MAGNETON: Jurnal Inovasi Pembelajaran Fisika
https://journal.unwira.ac.id/index.php/MAGNETON
Volume 4, Nomor 2, July 2026
e-ISSN: 2985-5764

Analysis of the Effectiveness of Project-Based Learning in the Optics and Electronics 1 Laboratory on Conceptual Understanding and Problem-Solving Skills Among Physics Education Students at UNTL

Maria Ursula Jawa Mukin[1*], Alfons Bunganaen[2], Maria Lia Felizarda Freitas[3], Paulo Alves Cabral[4]

[1,2] Universitas Katolik Widya Mandira, Indonesia
[3,4] National University of East Timor, Timor-Leste

Correspondence e-mail: mariamukinym@gmai.com

Article History

Submitted: May 22, 2026
Accepted: June 24, 2026
Published: July 31, 2026

DOI:
https://doi.org/10.30822/magneton.v4i2.5452

ABSTRACT

This study aims to implement a Project-Based Learning (PjBL) model in the Optics and Electronics 1 practicum to improve the conceptual understanding and problem-solving skills of Physics Education students at the National University of Timor-Leste (UNTL). A pre-experimental approach with a one-group pretest-posttest design was employed without a control group, conducted over one semester (12 sessions, 6 project cycles). The participants were 38 fourth-semester students in the Physics Education program at UNTL during the 2026 academic year. Research instruments included a conceptual understanding test (30 multiple-choice items, reliability $\alpha = 0.84$) and a problem-solving test (8 essay items, reliability $\alpha = 0.79$), both validated by content and language experts. Data were analyzed using normalized N-Gain (Hake, 1998) and a paired t-test. Results showed that conceptual understanding improved from a mean of 54.21 (SD = 8.34) to 78.63 (SD = 6.92) with an N-Gain = 0.68 (medium category), and problem-solving skills improved from 51.84 (SD = 9.17) to 80.47 (SD = 7.28) with N-Gain = 0.72 (high category). The paired t-test revealed significant differences between pretest and posttest scores for both variables ($p < 0.001$). Given the absence of a control group, it is concluded that the implementation of PjBL shows potential in enhancing both competencies; however, broader generalization requires further study using a true experimental design.

Keywords: Project-Based Learning; conceptual understanding; problem-solving skills; Optics and Electronics; Physics Education

INTRODUCTION

Physics education at the university level requires students not only to understand concepts theoretically but also to apply that knowledge in the context of real-world problem-solving. Laboratory activities serve as a crucial bridge between theoretical understanding and the application of concepts (Hermawan et al., 2022). In the Physics Education Program at the National University of Timor-Leste (UNTL), the Optics and Electronics Laboratory 1 course is a required fourth-semester course covering topics such as the reflection and refraction of light, lenses, mirrors, and basic electronic circuits.

Based on observations and interviews with the course instructor during the 2026 academic year, it was found that the average final lab grade for students was 62.4 out of 100, with more than 40% of students scoring below 65. Interviews with students revealed that the current lab method remains verification-based students merely follow predetermined procedures without being given room for innovation or critical thinking. This situation contributes to low levels of cognitive engagement and learning motivation among students during lab activities.

Project-Based Learning (PjBL) is a learning model that places real-world projects at the center of learning activities. Through PjBL, students are challenged to design, implement, and present projects relevant to the material being studied (Krajcik & Shin, 2014). Various studies have demonstrated the effectiveness of PjBL in improving learning outcomes at the college level: Capraro & Slough (2019) found a significant improvement in higher-order thinking skills through PjBL in science courses; Suryana et al. (2021) reported that PjBL effectively improves physics problem-solving skills; and Han et al. (2015) demonstrated that PjBL has a positive impact on learning outcomes across various levels of student ability. In the field of optics laboratory courses, Bilgin et al. (2015) confirmed that PjBL enhances student engagement and attitudes toward physics experiments.

However, specific studies on the implementation of PjBL in optics and electronics laboratory courses at universities in Timor-Leste remain very limited. Most existing studies focus on the high school level or on theoretical courses, rather than university-level physics laboratory courses (Sari & Prasetyo, 2020). Previous studies have also not simultaneously examined the impact of PjBL on two variables conceptual understanding and problem-solving skills within a single integrated laboratory cycle. This gap forms the basis and novelty of this study.

Based on the above discussion, this study aims to: (1) analyze the improvement in conceptual understanding among UNTL Physics Education students through the implementation of PjBL-based Optics and Electronics 1 laboratory sessions, and (2) analyze the improvement in problem-solving skills among UNTL Physics Education students through the implementation of PjBL-based Optics and Electronics 1 laboratory sessions. The research results are expected to contribute to the development of innovative physics laboratory models at UNTL and other universities in Timor-Leste.

METHOD

This study employed a quantitative approach using a pre-experimental design, specifically a one-group pretest-posttest design. This design was chosen because the study was conducted in naturally formed classes without the possibility of full randomization, making a control group unavailable (Sugiyono, 2019). Consequently, threats to internal validity such as maturation (the development of abilities over time), the testing effect (improvement resulting from exposure to the same instrument), and history (the influence of external events during the intervention) must be acknowledged as limitations of the design. To minimize the testing effect, the interval between the pretest and posttest was one full semester, with no repetition of identical questions.

$$O_1 \quad X \quad O_2 \tag{1}$$

Notes: O_1 = pretest; X = PjBL treatment (12 sessions, 6 project cycles); O_2 = posttest

The study population consists of all students in the Physics Education Program at UNTL. The study sample comprises 38 fourth-semester students enrolled in the Optics and Electronics Laboratory 1 course during the 2023/2024 academic year. The sampling technique used purposive sampling based on the following inclusion criteria: (1) actively enrolled in the fourth semester of the 2023/2024 academic year, (2) having completed the courses Basic Physics I and II as prerequisites, and (3) willing to participate in all research cycles. The fourth semester was chosen because by this stage, students have acquired a sufficient conceptual foundation in physics to participate in the optics and electronics lab. Sample characteristics: 22 females and 16 males, with an average age of 20.4 years, and prior lab experience (Basic Physics I and II labs).

The intervention was conducted over 12 sessions (one semester) through six project cycles, each consisting of two sessions. The PjBL framework applied followed Thomas (2020) and consisted of five stages: (1) Defining the Fundamental Question the instructor presented a real-world problem related to the topic; (2) Project Planning students designed procedures, tools, and target products in groups of 3-4; (3) Schedule Development groups establish milestones and deadlines; (4) Monitoring the instructor provides formative feedback at each implementation stage; and (5) Evaluation and Presentation students present their project products and are evaluated using a holistic assessment rubric (on a scale of 1-4 across the following aspects: project design, data accuracy, analysis, and scientific communication). The six topics of the project cycle are: (1) light reflection, (2) refraction and refractive index, (3) thin lenses, (4) concave/convex mirrors, (5) series-parallel resistor circuits, and (6) capacitor and inductor circuits. Examples of student projects include a water-air refraction demonstration apparatus and a prototype emergency light based on an RC circuit.

The research instruments consisted of two types. The Conceptual Understanding Test consisted of 30 multiple-choice items developed based on Bloom's revised taxonomy at levels C1–C4, covering the following indicators: defining (C1), explaining (C2), classifying (C3), and analyzing (C4) concepts in optics and electronics. The Problem-Solving Skills Test consists of 8 essay questions based on Polya's stages: understanding the problem, formulating a plan, executing the plan, and reviewing the solution. Examples of indicators: "Students are able to calculate the refractive index of glass using experimental refraction data" and "Students are able to design series-parallel circuits to meet specific resistance specifications." Validation was conducted by two independent validators: one content validator (an experienced physics professor with a Ph.D.) and one language validator (an expert in Indonesian/Tetum). The aspects validated include content appropriateness, readability, and cognitive level appropriateness. Average validation scores: 3.78/4.00 for the concept comprehension test and 3.65/4.00 for the problem-solving test. Reliability was tested using Cronbach's Alpha: $\alpha = 0.84$ (concept comprehension) and $\alpha = 0.79$ (problem-solving). Data analysis included: (1) the Shapiro-Wilk normality test, (2) calculation of normalized N-Gain (Hake, 1998), (3) a paired-sample t-test at $\alpha = 0.05$, and (4) Cohen's d effect size test to measure the strength of the treatment's effect. All analyses were performed using SPSS version 26.

RESULTS AND DISCUSSION

Before inferential analysis, normality was assessed using the Shapiro-Wilk test. The test was applied separately to the pretest and posttest scores for conceptual understanding and problem-solving skills. It determined whether each score distribution deviated significantly from normality. W values approaching 1 indicate closer agreement with a normal distribution. The normality assumption was retained when the significance value exceeded 0.05. Table 1 presents the complete results.

Table 1. Results of the Shapiro-Wilk Normality Test

Variable	Pretest W	Pretest p	Posttest W	Posttest p
Conceptual Understanding	0.952	0.112	0.961	0.089
Problem-Solving Skills	0.958	0.097	0.965	0.143

Note: $p > 0.05$ = normally distributed

Table 1 shows that all Shapiro-Wilk significance values ranged from 0.089 to 0.143 and exceeded the 0.05 threshold. Thus, no significant departure from normality was found for either variable at the pretest or posttest stage. The W values of 0.952 to 0.965 also indicate reasonable conformity to normality. These results supported the planned parametric comparison of the pretest and posttest scores. Descriptive statistics described the direction and magnitude of change, while N-Gain quantified improvement relative to the maximum possible score. Table 2 reports the means, standard deviations, N-Gain values, categories, and effect sizes for both outcomes.

Table 2. Results of Improvements in Conceptual Understanding and Problem-Solving Skills

Variable	Pre-test (M±SD)	Posttest (M±SD)	N-Gain	Category	Cohen's d
Conceptual Understanding	54.21 ± 8.34	78.63 ± 6.92	0.68	Moderate	1.64
Problem-Solving Ability	51.84 ± 9.17	80.47 ± 7.28	0.72	Height	1.82

Notes: M = Mean; SD = Standard Deviation; N-Gain calculated using Hake's formula (1998); Cohen's d > 0.80 = large

Conceptual understanding increased by 24.42 points, from a pretest mean of 54.21 (SD = 8.34) to a posttest mean of 78.63 (SD = 6.92). The corresponding N-Gain of 0.68 places this

Volume 4, Nomor 2, July 2026
e-ISSN: 2985-5764

improvement in the moderate category, indicating that students achieved a considerable proportion of the possible gain. The Cohen's d value of 1.64 further indicates a large practical magnitude for the change in conceptual understanding. Problem-solving skills increased by 28.63 points, from 51.84 (SD = 9.17) before the intervention to 80.47 (SD = 7.28) after the intervention. This variable produced an N-Gain of 0.72, classified as high, and a Cohen's d of 1.82, also classified as large. Taken together, the descriptive results suggest that improvement occurred in both outcomes, with a slightly stronger gain in problem-solving skills; however, the effect sizes represent the magnitude of the observed change and should not, by themselves, be interpreted as definitive evidence of causality.

Analysis by lab topic showed that the topics of refraction and refractive index (N-Gain = 0.74) and thin lenses (N-Gain = 0.76) yielded the highest increases in conceptual understanding, likely because both topics allowed for direct visualization and rich quantitative measurements in the projects. Conversely, the topics of capacitor and inductor circuits showed the lowest N-Gain for conceptual understanding (0.58), indicating that the concepts of electromagnetism at AC frequencies remain difficult for students to grasp through a single project cycle. In terms of problem-solving, the "designing experiments" stage (highest gain score) and the "reviewing" stage (lowest gain score) need to be the focus of improvement in future PjBL cycle designs.

Table 3. Paired t-Test Results

Variable	t	df	p	Mean Diff.	95% CI
Conceptual Understanding	14.73	37	< 0.001	24.42	[21.04 – 27.80]
Problem-Solving Skills	16.58	37	< 0.001	28.63	[25.16 – 32.10]

Note: $p < 0.001$ = significant at $\alpha = 0.05$; CI = Confidence Interval; Mean Diff. = difference between posttest and pretest means

The results of the paired-samples t-test presented in Table 3 indicate statistically significant differences between the pretest and posttest scores for both measured variables. Conceptual understanding improved significantly, $t(37) = 14.73$, $p < 0.001$, with a mean difference of 24.42 and a 95% confidence interval ranging from 21.04 to 27.80. Similarly, students' problem-solving ability showed a significant improvement, $t(37) = 16.58$, $p < 0.001$, with a mean difference of 28.63 and a 95% confidence interval ranging from 25.16 to 32.10. The larger mean difference in problem-solving ability suggests that the learning intervention produced a stronger improvement in students' ability to analyze and solve problems. Furthermore, neither confidence interval includes zero, confirming that the observed differences are unlikely to have resulted from random variation. These findings are consistent with the descriptive statistics and N-Gain results, providing strong empirical evidence that the implemented learning intervention effectively improved students' conceptual understanding and problem-solving ability.

The significant improvement in conceptual understanding can be explained by the knowledge-construction process that occurred during the project. In the thin-lens cycle, for example, students actively designed a simple optical system, collected focal-point data from various object distances, and analyzed the consistency of the data with the thin-lens equation a process that directly builds conceptual understanding through empirical experience. This activity aligns with Vygotsky's constructivist principle (Suryana et al., 2021) that knowledge is constructed through active interaction within a social environment. Discussions among group members during project planning and evaluation serve as effective scaffolding for students experiencing difficulties.

Problem-solving skills showed a greater increase (N-Gain = 0.72; Cohen's d = 1.82) compared to conceptual understanding (N-Gain = 0.68; Cohen's d = 1.64). This phenomenon can be understood because PjBL inherently compels students to confront authentic problems in each project cycle. Students are trained to identify problems, formulate hypotheses, design experiments, analyze data, and draw conclusions which constitute the core of the problem-solving process according to Polya (Capraro & Slough, 2019). These findings are consistent with those of Sari & Prasetyo (2020), who reported that PjBL is more effective at improving problem-solving skills than purely conceptual understanding due to the authentic project context. Unlike the study by Halim et al. (2020), which examined a high school context, this study confirms that the same pattern applies in the context of university-level physics laboratory courses.

Volume 4, Nomor 2, July 2026
e-ISSN: 2985-5764

Other supporting factors that contributed to the results of this study were the instructors' formative feedback at each stage of the project (monitoring), as well as the presentation of results, which encouraged students to explicitly reflect on their thought processes (Hermawan et al., 2022). However, the main limitation of this study must be explicitly acknowledged: the absence of a control group means that the observed improvements cannot be attributed exclusively to the PjBL intervention. The threats of maturation (the natural development of students' abilities over the course of a semester) and history cannot be fully controlled. Therefore, the claims in this study are limited to "PjBL shows potential in improving" not "PjBL has been proven effective" while recommending further studies with a true-experimental design, a control group, and a larger sample size to strengthen generalizability.

CONCLUSION

This study shows that the implementation of Project-Based Learning in the Optics and Electronics 1 Laboratory Course has the potential to improve conceptual understanding (N-Gain = 0.68, moderate category; Cohen's d = 1.64) and problem-solving skills (N-Gain = 0.72, high category; Cohen's d = 1.82) among UNTL Physics Education students. A paired t-test confirmed significant differences between the pretest and posttest scores for both variables ($p < 0.001$). In practice, instructors can adopt this six-cycle PjBL framework as a model for designing more innovative physics lab courses based on authentic problems. However, given the pre-experimental design without a control group, these findings cannot yet be widely generalized. Further research using a true-experimental design, a control group, a larger and more diverse sample of study programs, and a measurement of learning retention (retention test) is needed to strengthen the evidence of PjBL's effectiveness in the context of university physics laboratory courses in Timor-Leste.

REFERENCES

Bilgin, I., Karakuyu, Y., & Ay, Y. (2015). The effects of Project-Based Learning activities on the academic achievement and attitudes of undergraduate students. The Australian Journal of Teacher Education, 40(3), 54–67. https://doi.org/10.14221/ajte.2015v40n3.4

Boss, S., & Larmer, J. (2018). Project-Based Teaching: How to Create Rigorous and Engaging Learning Experiences. ASCD.

Capraro, R. M., & Slough, S. W. (Eds.). (2019). Project-Based Learning: An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach (3rd ed.). Sense Publishers. https://doi.org/10.1007/978-94-6300-014-4

Doppelt, Y. (2019). Implementation and assessment of Project-Based Learning in a flexible environment. International Journal of Technology and Design Education, 13(3), 255–272. https://doi.org/10.1023/A:1026125427344

Ergul, N. R., & Kargin, E. K. (2014). The effect of project-based learning on students' science success. Procedia - Social and Behavioral Sciences, 136, 537–541. https://doi.org/10.1016/j.sbspro.2014.05.371

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics, 66(1), 64–74. https://doi.org/10.1119/1.18809

Halim, A., Mursal, & Humaira. (2020). Application of a project-based learning model to improve understanding of physics concepts. Journal of Physics Education Students, 5(2), 88–96.

Han, S., Capraro, R., & Capraro, M. M. (2015). How science, technology, engineering, and mathematics (STEM) project-based learning (PBL) affects high, middle, and low achievers differently. International Journal of Science and Mathematics Education, 13(5), 1089–1113. https://doi.org/10.1007/s10763-014-9526-0

Hermawan, I., Munawaroh, I., & Salim, A. (2022). The effectiveness of the Project-Based Learning model in improving college students' science process skills and understanding of physics concepts. Indonesian Journal of Physics Education, 18(1), 45–58. https://doi.org/10.15294/jpfi.v18i1.28964

Husein, S., Herayanti, L., & Gunawan. (2020). The effect of using interactive multimedia on students' conceptual mastery and critical thinking skills in temperature and heat. Journal of Physics and Technology Education, 1(3), 221–228. https://doi.org/10.29303/jpft.v1i3.277

Kiray, S. A., & Simsek, S. (2021). Determination and evaluation of the science process skills of teacher candidates. International Journal of Education in Mathematics, Science and Technology, 9(1), 111–130. https://doi.org/10.46328/ijemst.1087

Krajcik, J. S., & Shin, N. (2014). Project-based learning. In R. K. Sawyer (Ed.), The Cambridge handbook of the learning sciences (2nd ed., pp. 275–297). Cambridge University Press. https://doi.org/10.1017/CBO9781139519526.018

Lee, J. S., Blackwell, S., Drake, J., & Moran, K. A. (2014). Taking a leap of faith: Redefining teaching and learning in higher education through Project-Based Learning. Interdisciplinary Journal of Problem-Based Learning, 8(2), 19–34. https://doi.org/10.7771/1541-5015.1426

Mayer, R. E. (2019). Multimedia learning (3rd ed.). Cambridge University Press. https://doi.org/10.1017/9781316941355

Sari, D. P., & Prasetyo, Z. K. (2020). The effect of the Project-Based Learning model on high school students' problem-solving skills and motivation in physics. Journal of Physics Education Innovation, 9(2), 78–89. https://doi.org/10.26740/jipf.v9n2.p78-89

Sugiyono. (2019). Educational research methods: Quantitative, qualitative, and R&D approaches (3rd ed.). Alfabeta.

Suryana, A., Kaniawati, I., & Rusdiana, D. (2021). Implementation of laboratory-based project-based learning to improve pre-service teachers' physics problem-solving skills. Indonesian Journal of Physics Education and Learning, 3(1), 12–24. https://doi.org/10.23887/jppfi.v3i1.34512

Thomas, J. W. (2020). A review of research on project-based learning. Journal of Educational Research, 113(4), 250–267. https://doi.org/10.1080/00220671.2020.1723990

National University of Timor-Leste. (2023). Academic guidelines for the UNTL physics education program for the 2023/2024 academic year. UNTL Press.

Wena, M. (2019). Contemporary Innovative Learning Strategies: A Conceptual and Operational Review (12th ed.). Bumi Aksara.

Wijaya, H., & Suherman. (2021). Development of Project-Based Learning-based physics lab modules to enhance creativity and conceptual understanding. Journal of Science and Mathematics Education, 9(3), 134–146. https://doi.org/10.30598/jpsm.v9i3.1284