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Optics Learning Transformation through Project-Based Learning: Enhancing Scientific Abilities and Affective Learning Outcomes in Students with the Pinhole Camera Project

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Abstract – *In physics education, the topic of optics requires a thorough and detailed understanding due to its challenging and intangible nature. To help students learn physics through practice, it is necessary to enhance their scientific abilities. Additionally, learning outcomes serve as a benchmark for success in education. In this context, project-based learning is chosen as the instructional model for presenting optics material in the classroom, since several studies have found this model to be effective in teaching. This research aims to measure the improvement of scientific abilities and affective learning outcomes of students in the field of physics, specifically the topic of optics. The quasi-experimental design method was employed in this study. The research sample comprised 11th-grade science students divided into two groups: the control group using which employed an inquiry-based learning model and the experimental group which utilized a combination of inquiry-based learning and project-based learning. The final project for the applied teaching model involved a pinhole camera. Data was gathered using observation sheets and questionnaires and subsequently analyzed using non-parametric tests (Mann-Whitney U and Wilcoxon). The data analysis results revealed a significant value (<0.001), demonstrating that the project-based learning model effectively enhanced students' scientific abilities and affective learning outcomes, highlighting marked improvements in the experimental class compared to the control class. Additionally, the project-based learning model proved effective in engaging students actively, creating a more effective and interactive learning experience. Students also expressed greater interest in physics, as lessons incorporated practical activities rather than solely focusing on theoretical concepts.*

Keywords: *learning outcomes; optics; pinhole camera; project-based learning; scientific abilities*

I. INTRODUCTION

Discussing the effectiveness of learning strategies is crucial for improving student outcomes. Research shows that many students, including graduates, often employ suboptimal learning methods (Alard, 2022). In general, the achievement of learning objectives can be observed through students learning outcomes.

Learning outcomes encompass cognitive, affective, and psychomotor domains. The benchmark for students learning success is often measured by their grades (Malfani & Zainil, 2020). To achieve optimal learning outcomes, students must require favorable learning conditions. Two factors influence the learning process: internal and external factors (Zulqarnain et al., 2021). Internal factors include intrinsic elements like intention, motivation, attitudes, and learning drive. External factors, on the other hand, refer to extrinsic influences such as the instructional model and teaching methods.

Understanding physics requires more than just reading, calculating, and listening to explanations. It demands experiential learning through hands-on experiments with natural phenomena (Alatas & Solehat, 2022). Due to its abstract nature, students need to engage in experiments to validate and deepen their understanding. Previous research has shown that one of the most challenging topics in physics education is the concept of light and optics (Wahyuni, 2015). Optics, in particular, is a complex and abstract topic that demands effective teaching strategies for proper comprehension (Sampurno et al., 2015). To help students learn physics through practice, it is necessary to enhance their scientific abilities. Field observations indicate that many students find it difficult to learn physics. This difficulty often fosters a dislike for the subject, leading to poor affective learning outcomes. Additionally, physics lessons are still dominated by traditional lecture methods that emphasize theory and formulas, reducing opportunities for engaging scientific exploration.

The interactive learning model has been chosen as a solution to enhance scientific abilities and learning outcomes in this research. Learning models play a crucial role in creating effective learning processes (Restiana & Djukri, 2021). A good teaching model not only assists students in focused learning but also provides guidance to teachers during the teaching process. This model includes defining instructional objectives, organizing learning stages, managing classrooms effectively, and using appropriate teaching methods and tools (Octavia, 2020). Consequently, the teaching model aids teachers in planning and implementing effective learning activities.

One effective teaching model is Project-Based Learning (PjBL). PjBL is central to this research. Several studies have shown that PjBL can improve student learning outcomes. For instance, a study conducted at SMPN 3 Purworejo demonstrated that students' learning outcomes in optics improved after using the PjBL model (Juniati, 2021). Additionally, research has highlighted the development of STEM-PjBL e-science modules, which significantly enhanced student outcomes by promoting effective and meaningful learning tied to real-world problem-solving. STEM PjBL can increase effectiveness, meaningful learning, and support students' future careers based on their experience in solving real-world problems (Agung et al., 2022).

PjBL plays a significant role in enhancing student engagement and skills across various educational levels (Widhiastuti et al., 2023; Clark et al., 2020). This model is grounded in constructivist theory, encouraging students to actively construct knowledge and address contextual problems (Amin & Sumendap, 2022). Students can gain a deeper understanding through learning experiences that emphasize in-depth scientific inquiry (Rahman, 2021). One form of learning experience that students can develop through the PjBL model includes designing and creating projects to apply scientific concepts. Students work autonomously to design viable products and present their findings.

In PjBL, authentic and constructive project creation is essential (Malfani & Zainil, 2020). For this study, a pinhole camera was chosen as the final project within the PjBL model. This choice stemmed from its simplicity and alignment with geometric optics theory. The pinhole camera is a straightforward device consisting of a light-tight box with a small hole that serves as an aperture. Light enters through this tiny aperture, forming an image projected inside the box (Anggraini, 2021). Through this project, students can directly and practically learn fundamental optical concepts.

This study aims to test the effectiveness of implementing the PjBL teaching model in enhancing students' scientific abilities and learning outcomes related to optics topic. Additionally, it compares the performance of experimental and control groups utilizing the PjBL model. The study results are expected to provide empirical evidence of PjBL's benefits in optics education and offer recommendations for educators to design more effective teaching strategies.

II. METHODS

This research was conducted at SMAN 5 Tangerang Selatan over a period of two weeks, involving a population of science students. The sample for this study comprised 87 eleventh-grade students, selected using a non-probability sampling technique. The research method employed in this study was experimental research. Experimental research is a method where the researcher manipulates an independent variable to observe its impact on the dependent variable while controlling other variables that may affect the research outcomes. The research design adopted was a quasi-experimental design. Quasi-experimental design involves at least two groups: one as the control group and the other as the experimental group (Hastjarjo, 2019).

The learning process took place over two weeks, consisting of two cycles. In the control class, an inquiry-based learning model was employed, while in the experimental class, a combination of inquiry-based learning and PjBL models was implemented. Data collection in this research involved observations and questionnaires. The non-test instruments included an observation sheet with 52 assessment items to measure students' scientific abilities during the learning process, as well as a questionnaire consisting of 42 statements to assess affective learning outcomes. The obtained data was subsequently analyzed using normality tests to determine whether the data was derived from a normally distributed population, and homogeneity tests to assess whether the sample data group had consistent variances across groups.

After conducting normality and homogeneity tests, the obtained data was further examined using the Wilcoxon test to determine the effectiveness of the treatment in enhancing scientific abilities and affective learning outcomes among students. Additionally, the Mann-Whitney U test was employed to assess the significance of differences between classes utilizing the PjBL model and those employing other methods. The procedure for data collection and analysis is shown in the following figure.

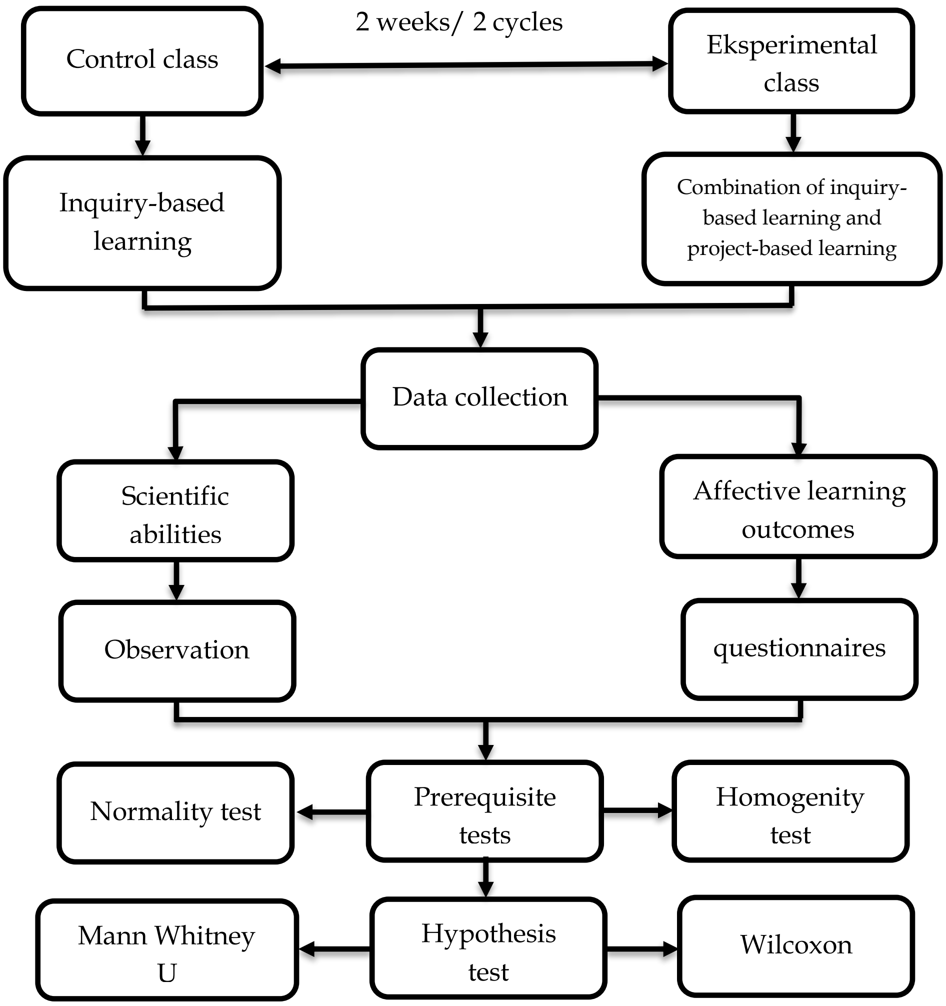

Figure 1. Flowchart of data collection and analysis procedures

III. RESULTS AND DISCUSSION

Based on the observations and distribution of questionnaires conducted, the researcher obtained data on the improvement of scientific abilities and affective learning outcomes of students, as well as a comparison with classes that did not implement the PjBL model. These scientific abilities include formulating questions, designing and conducting experiments, collecting, representing, and analyzing data, creating models, testing hypotheses, and solving complex and ambiguous problems (Murthy & Etkina, 2005). Assessing students' scientific abilities is an essential aspect that relates to their competence and performance in the learning process (Heller, 2007). As for affective learning outcomes, they encompass attitudes toward learning, acceptance, responsiveness, and responsibility. Understanding students' affective domains during the learning process is crucial for comprehending their learning motivation (Imtihan et al., 2017).

The following are the results of the normality test conducted on the control class and the experimental class.

Table 1. Normality test results for control class and experimental class

Normality Test (Shapiro-Wilk)				
Assessment	**class**	**Statistic**	**df**	**Sig.**
Scientific abilities	Control	0.934	44	0.014
	Experimental	0.927	43	0.009
affective learning outcomes	Control	0.981	44	0.688
	Experimental	0.902	43	0.001

The significance value of the normality test results shown in the table is <0.05, except for the observations conducted in the control class. According to the criteria for testing data normality using Shapiro-Wilk, data is considered normally distributed if the significance level is >0.05. This indicates that the data obtained in this research sample is not normally distributed.

As for the data homogeneity test analysis, it is shown in the following table.

Table 2. Homogeneity test results for control class and experimental class

Assessment		**Levene Statistic**	**df1**	**df2**	**Sig.**
Affective learning outcomes	Based on mean	0.034	1	85.000	0.853
	Based on median	0.092	1	85.000	0.763
	Based on median and with adjusted df	0.092	1	77.006	0.763
	Based on trimmed mean	0.044	1	85.000	0.834
Scientific abilities	Based on mean	0.197	1	85.000	0.658
	Based on median	0.007	1	85.000	0.933
	Based on median and with adjusted df	0.007	1	83.312	0.933
	Based on trimmed mean	0.144	1	85.000	0.705

The significance value of data homogeneity shown in the table is >0.05. According to the criteria for testing data homogeneity, data is considered to have the same variance (homogeneous) if it meets the significance level >0.05. This indicates that the data obtained in this research sample is homogeneous. Even though the data are homogeneous, hypothesis testing was not performed using the t-test; instead, non-parametric statistical tests such as the Wilcoxon and Mann-Whitney U tests were used because the data were not normal.

The table below shows the values of scientific ability improvement and affective learning outcomes of students based on the results of the Wilcoxon test conducted in the experimental class.

Table 3. Wilcoxon test results increase students' scientific abilities and affective learning outcomes

Assessment		N	Mean Ranks	Sum of Ranks	Z	Sig.
Scientific abilities	Negative Ranks	0	0.00	0.00		
	Positive Ranks	43	22.00	946.00	-5.716	<0.001
	Ties	0				
Affective learning outcomes	Negative Ranks	9	12.50	112.50		
	Positive Ranks	33	23.95	790.50	-4.240	<0.001
	Ties	1				

Based on the table above, the Wilcoxon test results conducted on the observation scores in the experimental class indicate a significant difference between the observations carried out in the first cycle and the second cycle. Negative ranks indicate that none of the students had observation scores in the second cycle lower than those in the first cycle, with mean ranks equal to 0.00. Conversely, positive ranks show that 43 students had observation scores in the second cycle higher than those in the first cycle, with a mean rank of 22.0. The significance value for the observation results of students' scientific abilities is <0.001, indicating an improvement in students' scientific abilities after implementing the PjBL model in teaching. This improvement is attributed to active student engagement facilitated by the PjBL model, which involves creating a pinhole camera. As previously mentioned, the PjBL model encourages students to actively engage in learning through projects or tasks that require creative thinking, initiative, and idea exploration (Amalia & Thahar, 2024).

Not only in terms of students' scientific abilities observation results, but the table above also indicates a significant difference in the affective learning assessment questionnaire between the first and second cycles. Negative ranks show that 9 students had lower questionnaire scores in the second cycle compared to the first cycle, with mean ranks of 12.50. Conversely, positive ranks indicate that 33 students had higher questionnaire scores in the second cycle than in the first cycle, with a mean rank of 23.95. The significance value for students' learning outcomes based on the questionnaire is <0.001, demonstrating an improvement in students' learning outcomes after implementing the PjBL model in optics physics teaching. This finding supports the idea that the PjBL model enhances students' learning outcomes, similar to how math learning outcomes were improved, meeting success indicators using the PjBL model (Setyowati & Mawardi, 2018). Other research results demonstrate that the implementation of the PjBL model in learning can enhance students' understanding of the material being studied (Londa & Kamaruddin, 2023).

The table below shows the results of the Mann Whitney U test on the observation scores and student questionnaires in the second cycle for both the control class and the experimental class.

Table 4. Mann Whitney U test results to compare the scientific abilities and affective learning outcomes of control class and experimental class students

	Class	N	Mean Rank	Sum of Ranks	U	Sig.
Scientific Abilities	Control class	44	22.50	990.00		
	Experimental class	43	66.00	2838.00	0.000	<0.001
	Total	87				
Affective learning outcomes	Control class	44	31.10	1368.50		
	Experimental class	43	57.20	2459.50	378.500	<0.001
	Total	87				

The results of the Mann Whitney U test indicate a significant difference in both the observation outcomes and questionnaires between the control class and the experimental class. Regarding students' scientific observation abilities, the experimental class achieved higher mean ranks and sum of ranks compared to the control class, with a significance level of <0.001. This finding suggests a significant difference in scientific abilities between the experimental class, which implemented the PjBL model, and the control class, which did not. Additionally, the data analysis reveals a significant difference in affective learning outcomes between the experimental and control classes. The questionnaire data yielded a significance value of <0.001. Furthermore, the mean rank and sum of ranks for affective learning outcomes in the experimental class significantly differed from those in the control class. Beyond technical aspects, the project-based exploration in the PjBL model encourages students to delve deeper into topics that may not be explicitly covered. This approach also provides insights into its potential application in future teaching contexts (Romadhon et al., 2023).

It was demonstrated that the PjBL model significantly influences students' scientific abilities and learning outcomes in optics. Additionally, the PjBL model positively impacts optics education in the classroom. As mentioned in several studies, this teaching model notably enhances students' scientific communication skills, including reading, writing, and presentation (Fadly & Wasis, 2017). This improvement is attributed to the nature of the PjBL model, which is not solely teacher-centered; students can grasp physics concepts by solving problems and independently seeking information related to the material they are studying. Other research indicates that that learning models involving active student participation significantly enhance students' scientific reasoning abilities (Mochsif et al., 2021). Through the PjBL approach, students gain new experiences by engaging in real-world activities during learning and producing project-based outcomes. This aligns with the notion that the PjBL model encourages students to learn through projects, involving research activities and complex tasks such as design, problem-solving, and decision-making (Ariani & Yolanda, 2019).

IV. CONCLUSION AND SUGGESTION

Based on the study, it can be concluded that the PjBL model significantly influences students' scientific abilities and affective learning outcomes in optics. The implementation of PjBL enables students to actively engage in the learning process through real-world projects, ultimately enhancing their understanding of complex and abstract optical concepts. Additionally, this model contributes to improving students' scientific communication skills. The empirical evidence from this research demonstrates the efficacy of PjBL as a teaching strategy and recommends its adoption for creating interactive and engaging learning environments.

This study demonstrated the effectiveness of the PjBL model in enhancing students' scientific abilities and affective learning outcomes in optics through the pinhole camera project. However, several limitations should be addressed in future research. First, the short duration of two weeks may not fully capture the long-term impact of PjBL on students' learning outcomes. Second, the relatively small and homogenous sample limits the generalizability of the findings, necessitating studies with larger and more diverse populations. Third, the focus on a single topic optics suggests the need for exploration across other physics topics to assess the broader applicability of the model.

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