

Enhancing Learning Outcomes in Dynamic Electricity through Problem-Based Learning Supported by Virtual Labs

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Abstract: Dynamic Electricity Material Student Learning Outcomes Using the Problem-Based Learning Model and Virtual Lab. Postgraduate Science Education Study Program, Manado State University. This study examines the effects of Problem-Based Learning (PBL), Virtual Lab, and their combination on student learning outcomes in dynamic electricity content. The study used a quantitative quasi-experimental design at SMK Negeri 1 Langowan. The study sample included four treatment groups: control, PBL, Virtual Lab, and PBL integrated with Virtual Lab. Multiple-choice exams with established validity and reliability provided learning-outcome data. At the 0.05 significance level, researchers used descriptive statistics, normality testing, homogeneity testing, one-way ANOVA, and Tukey's post hoc tests to analyze the data. All study data were normally distributed and homogeneous. The control class averaged 69.50 posttest scores, the PBL class 80.50, the Virtual Lab class 81.50, and the PBL integrated Virtual Lab class 86.75. The ANOVA test revealed significant differences between treatment groups (Sig. = 0.000 < 0.05). The Tukey additional test demonstrated that PBL, Virtual Lab, and integration models outperformed conventional learning. The PBL-integrated Virtual Lab class achieved the highest learning outcomes and was significantly different from both the PBL and Virtual Lab classes. The findings show that the Problem-based learning paradigm, when linked with Virtual Lab, improved student learning outcomes in dynamic electricity material, making it an excellent learning alternative.

Keywords: Problem-Based Learning; Virtual Lab; Learning Outcomes; Dynamic Electricity Material; Conventional Learning; Integration Model; Normality Testing.

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1. Introduction

Education is crucial to improving human resource quality. In the era of globalization and rapid technological development, education must produce students who not only possess knowledge but also critical, creative, collaborative, and communicative

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thinking skills [1]. In this context, science learning, particularly physics, plays a strategic role because it directly relates to natural phenomena and rapidly evolving technology [2]. Physics not only teaches formulas but also trains students to think logically, systematically, and analytically in solving everyday problems. However, school learning is still often oriented toward mastering formulas and theoretical concepts. One fundamental physics topic students often find difficult is the dynamics of electricity [3]. Based on the results of preliminary survey data conducted at State Vocational School 1 Langowan, it was found that the average value of students' daily tests on dynamic electricity material was still below the Minimum Completion Criteria (KKM), where, out of a total of 25 students who achieved learning completion, only 12 people (48%) did so. Many students still have average scores below the school's Minimum Completion Criteria (KKM) of 75. Several factors contribute to this low learning outcome, including teacher-centered teaching with lecture methods and formulaic recording; a lack of experimental or practicum activities; and minimal use of interactive learning media [4]. Field conditions indicate that school laboratories are often inadequate.

Practical tools such as ammeters, voltmeters, resistors, connecting cables, and circuit boards are often damaged, in short supply, or even unavailable. Furthermore, dynamic electricity labs pose safety risks, including short circuits, electric shocks, and even fires, if procedures are not followed correctly [5]. Consequently, many teachers avoid labs and rely solely on verbal explanations and practice problems [6]. In fact, based on the constructivist theories of Piaget and Vygotsky, students understand, remember, and apply knowledge more easily when they construct it themselves through exploration, experimentation, social interaction, and problem-solving [7]. Students learn better when they are actively involved in the learning process, rather than simply passive recipients of information. Therefore, a learning model is needed that engages students, integrates theory and practice, and provides authentic, contextual learning experiences [8]. One model considered most appropriate is Problem-based Learning (PBL). The PBL model uses real-world problems as context for students to learn to think critically, solve problems, and acquire essential knowledge and skills. According to Arends, PBL is a student-centered learning model with the following characteristics: (1) posing authentic problems, (2) focusing on interdisciplinary connections, (3) conducting authentic investigations, (4) producing real products or works, and (5) collaborating in groups [9]. In PBL, students work in small groups, identify problems, formulate hypotheses, seek information, conduct investigations, and present solutions. Studies show this model improves conceptual understanding, higher-order thinking skills, and overall student learning outcomes [10]. However, implementing PBL in Indonesian schools on dynamic electricity still faces a serious obstacle: limited tools and materials for investigation.

In PBL, after students identify a problem and formulate a hypothesis, they must conduct experiments or observations to test it. Without adequate laboratory tools, this investigation stage is suboptimal and may be skipped altogether [11]. As a result, PBL loses its essence. An innovative solution is to use virtual lab technology. Virtual lab: A virtual lab is a computer-based simulation environment that lets students conduct virtual experiments similar to real-life laboratory experiments, complete with interactive tools and materials [12]. One of the most popular, free, and easily accessible examples of virtual labs is PhET Interactive Simulations. In the Circuit Construction Kit (DC) simulation, students can assemble various electrical components such as batteries, resistors, lamps, switches, ammeters, and voltmeters on a computer or laptop screen [13]. They can change resistance and voltage values, observe electron flow in animations, and read measurement results in real time without fear of errors, short circuits, or equipment damage. Integrating the PBL model with a virtual lab creates an ideal, innovative synergy [14]. PBL provides a pedagogical framework that emphasizes authentic problem-solving, group work, and active learning. In contrast, the virtual lab provides tools and media for conducting investigations and experiments, which have been major obstacles [15]. Based on the description, PBL and virtual lab integration are seen as relevant solutions to overcome the problems of learning dynamic electricity.

2. Theoretical Review

2.1. Problem-Based Learning

Problem-based learning is a learning model that trains students to solve authentic problems from their real lives, stimulating high-level thinking skills. Then, Shoimin [8], as quoted by Amir [3], stated that problem-based learning is an instructional method that challenges students to "learn to learn" by working together in groups to solve real problems. The most important characteristic of the problem-based learning model is that it presents problems at the beginning of the lesson. According to Amir [3], some characteristics of the problem-based learning process include:

- Problems are used as a starting point for learning
- The problems used are real-world problems presented in a floating manner
- Problems typically require multiple perspectives. Solutions require students to use and derive concepts from previously taught disciplines or cross-disciplinary approaches
- Problems challenge students to learn in new learning areas
- Highly prioritize self-directed learning

- Utilize a variety of knowledge sources, not just one source
- Collaborative, communicative, and cooperative learning. Students work in groups, interact, teach each other (peer teaching), and give presentations

2.2. Virtual Laboratory (Virtual Lab)

According to Elmoazen et al. [6], a virtual lab is a technology-based environment that enables digital experiments, including 2D/3D simulations, to study and solve experimental problems. According to Stark et al. [11], a virtual lab is a computer program that lets users interact with experiments through a computer interface.

2.3. The Nature of Learning Outcomes

According to Sudjana [12], learning outcomes are behavioral changes that result from teaching and learning interactions and encompass the cognitive, affective, and psychomotor domains. Meanwhile, Bloom, in Anderson and Krathwohl [2], defines learning outcomes as the achievement of learning objectives measured through thinking skills, attitudes, and skills. Learning outcomes are classified into three main domains, namely:

- **Cognitive Domain:** Related to intellectual abilities, including: remembering (C1), understanding (C2), applying (C3), analyzing (C4), evaluating (C5), and creating (C6).
- **Affective Domain:** Relating to attitudes, values, and emotions, such as accepting, responding, appreciating, organizing, and internalizing values.
- **Psychomotor Domain:** Relating to physical skills and movement. Learning outcomes do not stand alone, but are influenced by internal and external factors:
 - **Internal Factors:** Intelligence, interests, motivation, talents, and physical condition.
 - **External Factors:** Family environment, school environment (teachers, facilities, curriculum), and community environment. This research will focus on learning models and learning media as variables suspected of influencing learning outcomes.

2.4. Relevant Research

Several prior studies have sought to combine Problem-Based Learning PBL with online laboratory environments and simulation technologies to enhance students' academic performance and to acquire broader learning competencies. With the rise of virtual laboratories in education, students can perform experiments, gain scientific knowledge, and participate in simulated learning settings without solely relying on traditional physical laboratory equipment. Virtual laboratory settings, when combined with PBL, can offer a systematic learning process in which students are introduced to problems, explore alternative solutions, conduct experiments, assess observations, and develop conclusions. This combination is highly relevant to science education as many scientific topics involve experimental observation and practical exploration. Previous research has studied various uses of PBL-supported virtual laboratories across physics and biology courses, in terms of learning outcomes, critical-thinking abilities, conceptual understanding, motivation, and science-process skills. The outcomes of this research form a valuable basis for evaluating the possible benefits and limitations of virtual laboratory technology integrated with problem-based instructional methodologies. Adha and Yanto [1] studied the influence of the OLABs virtual-laboratory media with the Problem Based Learning methodology on students' learning results. They conducted a quantitative quasi-experimental study with a nonequivalent control group design on junior high school pupils learning about the human digestive and respiratory systems. The study evaluated combining an online virtual laboratory with PBL to help students learn biological processes through problem-oriented learning activities.

The virtual-lab-based PBL approach achieved 95%, categorised as very good, and students' responses reached 92.93%, also categorised as very good. Hypothesis testing showed $t_{hitung} = 2.306 > t_{tabel} = 2.00$. Based on these results, the researchers concluded that using OLABs virtual-laboratory media with PBL had a favourable impact on students' learning outcomes. The study shows how online laboratory environments can foster problem-oriented learning through student interaction with experimental materials and ideas in a digital setting. Damayanti et al. [5] studied the use of PBL-based virtual laboratory learning media to improve critical-thinking abilities and learning outcomes of students in the excretory-system topic. The researchers used a quantitative quasi-experimental pretest-posttest control-group design, which allowed them to compare students' performance before and after the instructional intervention. The study is highly relevant because it included not only cognitive learning results but also higher-order thinking abilities, not simply academic accomplishment. The results showed that the PBL-based virtual laboratory had a substantial effect on critical-thinking abilities and learning outcomes. The N-Gain value of critical-thinking skills was 0.53 (moderate). The N-Gain value of learning outcomes was 0.72 (high). Moreover, both

results had a t-test significance value of 0.000, which is < 0.05 . Based on the findings, the investigators concluded that PBL-based virtual laboratory learning substantially affected students' critical thinking skills and learning outcomes.

The study shows that virtual labs can go beyond basic simulation and provide an environment where students can explore challenges, understand information, and apply scientific thinking. Luthfianingrum and Sumarna [7] investigated the impact of a virtual laboratory-supported Problem-Based Learning paradigm to enhance students' learning motivation and conceptual understanding. The researchers used a quasi-experimental nonequivalent control group design. The researchers collected data on students' learning processes and results through pretests, posttests, interviews, and observations. Focusing on both motivation and conceptual comprehension offers an important perspective, since technology innovation in education does not benefit all learners equally. The results showed that the PBL-assisted virtual-laboratory model did not help enhance students' learning motivation, but it was effective in improving students' conceptual comprehension. This research shows that virtual laboratory technology can enhance knowledge of subject concepts without necessarily increasing motivation. Other factors that can affect student motivation include instructional design, classroom interaction, individual traits, interest in the subject, teacher support and the learning environment. Therefore, the study underscores the need to analyse virtual-laboratory-based PBL using different educational indicators, rather than assuming that improving one dimension will necessarily improve another. Ranti et al. [16] explored the application of Problem-Based Learning facilitated by a virtual laboratory with a special emphasis on students' learning motivation and science-process abilities. The study demonstrates how virtual laboratory activities can be implemented into an organised PBL process to motivate students to participate in problem identification, inquiry, experimentation and interpretation.

The results showed improvement across learning cycles: learning motivation increased from 68.30% to 73.98%, while science-process skills increased from 57.02% to 77.48%. These results indicate that integrating PBL and virtual laboratory activities can foster student engagement and develop scientific skills. Enhancing science-process abilities is especially important because virtual laboratories allow students to observe, experiment, interpret data, analyze and draw conclusions in a controlled digital environment. Thus, the study provides evidence that virtual laboratories can serve as an alternative to actual experiments and as a supportive environment for developing scientific inquiry abilities in PBL. Harianja and Sinulingga [17] studied the influence of Problem-Based Learning through the PhET simulation medium on the learning outcomes of Grade XI high school students in physics. This quasi-experimental study examined temperature and heat. The aim was to compare a PBL-plus-PhET experimental class with a standard learning control class. The PhET simulation provided a virtual environment for interactive exploration of physical processes, while PBL provided the educational framework for students to research problems and propose solutions. The experimental group's mean score was 50.89 on the pretest and 76.22 on the posttest. The control group's mean score was 47.56 on the pretest and 65.11 on the posttest. The average learning activity score in the experimental class was 73.7, in the active category. The t-test showed that PBL with PhET simulation media influenced students' learning outcomes in temperature and heat.

The results support the idea that interactive simulation environments might enhance PBL by allowing students to visualise and explore scientific processes that might otherwise be difficult to witness directly in a traditional classroom. Overall, this research shows that the combination of Problem-Based Learning with online laboratories and simulation technologies has been studied in numerous subjects, educational levels and learning objectives. The results show an increase in learning outcomes, critical thinking skills, conceptual understanding, learning motivation and science process skills. However, the results also show that the technique's effectiveness is not consistent across all learning characteristics. For example, Damayanti et al. [5] observed improvements in critical thinking and learning outcomes, whereas Luthfianingrum and Sumarna [7] found the technique effective for conceptual understanding but not for learning motivation. Research by Adha and Yanto [1], Ranti et al. [16], and Harianja and Sinulingga [17] further supports the positive effects of PBL with a virtual laboratory across several subject areas. These differences show that the efficacy of virtual-lab-based PBL depends on factors such as subject matter, learning objectives, virtual laboratory quality, PBL implementation, teacher facilitation, student characteristics, assessment methods, and the availability of technological resources. The current literature provides a sound framework for exploring virtual-laboratory-supported PBL but also emphasises the necessity for context-dependent research that explores the design and integration of digital laboratory settings into the learning process.

2.5. Framework of Thinking

Figure 1 shows improved learning outcomes using the Problem-Based Learning (PBL) model supported by the PhET virtual laboratory simulation. Initially, the learning was teacher-centered; The students were less motivated, and their knowledge and achievement in dynamic electricity were relatively low. PBL activities with problem orientation, group inquiry, virtual experimentation, presentation and evaluation resulted in students being more actively involved in the learning process. These interventions led to increased motivation, conceptual comprehension, cognitive scores, and classical learning completion, with the average score exceeding the KKM of 75.

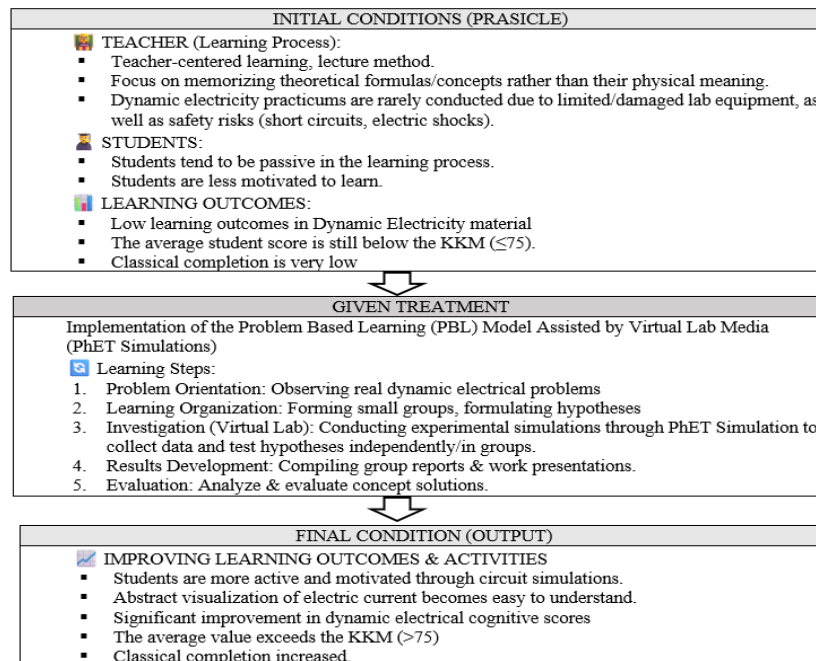


Figure 1: Framework of thinking

2.6. Research Hypothesis

Using the PBL model, virtual lab, and PBL-virtual lab interactions improves student learning outcomes in dynamic electricity. From this description, the following hypothesis can be formulated:

2.6.1. PBL Model Learning

- **H₀:** There is no influence of the use of the PBL model strategy on improving student learning outcomes in the dynamic electricity material.
- **H₁:** There is an influence of the use of the PBL model on improving student learning outcomes in the dynamic electricity material.

2.6.2. Virtual Lab Learning

- **H₀:** There is no influence of the use of virtual labs on improving student learning outcomes in the Dynamic Electricity material.
- **H₁:** There is an influence of the use of virtual labs on improving student learning outcomes in the Dynamic Electricity material.

2.6.3. Interaction Learning Using PBL and Virtual Lab Models

- **H₀:** There is no influence of the interaction between PBL and Virtual Lab models on improving student learning outcomes in the Dynamic Electricity material.
- **H₁:** There is an influence of the use of PBL and Virtual Lab model interactions on improving the learning outcomes of Class X students on the dynamic electricity material at State Vocational School 1 Langowan.

3. Research Methods

This study employed a quantitative approach with a Quasi-Experimental Design (Table 1).

Table 1: Research design

Class	Pretest	Treat	Posttest
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Experiment	X_1	X	Y_3
Control	X_2	X	Y_4

The design used was a Pretest-Posttest Nonequivalent Control Group Design involving four study groups. The visual form of this research design is as follows.

3.1. Information

- X_1 = Initial test or before treatment (pretest) in the experimental class
- X_2 = Final test (posttest) in the experimental class
- Y_3 = Initial test or before treatment (pretest) in the control class
- Y_4 = Final test (posttest) in the control class
- X = Learning treatment

The research was conducted in the computer laboratory of SMK Negeri 1 Langowan, Minahasa Regency, North Sulawesi Province, in the even semester of the 2025/2026 academic year, for three months (January-March). The study population consisted of Grade X students at SMK Negeri 1 Langowan, comprising 4 classes (Table 2).

Table 2: Research design

Treat	V_0	V_1
P_0	$P_0 V_0$	$P_0 V_1$
P_1	$P_1 V_0$	$P_1 V_1$

The study used purposive sampling and cluster random sampling. Independent Variable: Learning model consisting of 4 levels of treatment: conventional model (), PBL model (), Virtual Lab media (), and integrated PBL model Virtual Lab (). Dependent Variable: Student learning outcomes on dynamic electricity material $X_0 X_1 X_2 X_3$. The research design uses a 2x2 factorial:

- P_0 = Without PBL
- P_1 = With PBL Model
- V_0 = Without Virtual Lab
- V_1 = With Virtual Lab

3.2. Note

The test sheet instrument measures student learning outcomes using a written test consisting of 20 multiple-choice questions, tested for validity and reliability and arranged by indicator. This instrument is administered to students during the pretest (before the treatment) and the posttest (after the treatment).

Before being given to students, the instrument must be tested for validity and reliability. The researcher tested the validity of the question items using SPSS for Windows. The researcher collected data through three main stages:

- $P_0 V_0$ = Control Class
- $P_1 V_0$ = With PBL Model
- $P_0 V_1$ = With Virtual Lab
- $P_1 V_1$ = Virtual Lab Integrated Model

3.2.1. Preparation Stage

Prepare learning devices (Teaching Modules), prepare test instruments, and conduct instrument validation tests.

3.2.2. Implementation Stage

- Give a pretest to the entire group
- Carry out the learning process according to the treatment of each group
- Give a final test (posttest) with the same instrument

3.2.3. Final Stage

Tabulate the pretest and posttest score data for analysis. Data analysis begins with descriptive statistics to present data as average values (mean), highest and lowest values, and the standard deviation for each treatment group. Next, Normality and Homogeneity Tests are conducted as Prerequisite Analyses.

Hypothesis testing is carried out using parametric statistics, namely the One-Way ANOVA Test (One-Way Analysis of Variance) at a significance level ($\alpha = 0.05$). For further testing, a Post Hoc Test is used to compare the averages between groups in pairs to determine which group produces the highest learning outcomes significantly (proving superiority (over (X_1, X_2, X_3))).

4. Results and Discussion

4.1. Results

4.1.1. Learning Syntax Implementation Results Data

The data on the implementation of the learning syntax results were obtained by having the Science subject teacher complete an observation sheet on Ohm's law and electrical circuits during the classroom learning activity.

Table 3: Results of PBL syntax implementation

Syntax	Real Score/ Max Score	Implementation Value	Criteria
Orientation	11/12	91.7%	Very good
Organizing	11/12	91.7%	Very good
Guidance	11/12	91.7%	Very good
Presentation of Results	11/12	91.7%	Very good
Evaluation	11/12	91.7%	Very good
Average	55/60	91.7%	Very good

The syntax implementation results are explained as follows: Implementation in PBL, namely problem orientation, organizing, guiding, presenting results, and analyzing, reached 91.7%, showing that the syntax was implemented effectively and efficiently to improve student learning outcomes. Table 3 shows the results obtained across several syntaxes.

4.1.2. Instrument Test Results

Measurement of learning outcomes using test instruments that have previously been tested for validity and reliability using SPSS, as described below.

4.1.2.1. Validity Test Results

Instrument validity can be assessed by correlating each item with the total score. Table 4 shows the results in more detail.

Table 4: Validity test results

Question Items	Sig. Value	Conclusion
1	0.004	Valid
2	0.019	Valid
3	0.011	Valid
4	0.009	Valid
5	0.015	Valid
6	0.008	Valid
7	0.020	Valid
8	0.003	Valid
9	0.020	Valid
10	0.005	Valid
11	0.008	Valid
12	0.019	Valid

13	0.008	Valid
14	0.008	Valid
15	0.015	Valid
16	0.019	Valid
17	0.003	Valid
18	0.015	Valid
19	0.007	Valid
20	0.011	Valid

Based on Table 4, all 20 test items are declared valid with a sig. value of <0.05.

4.1.2.2. Reliability Test Results

Based on the validity of the questions, the next test is the reliability test, and the results are shown in Table 5.

Table 5: Reliability test results

Cronbach's Alpha Based on Standardized Items	Number of Question Items	Category
0.886	20	Very high

Table 5 shows that all test items are reliable, with a Cronbach's Alpha Based on Standardized Items value of 0.885. This result falls into the very high reliability category, with a value range of 0.80-1.00.

4.1.2.3. Difficulty Level Test Results

Based on the results of the difficulty level test in Table 6, the difficulty index of the questions varies.

Table 6: Difficulty level test results

Question Items	Mean	Classification of Difficulty Levels
1	0.60	Currently
2	0.40	Currently
3	0.30	Difficult
4	0.60	Currently
5	0.30	Difficult
6	0.45	Currently
7	0.55	Currently
8	0.50	Currently
9	0.60	Currently
10	0.35	Currently
11	0.40	Currently
12	0.45	Currently
13	0.45	Currently
14	0.45	Currently
15	0.45	Currently
16	0.40	Currently
17	0.30	Difficult
18	0.40	Currently
19	0.35	Currently
20	0.25	Difficult

The difficulty-level test results indicate that 7 items are in the difficult category and 16 are in the medium category.

4.1.2.4. Differential Power Test Results

Based on the results of the discriminatory power test in Table 7, 20 questions showed good discriminatory power, with a discriminatory power index between 0.40 and 0.69.

Table 7: Results of differential power test

Question Items	Corrected Item-Total Correlation	Classification of Differential Power
1	0.547	Good
2	0.448	Good
3	0.494	Good
4	0.505	Good
5	0.472	Good
6	0.508	Good
7	0.445	Good
8	0.575	Good
9	0.444	Good
10	0.540	Good
11	0.509	Good
12	0.447	Good
13	0.508	Good
14	0.508	Good
15	0.467	Good
16	0.448	Good
17	0.582	Good
18	0.468	Good
19	0.519	Good
20	0.499	Good

4.1.3. Learning Outcome Data

Learning outcome data were obtained from pretest and posttest scores in each class, as shown in Table 8.

Table 8: Average pretest and posttest scores of learning outcomes

Class	Pretest		Posttest		Selection	Improvement
	Mean	Std. Dev.	Mean	Std. Dev.		
Control Class	43.00	8,176	69.50	7,416	26.50	61.63%
PBL Class	47.00	7,847	80.50	5,356	33.50	71.28%
Virtual Lab Class	45.50	7,763	81.50	5,643	36.00	79.12%
PBL Class Integrated Virtual Lab	46.00	8,522	86.75	5,447	40.75	88.59%

Based on Table 8, the average pretest and posttest scores increased for each class. The increase was 71.28% for the PBL class, 79.12% for the virtual lab class, 88.59% for the PBL-integrated virtual lab class, and 61.63% for the control class. The PBL-integrated virtual lab class had the highest posttest mean (88.59%), while the control class had the lowest (61.63%).

4.1.4. Prerequisite Test Results

4.1.4.1. Normality Test

Table 9 presents the normality test results for the pretest and posttest data on student learning outcomes. The decision in this normality test is based on a p-value > 0.05, indicating that the data are normally distributed. Table 9 shows the summary results.

Table 9: Summary of normality test results

Class	Sig. Value		Conclusion
	Pretest	Posttest	
Control Class	0.449	0.192	Normal
PBL Class	0.336	0.128	Normal
Virtual Lab Class	0.359	0.117	Normal
PBL Class Integrated Virtual Lab	0.352	0.108	Normal

4.1.4.2. Homogeneity Test

Table 10 presents the homogeneity test results for the pretest and posttest data on student learning outcomes. The decision in this homogeneity test is based on a p-value > 0.05 , indicating that the data are not significantly different. Table 10 shows the summary results.

Table 10: Summary of homogeneity test results

Class	Sig. Value	Conclusion
Pretest	0.982	Homogeneity
Posttest	0.261	Homogeneity

4.1.5. Hypothesis Testing

The learning outcome hypothesis was investigated using an independent-samples t-test. Table 11 summarises the test findings. Table 11 shows substantial differences in learning outcomes ($p < 0.05$). This indicates that the treatment affects the PBL class, the Virtual Lab class, and the PBL class integrated with the Virtual Lab. Further post hoc tests used the Tukey test to identify the therapy with the greatest impact on student learning outcomes.

Table 11: Summary of hypothesis test results (ANOVA)

ANOVA					
Posttest Results					
Source of Variation	Sum of Squares	Diff.	Mean Square	F	Sig.
Between Groups	3150,938	3	1050,313	28,935	0,000
Within Groups	2758,750	76	36,299	-	-
Total	5909,688	79	-	-	-

4.2. Discussion

4.2.1. The Influence of PBL Strategy on Learning Outcomes

The results indicate that the Problem-Based Learning (PBL) model positively influences student learning outcomes in dynamic electricity material. This is evident in the PBL class's average posttest score of 80.50, which is higher than the control class's average of 69.50. The average difference of 11.00 points indicates that applying the PBL model can improve students' understanding of dynamic electricity concepts. This improvement in learning outcomes occurred because the PBL model gave students opportunities to actively participate in the learning process by identifying problems, formulating hypotheses, seeking information, conducting investigations, and developing solutions to the problems presented. Through this process, students not only received information from the teacher but also constructed their own knowledge based on the learning experiences gained during the course. This finding aligns with constructivist theory, which holds that knowledge is more meaningful when students construct it through active learning experiences. In dynamic electricity, students encounter contextual problems related to using electrical circuits in everyday life. This encourages critical thinking and connects physics concepts to real-world situations. These activities enable students to gain a deeper understanding than conventional, teacher-centered learning. Tukey's further test showed a significance value of 0.000 (< 0.05) between the control and PBL classes (average difference: -11.000).

A significance value of less than 0.05 indicates a significant difference in learning outcomes between students who learn using the Problem-based learning (PBL) model and those who learn using conventional methods. Thus, H_0 , which states that the PBL model does not affect student learning outcomes in dynamic electricity material, is rejected. In contrast, H_1 , which states that using the PBL model improves student learning outcomes in dynamic electricity material, is accepted. Suminarsih [13] also supports these results, finding that applying the Problem-Based Learning (PBL) model improved students' physics learning outcomes in dynamic electricity material. Soge et al. [10] reported similar findings, showing that student learning outcomes differed between the PBL and conventional models. Posttest data showed that student learning outcomes in the experimental class using the PBL model were higher than those in the control class using the conventional model. Based on the hypothesis test results, the t-count (8.53) exceeded the t-table value (2.042), indicating that applying the PBL learning model in static fluid material affected students' learning outcomes at St. Maria Rubit High School. In addition, research by Luthfianingrum and Sumarna [7] showed that using the Problem-Based Learning model in the inheritance of traits material at SMP Negeri 8 SATAP Tondano improved student learning outcomes and increased student engagement in active learning. These findings support the study's conclusion that applying the PBL model positively affected student learning outcomes.

4.2.2. The Influence of Virtual Labs on Student Learning Outcomes

The study found that using a virtual laboratory positively affected student learning outcomes. This was shown by the average posttest score of 81.50 in the Virtual Lab class, higher than 69.50 in the control class. Learning outcomes in the Virtual Lab class increased by 79.12%, compared to only 61.63% in the control class. The Virtual Lab provides a more engaging and interactive learning experience because students can directly simulate dynamic electrical experiments using the PhET Circuit Construction Kit application. Through these simulations, students can visually observe current flow, voltage changes, and how resistance affects current strength. These visualizations help students grasp abstract concepts that are difficult to observe in conventional learning. Furthermore, Virtual Labs address the limitations of existing school laboratory facilities. Students can conduct experiments repeatedly without worrying about equipment damage or safety risks such as short circuits and electric shocks. This gives students broader opportunities to explore dynamic concepts in electricity independently. This aligns with Elmoazen et al. [6], who argue that virtual laboratories let students conduct digital experiments in a safe, flexible environment, making learning more effective and efficient. The Tukey test showed a significance value of 0.000 (<0.05) between the control and Virtual Lab classes (average difference: -12,000). A p-value of less than 0.05 indicates a significant difference in learning outcomes between students who use the virtual lab and those who use conventional methods.

Thus, (H_0), which states that there is no effect of the use of the Virtual Lab on improving student learning outcomes in the dynamic electricity material, is rejected, while (H_1), which states that there is an effect of the use of the Virtual Lab on improving student learning outcomes in the dynamic electricity material, is accepted. Thus, the Virtual Lab has a positive, significant effect on student learning outcomes in the dynamic electricity material. This research is supported by several previous studies, such as Wijaya et al. [15], who found that virtual laboratories positively affect student learning outcomes. The study showed that virtual laboratories can improve conceptual understanding, critical thinking skills, and student learning outcomes. These results also align with Ulfia and Wahyuni [14] findings on the effectiveness of PhET simulations in visualizing difficult-to-observe scientific phenomena to boost learning outcomes. Furthermore, the urgency of using digital media and simulations supports Slameto [9], who emphasized that the success of the science learning process depends heavily on strengthening practical activities and students' science process skills. Several previous studies support this research. Wijaya et al. [15] found that virtual laboratories positively affect student learning outcomes, motivation, science process skills, and thinking skills in science learning. Ulfia and Wahyuni [14] reported similar results, showing that technology-based interactive learning methods, such as PhET, can positively affect student learning outcomes. Furthermore, Slameto [9] emphasized that the success of science learning depends heavily on strengthening students' practical activities and science process skills. These findings reinforce this study's conclusion that virtual laboratories can support a more effective learning process, thereby impacting student learning outcomes.

4.2.3. The Influence of the Integrated PBL Model with Virtual Lab

The results showed that integrating the Problem-Based Learning model with the Virtual Laboratory model yielded the highest learning outcomes among the groups. The average posttest score for students in the PBL class integrated with the Virtual Lab reached 86.75, representing an 88.59% increase. This score was higher than the PBL class (80.50), the Virtual Lab class (81.50), and the control class (69.50). The advantage of this integrated model lies in the complementary nature of the two approaches. The PBL model provides a problem-solving-oriented learning framework, while the Virtual Lab provides a platform for interactive investigations and experiments. During the learning process, students not only discuss problems but also test their hypotheses through virtual simulations. Integrating the PBL and virtual lab models also increased student engagement. Observations of syntax implementation showed that all PBL stages were implemented very well, with a 91.7% success rate. This indicates that students were actively involved in problem orientation, group organization, investigation, presentation of results, and learning evaluation. The Tukey test results showed a significance value of 0.000 (<0.05) between the control class and the class that implemented the interaction of Problem-based learning (PBL) and Virtual Lab models. A p-value less than 0.05 indicates a significant difference in learning outcomes between the two groups.

Therefore, the null hypothesis (H_0), which states that there is no effect of using the interaction of PBL and Virtual Lab models on improving student learning outcomes in dynamic electricity material, is rejected, while (H_1), which states that there is an effect of using the interaction of PBL and Virtual Lab models on improving student learning outcomes in dynamic electricity material, is accepted. Thus, the interaction between Problem-based learning (PBL) and Virtual Lab models has a positive and significant effect on student learning outcomes in dynamic electricity materials. These findings indicate that combining problem-based learning with virtual laboratories can create a more effective learning experience than conventional instruction. The results of this study are supported by several previous studies, one of which is Suminarsih [13], which showed that the application of the PBL model assisted by a virtual laboratory on dynamic electricity material was able to significantly improve learning outcomes because the combination of problem solving and virtual experiments effectively boosted students' conceptual understanding and learning activities. Similarly, Damayanti et al. [5] found that a PBL-based Virtual Lab significantly improved student learning outcomes by increasing engagement during the learning process. This positive impact is reinforced by Adha

and Yanto [1], who found that integrating the Virtual Lab into the PBL model led to higher learning outcomes than conventional learning, as students had the opportunity to conduct investigations.

4.2.4. Differences in Effectiveness Between Treatment Groups

The ANOVA test results showed a significance value of 0.000 (<0.05), indicating a significant difference in learning outcomes between the treatment groups. Therefore, a Tukey test was conducted to determine which group was most effective. The results of the Tukey test show that:

- The PBL class was significantly different from the control class (Sig. = 0.000)
- The Virtual Lab class was significantly different from the control class (Sig. = 0.000)
- The PBL and Virtual Lab Interaction Class was significantly different from the control class (Sig. = 0.000)
- The PBL class did not differ significantly from the Virtual Lab class (Sig. = 0.953)
- The PBL and Virtual Lab Interaction Class was significantly different from the PBL class (Sig. = 0.008)
- The PBL and Virtual Lab Interaction Class was significantly different from the Virtual Lab class (Sig. = 0.036)

These findings indicate that PBL and Virtual Labs are roughly equally effective in improving student learning outcomes. However, when the two approaches are combined in a single learning process, student learning outcomes improve significantly and achieve the highest scores. This demonstrates a synergistic effect between the PBL and Virtual Lab models. PBL develops critical thinking and problem-solving skills, while the Virtual Lab strengthens conceptual understanding through visualization and virtual experiments. Together, they produce more meaningful learning and improve student outcomes.

5. Conclusion and Suggestions

5.1. Conclusion

The Problem-Based Learning (PBL) model has a positive and significant effect on student learning outcomes in dynamic electricity. This is indicated by the PBL class's average posttest score of 80.50, which is higher than the control class's 69.50. The Tukey test results show a significance value of 0.000 (<0.05), so H_0 is rejected, and H_1 is accepted. Using the Virtual Lab positively and significantly affected student learning outcomes in dynamic electricity. The average posttest score in the Virtual Lab class was 81.50, higher than the control class's average of 69.50. The Tukey test showed a p-value of 0.000 (<0.05), indicating that H_0 was rejected and H_1 was accepted. Using Virtual Lab helps students understand abstract concepts in dynamic electricity through interactive simulations, improving conceptual understanding and learning outcomes. The Problem-Based Learning (PBL) model integrated with Virtual Lab positively and significantly affected student learning outcomes in dynamic electricity. The PBL class integrated with Virtual Lab had the highest average posttest score (86.75), with an 88.59% increase. Tukey's test showed that the PBL class integrated with Virtual Lab differed significantly from the PBL class (Sig. = 0.008) and the Virtual Lab class (Sig. = 0.036). Therefore, H_0 is rejected, and H_1 is accepted. Integrating PBL and Virtual Lab proved to be the most effective learning approach because it combines problem-solving activities with interactive virtual experiments, thereby optimally increasing student engagement, conceptual understanding, and learning outcomes.

5.2. Suggestion

The suggestions that can be given in this research are as follows:

- The integrated PBL learning strategy and virtual lab can be applied to other materials and classes at other levels, yielding a variety of research models that contribute to scientific knowledge.
- Teachers are advised to implement a problem-based learning (PBL) model integrated with a virtual lab in their instruction, particularly for abstract physics topics that require practical work, such as dynamic electricity. This model can improve student engagement, critical thinking skills, and learning outcomes by making learning more interactive and student-centered. Teachers are also expected to manage learning effectively so students can collaborate, discuss, and solve problems optimally.
- Future researchers are advised to expand this research to other science subjects or at different educational levels to obtain broader results. Further research could also include variables such as learning motivation, critical thinking skills, creativity, or science process skills to further explore the impact of the virtual lab-integrated PBL model.

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