ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25may2177

Effect of Problem-Based Learning on Secondary School Chemistry Students' Achievement in the Law of Electrolysis, Oyo Town

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Publication Date: 2025/06/09

Abstracts: This study examined the effect of Problem-Based Learning (PBL) on secondary school chemistry students' achievement in the Law of Electrolysis in Oyo Town, Nigeria. Despite the importance of chemistry as a foundational science subject, students' performance in topics like electrolysis has persistently remained low, attributed to its abstract nature and the predominance of conventional, teacher-centered instructional strategies. A quasi-experimental design, involving non-equivalent control and experimental groups with pre-test and post-test measures, was adopted. A total of 58 Senior Secondary II Chemistry students from two purposively selected public secondary schools participated in the study. The experimental group received instruction through PBL, while the control group was taught using the traditional lecture method. Data were collected using the Electrolysis Accomplishment Test (EAT) and analyzed using Analysis of Covariance (ANCOVA). The results revealed a significant main effect of PBL on students' achievement in the Law of Electrolysis ($F_{(1, 55)} = 8.043$, $p < 0.05$, $\eta^2 = 0.838$), with students in the PBL group outperforming those in the control group. Additionally, a significant interaction effect of teaching method and gender was observed ($F_{(1, 53)} = 43.944$, $p < 0.05$, $\eta^2 = 0.914$), though the gender-based performance difference within each group was not statistically significant. The findings affirm the effectiveness of PBL in enhancing students' conceptual understanding and academic performance in challenging chemistry topics, regardless of gender. The study recommends integrating PBL into secondary school chemistry curricula and promoting the professional development of teachers in learner-centered instructional approaches.

Keywords: *Problem-Based Learning, Chemistry Achievement, Law of Electrolysis, Secondary School, Gender, Nigeria.*

How to Cite: Bolarinwa, O. T; Abubakar A; Akintokun O. A.; Adedoyin, S. A.; Adeoye, B. A. (2025) Effect of Problem-Based Learning on Secondary School Chemistry Students' Achievement in the Law of Electrolysis, Oyo Town. *International Journal of Innovative Science and Research Technology*, 10(5), 3963-3969. https://doi.org/10.38124/ijisrt/25may2177

I. INTRODUCTION

Science education refers to the combination of science and education. In the same line, studying science provides educational benefits. It is necessary for both national development and technological advancement. It allows pupils to develop certain competencies as well as the proper attitudes and values required for peaceful coexistence and the resolution of specific societal security concerns (Fakai, Namagare, Abdullahi, and Dabai, 2023). The importance of high-quality scientific instruction in Nigerian secondary schools cannot be overstated because it prepares students for professions in STEM (science, technology, engineering, and mathematics) (Obialor, Mbaegbu, Okonkwo, and Okonkwo, 2022). The Law of Electrolysis is an abstract subject that often presents difficulties for students to understand due to its intricate theoretical underpinnings and real-world implications, because electrolysis involves the motion of electrons and ions, which are not readily visible. Nevertheless, despite its importance, teaching and learning science courses like physics and chemistry frequently face challenges, such as abstract ideas, a lack of resources, and teacher-centered teaching strategies that do not adequately interest students (Murniningsih, Muna, and Irawati, 2020). Students may find it challenging to comprehend the calculations and mathematics required by Faraday's Laws, especially when they are mixed with irrelevant and real-world applications. Students' capacity to interact with the material may be hampered by their inability to connect these concepts to actual circumstances.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25may2177

The Chief Examiner's Report (2012) for WAEC Physics 2 on electrolysis, which concentrates on the definition of electrolysis, Faraday's laws, and their real-world applications, typically highlights common mistakes made by candidates. Also, students' incapacity to complete electrolytic-related calculations was emphasised in the Chief Examiner's Report (2022). The paper also highlights the importance of understanding Faraday's first and second laws of electrolysis and their practical applications. Many applicants struggle to provide a suitable explanation of electrolysis in addition to having difficulty understanding and applying Faraday's laws, especially the second rule, which connects the mass of material liberated to the quantity of charge transmitted. A better understanding of the relationship between charge, moles, and the amount of material released is encouraged by the study.

Nigerian education has historically been based on teacher-centered methods that prioritize memorization and rote learning (Nwambo et al., 2022). The traditional lecture-based teaching strategies that are frequently employed in Nigerian classrooms fall short in creating the dynamic and captivating atmosphere required for pupils to get a thorough comprehension of these subjects. But more people are realizing how inadequate these methods are at educating kids for the complexity of the twenty-first century. Furthermore, there are several widespread issues with the Nigerian educational system. With student-teacher ratios frequently surpassing 1:50, crowded classrooms make it difficult to apply personalized attention and participatory learning. This problem is especially noticeable in cities where population expansion has surpassed the construction of educational infrastructure (George, Ezeador & Ezeanolue, 2024). Although the lecture method is widely used by chemistry teachers to instruct their students, it can spread a lot of knowledge quickly. The effectiveness of the lecture method depends on a number of factors, including topic matter, instructional objectives, classroom setting, student characteristics, and the teacher's abilities and traits (Abd Elgadir et al., 2023; Alaagib, Musa, and Saeed, 2019), the lecture method remains the most economical and useful teaching strategy. Scientific instruments, experiments, or equipment are rarely needed outside of the chalkboard. The lecture method is a teacher-directed, content-driven technique in which the instructor acts as a resource for role-playing by the students. In this setup, the instructor talks while the pupils primarily listen (Sanchita, 2023).

In involving students in real-life challenges and collaborative inquiry, Problem-Based Learning (PBL) has been identified as an effective teaching technique that promotes active learning, critical thinking, and problem-solving skills. PBL has the potential to boost students' comprehension and academic performance in challenging science courses. Through problem-based learning, this student-centered approach to teaching encourages critical thinking and encourages students to actively participate in their education. Investigation, assessment, and creative thinking are all necessary for the successful execution of a problem-based learning project or challenge. This method can be used for a variety of courses in inquiry-based classrooms at the start of the year and is essential for encouraging students to apply what they have learnt to real-world circumstances (Yu and Zin, 2023).

Although Problem-based Learning (PBL) is an effective educational method, it remains questionable whether students respond to and benefit from it. According to the findings on "the effects of problem-based learning (PBL) on academic achievements of students studying Electrochemistry", which was conducted with second-year chemistry teaching program students from Dokuz Eylul University's Faculty of Education using a pretest–posttest control group quasi-experimental design, the results showed that the scores from the open-ended questions of the students in the experimental group and the scores from the CAT post-test indicated a favorable and very significant statistical relationship. Thus, the conclusion that students in the experimental group were better able to comprehend the issue and its structure than students in the control group is also supported by this data. Students in the experimental group had positive impressions about PBL, according to the findings from semi-structured interviews conducted at the end of the application (Tugce and Sibel, 2017). Another study investigated "the effect of problem-based learning on students' achievement in chemistry. Learners' low achievement in Science in South Africa", using the traditional lecture method as the control group, while the experimental group received instruction with PBL. An independent t-test was used for the analysis. Results showed that there was a significant difference ($p < 0.05$) in chemistry achievement of students between the control and the experimental group, while there was no significant difference before the study. The results show that PBL is an effective way to teach chemistry to enhance students' critical thinking and problem-solving skills (Aidoo, Boateng, Kissi, and Ofori, 2016).

Additionally, research on Students' Acquisition of Agricultural and Entrepreneurship (Agripreneurship) Knowledge and Skills: Does Instructional Approach and their Sex Matter? Which examined the impact of using the lecture method (counterfactual group) versus Problem-based Learning (treatment group) approaches on student acquisition of agricultural knowledge in the context of poultry science and their intentions to become agripreneurs. The findings revealed that females in the treatment group benefited more from the intervention, Problem-based Learning, than their male peers (Mukembo, Edwards, & Robinson, 2023). Also, a study that attempted to determine if three teaching techniques, namely the demonstration-teaching method (DTM), the lecture-teaching method (LTM), and problem-based learning (PBL), would have a substantial impact on students' academic performance, dependent on their gender, revealed that female students fared better (51.356) than male students (48.852). Educators may better understand the advantages of PBL and DTM as teaching methodologies because the findings are that both are more successful at disseminating knowledge (Ogweno, Ongang'a, & Mbai, 2024).

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This study, therefore, investigates the effect of problem-based learning on secondary school chemistry students' achievement in the law of electrolysis, Oyo Town.

➢ *Statement of the Problem*

Even though chemistry is a fundamental science, students have continuously performed poorly on internal and external exams when it comes to subjects like the Law of Electrolysis. The abstract character of the subject, a lack of relevant real-world experience, and the widespread adoption of conventional teacher-centered teaching methods are some of the reasons for this underperformance. A viable substitute teaching strategy is Problem-Based Learning (PBL), which has been effectively implemented in various settings. Nevertheless, there is little empirical data regarding its efficacy in science classes in secondary schools in Nigeria, especially when it comes to chemistry and the Law of Electrolysis. This study seeks to fill this gap by examining the effect of Problem-Based Learning on the academic performance of Senior Secondary School science students in the Law of Electrolysis, Oyo Metropolis, thereby providing evidence-based recommendations for Chemistry instruction in Nigerian secondary schools.

➢ *Objectives of the Study*

The specific objectives of this study are to:

- To determine the main effect of problem-based learning on chemistry students' academic achievement in the Law of Electrolysis.
- Investigate the interaction effect of problem-based learning and gender on students' academic achievement in the Law of Electrolysis.

➢ *Hypotheses*

Based on the stated problems, the following hypotheses will be tested at a 0.05 level of significance.

- **$H_0$1:** There will be no significant main effect of problem-based learning on chemistry students' achievement in the Law of Electrolysis.
- **$H_0$2:** There will be no significant interactive effect of problem-based learning and gender on chemistry students' achievement in the Law of Electrolysis.

II. METHODOLOGY

A non-randomized control group, non-equivalent intact groups, pre-test and post-test measures, and a 2x2x2 factorial quasi-experimental design were all included in the study. The Teaching Service Commission (2024) estimates that there are 2,639 senior secondary II pupils in Oyo Metropolis, Oyo State, Nigeria. The schools involved in this study are Akinmorin Grammar School, Akinmorin (Afijio Local Government), and Abiodun Atiba Memorial Institute, Kosobo (Oyo East Local Government). It adopted a multistage technique to select the students required, which includes two (2) intact science classes of senior secondary II.

Two public coeducational secondary schools, one (1) each, were chosen from a Local Government area in the Oyo Educational Zone of Oyo State using a purposive sampling technique with the following criteria:

- Schools that have been in existence for more than 20 years.
- Schools that have qualified chemistry teachers with at least five (5) years of working experience and also five (5) years of experience as a West African Examinations Council (WAEC) Examiner.
- Schools that have a standard, well-equipped laboratory and a laboratory assistant.

Akinmorin Grammar School, Akinmorin, which has 24 Chemistry students in Senior Secondary School II, was chosen as the school in Afijio Local Government. Additionally, Abiodun Atiba Memorial Institute, Kosobo, Oyo, which has 34 Chemistry students in senior secondary school II, was chosen as the school in Oyo East Local Government.

The Electrolysis Accomplishment Test (EAT), Lesson Plan Format for Experimental Group 1 (Problem-Based Learning), and Lesson Plan Format for Conventional Group (Control Group) were the three (3) research tools utilized in this study. The Electrolysis Accomplishment Test (EAT) was created to evaluate students' prior understanding of the law of electrolysis (pre-test) and evaluate their progress following the completion of instructional interventions (post-test). The thirty multiple-choice questions on the law of electrolysis in the Electrolysis Accomplishment Test have four possible answers. The two sections of this assessment were completed by senior secondary II chemistry students.

The Experimental Group 1 Lesson Plan Format is a comprehensive manual for instructing students in problem-based learning. It is a method of instruction where students learn by addressing problems in the actual world. To foster collaboration and communication, the learning experience segment entails identifying the problems and dividing the students into smaller groups. Each group is then allowed to investigate the problems by asking questions or engaging in discussions about them. They then research the topic, collecting relevant data from a range of sources (books, articles, interviews, etc.), evaluating the data, and developing solutions. The Conventional Group Lesson Plan Format places a strong emphasis on organized, teacher-centered direct instruction and guided practice.

After a thorough analysis, the instrument's validity was partially established and then sent to specialists for review to obtain trustworthy feedback on both face and content validity. Then, significant adjustments and revisions were made in response to their suggestions. A pilot study was conducted to assess the Electrolysis Accomplishment Test (EAT), a research tool, for dependability. The instrument was pre-tested by thirty Senior Secondary II Chemistry students from Ladigbolu Grammar School II in Ladigbolu, Oyo. The discriminating and difficulty indices for each item are calculated using this coeducational school, which is similar to the planned population. In the end, all of the remaining items with difficulty indices between 0.40 and 0.60 and discriminating indices of 0.3 and above were selected for the study. Before delivering the instruments to the students, the administrators of the two selected schools for data collection

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25may2177

were contacted to secure their consent and appropriately inform them about the study. The selected chemistry students and research assistants, or teachers (2), were also asked for their cooperation and consent. Two distinct teaching philosophies were used for the experiment: the traditional method and problem-based learning.

The experiments lasted eight (8) weeks, during which the chemistry teachers were trained to become research assistants and told about their intention to participate in the trial. In the third week, each group was given a pre-test before the students began using the lesson plan for the next four weeks, and in the final week, the post-test was given. The data collected were analysed using analysis of covariance (ANCOVA) to test the hypotheses at the 0.05 significance level.

III. RESULTS

The results and discussion of conclusions are given based on the demographic characteristics of the participants, and the hypotheses are as follows:

➢ *Demographic Data Analysis*

Below are the socio-demographic characteristics of the participants.

Table 1: Distribution of the Participants by Gender

Gender	Frequency	Percent	Cumulative Percent
Female	32	55.2	44.8
Male	26	44.8	100.0
Total	58	100.0	

Source: Field Survey, 2024

Table 1 reveals that 32 (55.2%) participants were females, while 26 (44.8%) were males. This means that most of the participants were females.

➢ *Test of Hypotheses*

- **$H_0$1: There will be no significant main effect of problem-based learning on chemistry students' achievement in the Law of Electrolysis.**

Table 2a: Analysis of Covariance of the Main Effect of Problem-Based Learning on Chemistry Students' Achievement in the Law of Electrolysis.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	1568.631[a]	2	784.315	142.705	.000
Intercept	1103.941	1	1103.941	200.861	.000
Pre-Test	1558.392	1	1558.392	283.547	.000
Group	44.205	1	44.205	8.043	.006
Error	302.283	55	5.496		
Total	22393.000	58			
Corrected Total	1870.914	57			
a. R Squared = .838 (Adjusted R Squared = .833)					

Source: Field Survey, 2025

Table 2a indicates a notable main effect of problem-based learning on the achievement of chemistry students in the law of electrolysis ($F_{(1, 55)}$ =8.043, $p<0.05$, $\eta 2$=0.838). The null hypothesis, which posits that problem-based learning will not have a significant main effect on the achievement of chemistry students in the law of electrolysis, is consequently rejected. This suggests that utilizing problem-based learning for training chemistry students in the law of electrolysis proves to be more effective than traditional methods. The eta square value of 0.838 indicates a contributing effect size of 83.8%.

Table 2b: Estimated Marginal Means of Problem-based Learning on the Academic Achievement of Chemistry Students in the Law of Electrolysis

Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Conventional Group	12.617[a]	.480	11.656	13.578
Problem-based Learning	23.182[a]	.403	22.375	23.989

Source: Field Survey, 2024

Table 2b illustrates that in the two-way interactive comparison of the combined groups, participants who experienced the conventional teaching method (control group) achieved a lower post-test mean score of 12.617, whereas those engaged in problem-based learning (experimental group 2) attained a higher post-test mean score of 23.182. This indicates that the participants who engaged in Problem-based learning achieved superior results compared to those in the control group. Therefore, problem-based learning may be suggested as a highly effective approach for instructing chemistry students in the law of Electrolysis.

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- **$H_0$2: There will be no significant interactive effect of problem-based learning and gender on chemistry students' achievement in the Law of Electrolysis.**

Table 3a: Analysis of Covariance of the Interactive Effect of Problem-based Learning and Gender on Chemistry Students' Achievement in the Law of Electrolysis.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	1709.469[a]	4	427.367	140.298	.000
Intercept	1189.223	1	1189.223	390.404	.000
Pre-Test	21.271	1	21.271	6.983	.011
Method	1434.822	1	1434.822	471.030	.000
Gender	133.859	1	133.859	43.944	.000
Method*Gender	.737	1	.737	.242	.625
Error	161.445	53	3.046		
Total	22393.000	58			
Corrected Total	1870.914	57			
a. R Squared = .914 (Adjusted R Squared = .907)					

Source: Field Survey, 2024

Table 3a indicates a significant interaction effect of problem-based learning and gender ($F_{(1, 53)}$ =43.944, $p<0.05$, $\eta 2=0.914$) on the success of chemistry students. The null hypothesis, asserting the absence of a substantial interaction effect of problem-based learning and gender on the success of chemistry students, is thus rejected. This indicates that the implementation of treatment-problem-based learning, in conjunction with gender considerations, greatly influences the academic performance of chemistry students in the law of electrolysis. The eta squared value of 0.914 indicates an effect size contribution of 91.4%.

Table 3b: Estimated Marginal Means of Treatments, Problem-based Learning, and Gender on the Academic Achievement of Chemistry Students in the Law of Electrolysis.

Gender	Group	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Male	Conventional Group	11.187[a]	.504	10.176	12.198
	Problem-based Learning	21.178[a]	.471	20.233	22.123
Female	Conventional Group	14.101[a]	.507	13.084	15.118
	Problem-based Learning	24.553[a]	.391	23.769	25.336

Source: Field Survey, 2024

Table 3b demonstrates that, in the gender comparison between the two groups, males subjected to the conventional approach exhibited a lower post-test mean than those engaged in problem-based learning. Similarly, female individuals subjected to the traditional technique had a lower post-test mean than those engaged in problem-based learning, who demonstrated a higher post-test mean. The males in the control group (conventional method) achieved a post-test mean score of 11.187, but those in the problem-based learning group attained a post-test mean score of 21.178, resulting in a difference of 9.991. The females in the control group achieved a post-test mean score of 14.101, whereas female participants in the problem-based learning group attained a post-test mean score of 24.553, resulting in a difference of 10.452. A disparity of 0.461 existed between the two genders. This indicates that, despite a mean difference between the genders of the two groups, the difference was not statistically significant.

IV. DISCUSSION OF THE FINDINGS

The findings of this study reveal that Problem-Based Learning (PBL) has a significant main effect on Chemistry students' academic achievement in the Law of Electrolysis. The result from Table 2a shows that students exposed to PBL outperformed their counterparts taught using the conventional lecture method, with a significant F-value of 8.043 at $p < 0.05$ and a large effect size ($\eta^2 = 0.838$). This corroborates prior research by Aidoo et al. (2016) and Balemen & Keskin (2018), who found that PBL enhances learners' comprehension, critical thinking, and academic performance in science subjects, including Chemistry.

Furthermore, the estimated marginal means in Table 2b confirm that students taught through PBL achieved a higher mean score (23.182) than those taught through conventional methods (12.617). This underscores the assertion that PBL fosters active engagement, collaborative problem-solving, and deeper conceptual understanding, which are critical in clarifying abstract Chemistry concepts like the Law of Electrolysis.

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Regarding gender interaction (H02), Table 3a indicates a significant interaction effect between PBL and gender on students' achievement ($F(1, 53) = 43.944$, $p < 0.05$, $\eta^2 = 0.914$). However, Table 3b reveals that while both male and female students significantly benefited from PBL compared to the conventional method, the difference in achievement between male and female students within each instructional method was marginal and statistically insignificant. This aligns with findings from Ogweno, et al. (2024) and Mukembo, et al. (2023), which indicated that while PBL improves the academic performance of both genders, it does not significantly favor one over the other in science-related subjects. In essence, these outcomes validate PBL's efficacy as a gender-inclusive instructional strategy capable of enhancing student achievement across demographic lines in challenging Chemistry topics.

V. CONCLUSION

Based on the results of this study, it is concluded that Problem-Based Learning significantly improves Chemistry students' achievement in the Law of Electrolysis compared to conventional teaching methods. Both male and female students exposed to PBL demonstrated notably higher post-test scores, indicating the method's effectiveness in fostering better understanding and academic performance irrespective of gender. This confirms that PBL offers an engaging, inclusive, and effective pedagogical alternative to traditional lecture methods in secondary school Chemistry education.

RECOMMENDATIONS

In light of the findings, the following recommendations are proposed:

- Adoption of Problem-Based Learning: Chemistry teachers should incorporate PBL strategies into their classroom instruction, particularly for abstract topics such as the Law of Electrolysis, to enhance students' comprehension, problem-solving abilities, and overall achievement.
- Gender-Inclusive Instructional Planning: While the study found no significant gender disparity, teachers need to maintain an inclusive learning environment that supports both male and female students equally within PBL activities.
- Capacity Building for Teachers: Workshops and training programs should be organized by educational stakeholders to equip Chemistry teachers with the knowledge and skills necessary for the effective implementation of PBL in classrooms.
- Curriculum Review and Integration: Curriculum developers should incorporate PBL frameworks into the national Chemistry syllabus, ensuring that inquiry-based and student-centered approaches are systematically included in lesson plans and assessment strategies.
- Further Research: Future studies should investigate the long-term effects of PBL on students' retention of Chemistry concepts, as well as explore its impact on other science subjects and in different educational settings beyond Oyo Town.

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