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RESEARCH ARTICLE

The Application of Problem-Based Learning to Master the Concepts of Work and Energy in Physics

Lika Mariya[1]*, Muhammad Ferdiansyah[2]

[1] Electrical Engineering, Sekolah Tinggi Teknologi Nusantara Lampung, Indonesia
[2] Industrial Engineering, Sekolah Tinggi Teknologi Nusantara Lampung, Indonesia

**Corresponding Author, E-mail: likamariya@sttnlampung.ac.id*

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Abstract

This research investigates the impact of the Problem Based Learning model on students’ understanding of work and energy concepts in physics. This research is a quasi-experimental study that was conducted at SMAN 1 Sumberejo in the odd semester of the SDW academic year 2024/2025 with the subjects of this study were students in class X Science, which were divided into two classes, one as an experimental class (PBL) and classical learning approach. The research method used was quasi-experimental with a non-equivalent pre-test post-test control group. Data were obtained through twenty multiple-choice items that met the criteria of validity, reliability, difficulty index, and discriminative index. Data analysis utilized normality tests, homogeneity tests, independent samples t-tests, and N-gain calculations using SPSS 25. The results showed that the experimental class achieved an average N-gain of 0.7 (high category), higher than the control class’s 0.4 (moderate category). These results imply that compared to traditional learning, PBL is able to improve students’ mastery of physics concepts. PBL reduces misconceptions about the role of work and energy, improves students' critical and analytical thinking skills, and promotes better connections between abstract concepts in physics and students' understanding of everyday life. The findings reveal that PBL supports the implementation of the Merdeka Curriculum by facilitating contextual learning experiences and strengthening students’ higher-order thinking skills.

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INTRODUCTION

In an age of globalization and Fourth Industry Revolution, science and technology are rapidly progressing. In this situation the human resources in Indonesia have to be more competitive and competing on the global scale (Puspa et al., 2023). A nation can achieve progress through high-quality human resources that are supported by quality education. The process is build around the pillar of education, that stands at the center creating individual potential with structured and systematic means (Day et al., n.d.). An ideal classroom setup involves a healthy interface between the teachers, students, curriculum and supportive facilities and infrastructure for effective learning (Chaerunisa et al., 2023). Teachers are then tasked with being able to motivate students and implement, Effective learning objectives require the support of suitable methods, media, and learning models (Brundage et al., 2023).

To help improve the quality of education, the Ministry of Education and Culture launched a new curriculum called Merdeka, which is based on establishing so-called Pancasila Student Profile and aims to produce students with strong character who are capable as critical thinking students and adapt themselves (Kusumadewi et al., 2023). This curriculum places students at the center of learning by giving them the freedom to learn according to their interests and talents (E-assessment, 2020). In physics learning, one important goal for students is to master the key concepts. Conceptual mastery includes factual knowledge, but also conceptual understanding, procedural skills and metacognitive; where thinking ranks from lower to higher order skill (Guevara-betancourt, 2024)(Calalb, 2025).

But in reality it is most of the time a burden filled with complicated formulas and abstract concepts that frighten lots of high school students. Work and energy is one of the toughest topics because here students have to realize not only what the mathematical equation means, but also how can they connect the definitions of all these nonlinear concepts (force, displacement, energy changes) with present real life phenomena. Many students find it difficult to differentiate between force and work, Understand gravitational work,Interpret energy changes, and determine the sign of work for different cases (Pramesti & Mahmudi, 2020). The work and energy curriculum is different from more theoretical or descriptive physics topics this area of study is very contextual, phenomenon-based in nature, and it requires direct analytical, interpretive and problem-solving skills. Research suggests that there are abundant misconceptions when instruction is driven primarily by lectures and memorization of formulas, with many students struggling to apply concepts to real-life situations. Based on the observations in grade 10 MIPA class of SMAN 1 Sumberejo showed that students-teacher interaction was still weak, student answer to participate rarely occurs, and learning outcomes have not yet reached good category. Among 72 students, physics was mastered by only 41. The day before I came across this article, I wrote about the disconnect between what is required to master concepts and develop critical thinking skills in students as described by the curriculum, and their actual learning outcomes in the classroom.

Therefore, a novel learning model needs to be proposed to development the conceptual understanding and critical thinking. One of the several corresponding learning model to this predicament is Problem-Based Learning (PBL) (Darmawan & Airlanda, 2021). PBL is a teaching method that is rooted in constructivist theory, which seeks to engage students in processes of inquiry and real-world problem solving through exploration analysis, collaboration, modeling (Yu & Zin, 2023). These subjects are naturally suitable for PBL practices because their concepts can easily associate with daily activities like motion of vehicles, sports, electrical energy usage and transformation of mechanical energy in surroundings. Not only helps students memorize formulas, but trains them to study the relationship between concepts, interpret physical phenomena and apply educational content by using energy conservation law in contextual situations through a problem-based approach. Therefore, PBL overcomes the drawbacks of traditional education in work and energy as these topics have been experienced abstract, speculative, and devoid of any sound meaning by the students. Earlier research indicates that PBL supports the improvement of essential 21st century skills, including communication, collaboration, problem-solving and independent learning (Hendarwati et al., 2021). When students are actively involved in PBL, they also get more conceptual understanding because knowledge with meaningful context is best acquired through direct experience.

With the description above, this research was conducted to implement Problem-Based Learning model in Physics learning subject of tenth class science student at SMAN 1 Sumberejo, in the material of work and energy. This research focuses on improving students' physics concept mastery through Problem-Based Learning, which is anticipated to foster motivation, participation, and higher-order thinking skills (Maulana et al., 2022). This research is also predicted to be as an alternative modelling of teaching for physics teachers in handling students learning difficulties especially on work and energy topic, and can help practitioners develop their teaching practices in accordance with the Merdeka Curriculum objectives (Ummu Fitrah Widia Rahman et al., 2024).

METHOD

This study investigates the implementation of problem based learning to enhance students' mastery of physics concepts related to work and energy (Literacy, 2025). The methodology section outlines the research design, which consists of information on participants, data collection procedures and instruments, and the data analysis techniques employed.

Research Design and Procedures

This research was carried out during the odd semester of Indonesian 2024/2025 at SMAN 1 Sumberejo, Tanggamus Regency. We adopted quasi-experimental design using a nonequivalent pre-/post-test control group method (Buluş, 2021). This study employed a quantitative approach to examine the effect of the Problem-Based Learning model on students' mastery of physics concepts.

The research began by administering a pre-test to both groups in order to measure the students' prior knowledge of the topics of work and energy. Next, the experimental group was taught using the Problem-Based Learning (PBL) model, while the control group was taught using conventional learning methods. The learning process was conducted over three sessions, each lasting 135 minutes. Following the completion of the treatment, a post-test was given to both groups to evaluate students' improvement in mastering physics concepts.

Table 1. The Research Design

Class	*Pre-test*	Treatment	*Post-test*
Eksperimental	Tx_1	X	Tx_2
Control	Ty_1	Y	Ty_2

Explanation :

- Tx_1 = Pre-test, Tx_2 = Post-test
- Ty_1 = Pre-test, Ty_2 = Post-test
- X = Treatment with PBL model
- Y = Treatment with conventional model.

Population and Sample

The subject of this research is all students in the 10th-grade science program at SMAN 1 Sumberejo, Tanggamus Regency. The study sample consisted of 72 purposively selected students. The sample consisted of two groups: an experimental group (X MIPA 1), consisting of 36 students taught using the PBL model, and a control group (X MIPA 2), consisting of 36 students taught using conventional learning methods. Sample selection was based on the similarity of academic characteristics and initial abilities among students in both classes.

Data Collection and Instrument

Data were collected using a test instrument of 20 multiple-choice questions with solution steps to assess students' conceptual understanding of work and energy. Conceptual understanding was scored using:

- 0 = did not answer,
- 1 = did not understand,
- 2 = misconception,
- 3 = partial misconception,
- 4 = partial understanding, and
- 5 = concept understood.

The research instrument to be used was tested for validity, reliability, level of difficulty and discriminant validity before use. Based on the reliability analysis using Cronbach’s alpha, the instrument obtained a coefficient of 0.87, which is categorized as highly reliable. This indicates that the instrument has a good level of internal consistency and is suitable for use in research.

Measuring conceptual mastery refers to the revised Bloom’s Taxonomy, which encompasses cognitive levels C1 through C5: C1 (remembering) to measure the ability to recall basic concepts, C2 (understanding) to grasp the meaning of concepts, C3 (applying) s to apply concepts in problem-solving, C4 (analyzing) to analyze relationships between physics concepts, and C5 (evaluating) to evaluate and draw conclusions based on the concepts studied. The C6 (creating) cognitive domain was excluded from measurement because this study concentrated on concept mastery and higher-order thinking skills relevant to work and energy concepts. This investigation, PBL model served as the independent variable, while students’ mastery of physics concepts served as the dependent variable (Taber, 2018)

Data Analysis

The research data were statistically analyzed using the pre-test, post-test, and N-gain scores from both the experimental and control groups (Bao & Gery, 2006). The data were analyzed through normality tests, homogeneity tests, and independent samples t-tests using IBM SPSS Statistics 25 at the 5% significance level ($\alpha = 0.05$).

Improvements in students' conceptual mastery were calculated using the normalized gain (N-gain) formula to determine the effectiveness of the implemented instruction. N-gain values were then classified into high, moderate, and low categories to interpret the level of improvement in students' conceptual mastery following the intervention (Mishra et al., 2019)

The normalized gain (N-gain) value was calculated using the following formula to measure the improvement in students' conceptual mastery:

$$<g> = \frac{(\%< S_f > - \%< S_i >)}{(100 - \% < S_i >)}$$

Description:

- $\langle g \rangle$ = Normalized gain
- $\langle Sf \rangle$ = Post-test score
- $\langle Si \rangle$ = Pre-test score

The average N-gain values obtained were then classified according to Table 2.

Table 2. Classification of Normalized Gain Values

Average Gain	Classification
$\langle g \rangle \geq 0{,}7$	High
$0{,}3 \leq \langle g \rangle < 0{,}7$	Medium
$\langle g \rangle < 0{,}3$	Low

RESULT AND DISCUSSION

Result

This study applied the Problem-Based Learning (PBL) model to the experimental class (X MIPA 1) and conventional instruction to the control class (X MIPA 2). Both classes received the treatment over three sessions, with each session lasting 135 minutes (equivalent to three class periods). Before the treatment was administered, both classes first took a pre-test to measure students' initial conceptual understanding. This test aimed to evaluate the impact of the PBL model compared to the conventional method, focusing on cognitive domains C1 through C5.

Concept mastery was assessed based on the following cognitive indicators:

a. **Remembering (C1):**

- Identifying the definition of work.
- Explain the concepts of kinetic energy, potential energy, and mechanical energy.

b. **Understanding (C2):**
  - Explain the difference between the concept of work in physics and in everyday life.
  - Describe the concept of mechanical energy and the law of conservation of mechanical energy.
  - Give examples of how the law of conservation of mechanical energy is applied in daily life.

c. **Applying (C3):**
  - Calculating the amount of work done on an object.
  - Classify kinetic energy and potential energy in everyday situations.
  - Applying the equation of the law of conservation of mechanical energy through calculations and experiments.

d. **Analyzing (C4):**
  - Discuss how work is related to changes in kinetic and potential energy
  - Interpreting work using a force-displacement graph.
  - Investigate the principle of conservation of mechanical energy by conducting experiments.

e. **Evaluating (C5):**
  - Examine and draw conclusions regarding the concepts of work and energy.

The normality test shows that the pre-test and post-Post from experiment class and control class has Asymp. Sig (2-tailed) value > 0.05 which means that the data are normally distributed at table 3. The homogeneity test with the Asymp. The homogeneity test results show that Sig (2-tailed) based on the mean is 0.251 at the significance level: $\alpha = 0.05$, which means declared homogeneous (Table 4). This means that there is no meaningful distinction of the right pre-test results between learners in experimental classes and those in control group.

These results were in line with the research of (Mariskhantari et al., 2022). However, when combined with others in a number of data sets, can be classified as normal data if the significance value ≥ 0.05. In the same way, if the significance value for the post-test of both groups - experimental and control is ≥ 0.05, then homogeneous sense of the data. These results offer evidence of fidelity in the measurement and the treatment delivered to both groups of students.

Table 3. Normality Test Result

Class	**N (number of students)**	**Normality Test**			
		Pre test		**Post test**	
		Asymp. Sig (2-tailed)	**Description**	**Asymp. Sig (2-tailed)**	**Description**
Experimental	36	0,078	Normal	0,061	Normal
Control	36	0,200	Normal	0,081	Normal

Table 4. Results Homogeneity Test and Independent Sampel t-test

Class	**Homogeneity**		**t-test**	
	Pre test		**Post test**	
	Asymp. Sig (2-tailed)	**Description**	**Asymp. Sig (2-tailed)**	**Description**
Experimental Control	0,251	Homogeneous	0,000	Significant Difference

Table 5. Summary of Pre-test, Post-test, and N-Gain Analysis

Class	**Pre test**		**Post test**		**N-Gain**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Experimental	62,72	6,12	89,03	4,40	0,7	0,13
Control	63,03	4,94	80,97	5,92	0,4	0,17

After confirming the assumptions of normality and homogeneity, an independent samples t-test was applied to determine differences in concept mastery between the experimental and control classes. The purpose of this analysis was to test the proposed research hypothesis:

- If the Asymp. Sig (2-tailed) value is < 0.05, so there are significate difference between mean pre-test and post-test score than H_0 rejected.
- If the value of Asymp. Accepting H_0, if P > 0.05, which means that there is no difference between mean pre-test and post-test scores switching to Sig.(2-tailed).

Discussion

T-test analysis results show that the posttest score of the experimental class and control class is differ 3) Asymp. Sig (2-tailed) value =0.000 at significance level $\alpha = 0.05$. The results of this hypothesis testing are presented in Table 4. Table 5 indicates that the conceptual mastery increased more in the experimental class compared to that of the control. We obtained an average N-gain of 0.7 (which is in the high category) in the experimental class and a gain of 0.4 (which is in moderate category) for control class. These experimental results answer directly the research question that the application of Problem-Based Learning (PBL) model is better than conventional learning toward students' mastery over physics concepts about work and energy. These findings demonstrate that a problem-based learning approach is capable of producing more optimal learning outcomes compared to teacher-centered learning methods.

The learning approach that was implemented led to the two classes demonstrating differences in mastery of concepts. The experimental class was characterized not only by the focus on answers given directly to students by the teacher, but [was also] through interactions with you in detecting problems and analyzing physical phenomena; group activities; discussions, connecting what was studied work and energy to everyday life. These activities supported students in making more concrete connections between force, displacement, work and changes in energy compared to traditional approaches that are set up as lectures and routine problems emphasizing the solution of textual problems. Thus, it enabled the student to acquire a better conceptual comprehension and deactivate a significant percentage of misconceptions associated with work and energy topics.

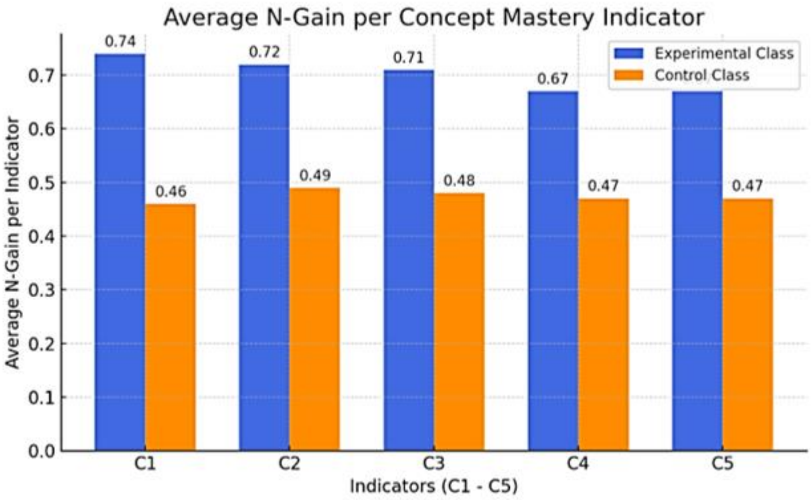

Figure 1. Students' Concept Mastery N-Gain Achievement by Indicator

Note :

- CMC1 = Remembering,
- CMC2 = Understanding,
- CMC3 = Applying,
- CMC4 = Analyzing,
- CMC5 = Valuating.

Both the experimental and control classes showed improvements in students' conceptual mastery on all indicators, as shown in Figure 1. In the experimental class, the greatest improvement occurred in indicator C1 (recall), with an N-Gain value of 0.74 (high category). Meanwhile, in the control class, the greatest improvement was found in indicator C2 (understanding), with an N-Gain value of 0.49 (moderate category). These results indicate that problem-based learning not only helps students recall basic concepts but also strengthens their ability to understand and apply physics concepts in the context of problem-solving.

Improved conceptual understanding of work and energy occurs because the stages of Problem-Based Learning directly support the process of constructing physics concepts. In this stage of understanding the problem, students encounter actual physical phenomena by being exposed to, say, the motion of an object or how energy is used in daily activities or changes that mechanical energy undergoes. This stage allows students to link abstract concepts with real-life experiences, which makes the concepts less intimidating. During the investigation and group discussion stage, students analyze the correlation between work and energy changes, interpret force-displacement graphs, and evaluate law of conservation of energy through simple experiments. The analysis and exploration of the data allows students to construct knowledge through hands-on learning experiences.

Aside from enhancing conceptual knowledge, problem-based learning also helps with the development of higher-order thinking skills. With students being taught to identify problems, make hypotheses, analyze data and interpret evidence during their studying. These tasks will further develop students' analytical and evaluative thinking skills, especially regarding the link between work, kinetic energy, potential energy and the law of conservation of mechanical energy. The findings are in line with Cantona’s view that Problem-Based Learning is effective in improving higher-order thinking skills and reinforcing students’ conceptual understanding at the same time (Cantona et al., 2023)

A science-based learning method also ensures creativity, communication, and collaboration by working in groups and solving problems. You train the students to deal with complex problems by guiding them to think systematically, seeking solutions in multiple alternatives, and integrating theory with practice. Rather, structured questions lead the student slowly to conceptual discovery and lessen their dependence on just plugging numbers into formulas (High, 2020). Therefore, problem-based learning not only improves student learning outcomes in work and energy but also creates physics learning that is more meaningful, contextual, and student-centered (Lukas et al., 2023).

CONCLUSION

The findings of the data analysis and discussion indicate that the Problem-Based Learning (PBL) model has a significant influence on enhancing students’ conceptual understanding in physics learning, especially in work and energy concepts. This is evidenced by an increase in the average N-gain score, where the experimental class that implemented the PBL model achieved a higher increase (0.7) compared to the control class (0.4). With how the PBL model is implemented they are proven because this has an effect on learning physics.

The research suggested the teachers to implement and apply PBL model more in the classroom learning process to deepen students understanding of physics concept. Through the C3 framework, students are encouraged to develop critical thinking and problem-solving abilities that correspond to the expectations of 21st century learning.

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