and are able to solve problems	Enhancing literacy skills to improve mastery of the material
2	Students are more confident in responding when other groups present their discussion results	Providing reinforcement and encouragement to participate more actively in the learning process
3	Students have a better grasp of the material, resulting in improved learning outcomes	Improving the ability to understand the material and manage time when taking tests

Overall, the findings demonstrate that the implementation of PBL enhanced student achievement—from an average score of 70.57 (pretest) to 85.16 in Cycle II—raised the completion rate from 33.33% to 80%, promoted more active participation in discussions and presentations, and strengthened students' motivation, collaboration, and problem-solving skills.

4. DISCUSSION

The implementation of Problem-Based Learning (PBL) has been proven to elevate the learning outcomes, participation, and motivation of 12th-grade MIPA-1 students at SMA Kolese De Britto in electrolysis. The average score increased from 70.57 in the pretest to 79.57 in Cycle I and 85.16 in Cycle II, with completion increasing from 33.33% to 80%. Student response to learning also increased from 85.07% in Cycle I to 89.59% in Cycle II. The most significant improvements were seen in problem-solving skills and discussion engagement, indicating that PBL fosters both motivation and collaborative skills.

The differences between Cycle I and Cycle II can be explained by the dynamics of implementation. In Cycle I, group discussions were not optimal because some students dominated, while others tended to be passive. Conceptual understanding was also uneven, as some students struggled to interpret ionic reactions and the role of electrodes. Improvements made in Cycle II included forming heterogeneous groups, providing scaffolding in the form of trigger questions and contextual practice problems, creating more balanced engagement, and achieving a more focused understanding. Students also became more accustomed to the PBL model, gaining confidence in discussions, managing time, and assigning roles. This explains the increase in average grades and the achievement of learning completion according to the Minimum Competency (KKM). These findings align with PBL principles, which emphasize active engagement, information integration, and the development of conceptual understanding through interaction (Hmelo-Silver, 2004; Loyens et al., 2015).

The contextual problems used, such as metal plating and identifying electrolysis products from various solutions, facilitate students' connection to reality. This process is crucial for bridging theory with practice and encouraging conceptual restructuring (Kirschner et al., 2006). These results are consistent with recent research reporting that PBL enhances critical thinking, creativity, and problem-solving skills through active student engagement in science learning (Jamilah et al., 2023; Rachmawati & Rosy, 2021).

The teacher's role in providing scaffolding is also crucial. Trigger questions posed during discussions serve as cognitive buffers to help students when they encounter difficulties, thereby reducing cognitive load and allowing information to be processed more effectively (Tarmizi & Bayat, 2012). Recent studies also confirm that the combination of PBL with teacher scaffolding results in increased motivation and conceptual understanding (Putri, 2022; Fauziah et al., 2023).

Overall, these research findings support the finding that PBL is an effective strategy for improving understanding of chemistry concepts and developing 21st-century skills. Numerous studies, both nationally and internationally, have shown that PBL contributes to improved collaboration, communication, and critical thinking skills in students (Sari et al., 2025; Haryanto & Kusmiyati, 2021; Suci et al., 2022; Martha et al., 2025; Jamilah et al., 2023). Thus, PBL can be seen as a comprehensive approach that connects abstract concepts with their real-life applications while simultaneously training essential 21st-century competencies.

5. CONCLUSION

This two-cycle classroom action research study demonstrated that the implementation of PBL was effective in promoting the learning outcomes of 12th-grade MIPA-1 students at SMA Kolese De Britto on electrolysis. Cognitive achievement increased significantly, with the average score rising from 70.57 in the pretest to 79.57 in Cycle I and 85.16 in Cycle II. The proportion of students achieving mastery also improved, from 33.33% in the pretest to 63.33% in Cycle I, and finally to 80% in Cycle II. Student learning activities also improved, indicated by more equitable engagement in discussions, presentations, and group interactions. Student responses to the learning process became more positive, with the average questionnaire score increasing from 85.07% in the first cycle to 89.59% in the second cycle, particularly in the areas of problem-solving, motivation, and social interaction. Overall, PBL not only strengthened understanding of the abstract concept of electrolysis but also fostered 21st-century skills, namely critical thinking, communication, collaboration, and creativity.

However, this study has limitations as it involved only one class of 30 male students from one school and was limited to the topic of electrolysis. The instruments used also did not include authentic assessments or long-term data that could provide a more comprehensive picture.

Based on these findings and limitations, future research is recommended to expand the scope to other chemistry topics, involve larger and more diverse samples, and compare the effectiveness of PBL with other innovative learning models such as project-based learning, inquiry-based learning, or STEM learning. Long-term studies are also needed to assess the sustainability of PBL's impact on students' academic achievement and learning attitudes.

6. LIMITATIONS AND RECOMMENDATIONS

Although the study demonstrated positive impacts, several limitations should be acknowledged. The research involved only one class of 30 male students, which restricts the generalizability of the findings to broader and more diverse populations. The study context was confined to a single school and one chemistry topic (i.e., electrolysis), so the effectiveness of PBL on other topics or educational levels remains uncertain. The instruments employed consisted of achievement tests, observations, and questionnaires, without the inclusion of authentic assessments or in-depth interviews that could have provided richer qualitative insights. Additionally, the study was conducted over only two cycles, limiting the ability to capture the long-term influence of PBL on students' learning development. Variations in students' learning styles were not examined in depth, although the effectiveness of PBL may differ for visual, auditory, or kinesthetic learners. Gender aspects were also not considered, as all participants were male, thereby limiting the applicability of the results to mixed-gender or female student groups.

Based on these findings and limitations, several recommendations can be proposed. For teachers, PBL may be considered a promising strategy to enhance learning outcomes and 21st-century skills; it is recommended that teachers design contextual, relevant problems and incorporate technology-based media, such as electrolysis simulations, to support students' understanding of abstract concepts. For schools, professional development in the form of training or workshops on PBL implementation is essential to ensure that teachers are equipped to design and facilitate effective problem-based learning; integrating PBL within a competency-based curriculum is also crucial to familiarize students with contextual problem-solving across subjects. For future researchers, expanding the scope to other chemistry topics, involving a larger and more diverse sample, and comparing the effectiveness of PBL with other innovative instructional models, such as project-based learning, inquiry-based learning, or STEM approaches, is strongly recommended. Further studies may also explore hybrid approaches, such as combining PBL with STEM education or virtual laboratories, to better meet the demands of 21st-century learning. Including mixed-gender classes or female participants is necessary to determine whether gender influences the effectiveness of PBL. Longitudinal research is also needed to assess the sustainability of PBL's impact on academic performance and learning attitudes over time. Moreover, incorporating additional instruments, such as in-depth interviews, portfolios, or authentic assessments, would provide a more comprehensive understanding of the influence of PBL on students' cognitive and non-cognitive development.

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Research Ethics. This study was conducted in full accordance with the ethical principles outlined in the Declaration of Helsinki.

Data Availability Statement. All data can be obtained from the corresponding author.

Conflicts of Interest. The author declares no conflicts of interest.

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