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The Effect of Project-Based Learning Assisted by PhET Simulation on Elementary School Students' Learning Outcomes in Light and Its Properties

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Abstract

Background: *Science learning on the topic of light and its properties still faces various obstacles because the concepts are abstract, resulting in suboptimal student learning outcomes. Although Project-Based Learning (PjBL) and PhET Simulation have proven effective in improving the quality of learning, research integrating both approaches on the topic of light and its properties in elementary schools is still limited. Therefore, this study aims to determine the effect of the Project-Based Learning model assisted by PhET Simulation on students' learning outcomes in the topic of light and its properties.* **Methodology:** *This research uses a quantitative approach with a quasi-experimental method and a nonequivalent control group design. The research was conducted on fifth-grade students of SDN Tengah 07 Pagi and SDN Dukuh 08 Pagi, consists of 52 students in the experimental class and 51 students in the control class, selected using purposive sampling technique. The research instrument in the form of multiple-choice tests has met content validity thru expert judgment as well as empirical validity and reliability tests. Data analysis was conducted using the Mann–Whitney U test and Rank-Biserial Correlation (r) as effect size measures.* **Findings:** *the experimental class achieved higher learning outcomes compared to the control class, with mean rank values of 60.56 and 43.27, respectively. The results of the Mann–Whitney test showed U= 881.000, Z= −2.977, and p= 0.003, indicating a significant difference between the two groups. The Rank-Biserial Correlation (r) value of 0.336 indicates that the implementation of the Project-Based Learning (PjBL) model assisted by PhET simulations has a moderate effect on students' learning outcomes in the topic of light and its properties, making it an effective alternative for improving science learning outcomes in elementary schools.* **Contribution:** *This research provides empirical evidence on the integration of Project-Based Learning and PhET Simulation as an interactive and technologoy-based approach to support elementary school science learning, particularly in helping students understand abtract concepts of light and its properties.*

Keywords: *Elementary School; Learning Outcomes; Light and Its Properties; PhET Simulation; Project-Based Learning*

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INTRODUCTION

The ability of science literacy is one of the important competencies that students need to understand various natural phenomena, solve problems, and make decisions based on scientific evidence. However, the results of the Program for International Student Assessment (PISA) in 2022 indicate that the science literacy skills of Indonesian students are still below the average of OECD member countries (OECD, 2023). This condition indicates that the quality of science learning still needs to be improved thru the implementation of teaching models that can encourage active student engagement and strengthen conceptual understanding.

Natural Sciences (IPA) is a subject that plays an important role in developing scientific thinking skills, problem-solving abilities, and students' understanding of various natural phenomena. In the Merdeka Curriculum, IPA learning not only focuses on concept mastery but also on developing scientific process skills thru activities such as observing, investigating, and communicating learning outcomes. One of the topics studied in phase C of elementary school is light and its properties, which include reflection, refraction, absorption, and propagation of light. This material requires good visualization skills because some of the concepts are abstract and difficult for students to observe directly (Pusmendik, 2023). In addition, elementary school students are still in the concrete operational stage and therefore require learning materials that can visualize abstract concepts to make them easier to understand (Imanulhaq & Ichsan, 2022).

Science learning on the topic of light and its properties still faces various obstacles. Based on observations at SDN Tengah 07 Pagi and SDN Dukuh 08 Pagi, the learning process is still dominated by the lecture method, causing students to tend to be passive and less involved in the learning process. In addition, the use of technology-based learning media that can aid in concept visualization is still limited. This condition affects the low understanding of concepts and the learning outcomes of students. The low achievement in science learning is also influenced by various factors, such as teaching strategies, the media used, and student engagement during the learning process (Astiti et al., 2021).

One of the learning models that can be used to increase student engagement is Project-Based Learning (PjBL). This learning model places students at the center of learning thru project activities that encourage them to conduct investigations, solve problems, collaborate, and produce a product as a form of applying the knowledge they have acquired. Through these activities, students gain more meaningful learning experiences, thereby enhancing their conceptual understanding and learning outcomes (Rahmi et al., 2022). In addition to improving learning outcomes, Project-Based Learning is also capable of developing creativity, collaboration skills, communication, and higher-order thinking, which are important competencies in the implementation of the Merdeka Curriculum (Dewi, 2022).

Various studies show that Project-Based Learning (PjBL) effectively improves the quality of science learning thru the active involvement of students in investigation activities, problem-solving, and project completion. The application of this model not only improves learning outcomes but also develops critical thinking skills, conceptual understanding, and more meaningful learning experiences (Agustin

& Fanani 2024; Suwele et al., 2024; Nafisa et al., 2024; Wardani et al., 2024). These findings indicate that PjBL has advantages in creating learner-centered education. However, most research still focuses on the effectiveness of the PjBL model without integrating it with interactive learning media that can help visualize abstract science concepts.

In addition to using the appropriate learning model, instructional media that can help students understand abstract science concepts are necessary. One such resource is PhET Simulation. PhET Simulation is an interactive learning tool that allows students to conduct virtual experiments and observe various scientific phenomena firsthand. Using this simulation can help students build conceptual understanding through more concrete and engaging visualizations (Fitriyati & Prastowo, 2022). In addition to enhancing conceptual understanding, the use of PhET also boosts students' learning motivation because it provides opportunities for independent exploration and experimentation in an interactive learning environment (Supriyadi et al., 2025).

Various studies also show that PhET Simulation is effectively used in science learning because it can visualize abstract concepts thru interactive simulations. The use of this media helps improve conceptual understanding, student engagement, and learning outcomes (Hardiansyah & Mulyadi 2022; Hadi et al., 2023; Wulandari & Baadilla 2025). However, these studies generally examine the use of PhET as a learning medium separately and have not extensively integrated it with project-based learning models, particularly in the topic of light and its properties in elementary schools

The integration of the Project-Based Learning model with PhET simulations has the potential to create more active, interactive, and meaningful learning. Students are not only involved in project completion but also have the opportunity to explore concepts thru virtual simulations that support the scientific inquiry process. Bintang et al., (2024) shows that the use of interactive media in project-based learning can enhance the effectiveness of science education. Similar results were also reported by Syarifah & Musriandi (2025), who found that the integration of innovative learning models with digital media can significantly improve students' learning outcomes.

Although various studies have proven the effectiveness of Project-Based Learning and PhET simulations, most research still examines these two variables separately or is conducted on different subjects and educational levels. Research on the application of the Project-Based Learning model assisted by PhET simulations on light and its properties in elementary schools is still relatively limited. Therefore, further research is still needed to examine the impact of integrating these two components on the learning outcomes of elementary school students.

The novelty of this research lies in the application of the Project-Based Learning model assisted by PhET simulations on the topic of light and its properties in elementary schools. The integration of the project-based learning model with interactive simulations is expected to provide a more contextual learning experience, increase student engagement, and help them understand abstract concepts more effectively. Based on the description, this study aims to analyze the influence of the Project-Based Learning model assisted by PhET Simulation on students' learning outcomes in the subject of light and its properties in elementary schools, as well as to

contribute to the development of science education thru the integration of the project-based learning model with interactive simulation media to help students understand abstract concepts.

METHOD

This research uses a quasi-experimental method with a Nonequivalent Control Group Design. The research was conducted at SDN Tengah 07 Pagi and SDN Dukuh 08 Pagi. The treatment was given during three meetings in each class. The first meeting was used for the implementation of the pretest, the second meeting for the application of the Project-Based Learning model assisted by PhET Simulation, and the third meeting for the implementation of the posttest. Each meeting lasts for 2 × 35 minutes.

Sample or Participant

The participants in this study are 103 fifth-grade students from SDN Tengah 07 Pagi and SDN Dukuh 08 Pagi, East Jakarta, Indonesia. The research sample was selected using purposive sampling techniques based on characteristics that align with the research objectives. Participants consisted of 52 students in the experimental class who received instruction using Project-Based Learning (PjBL) assisted by PhET Simulation and 51 students in the control class who received conventional instruction. Before the research was conducted, the researcher obtained research permission from the principal of each school. All data obtained were used solely for research purposes, and the confidentiality of the students' identities was maintained throughout the research process

Instrument

The research instrument is a multiple-choice test consisting of 30 items designed to measure students' learning outcomes on the topic of light and its properties. The items are structured based on learning objectives and cover the cognitive domains of applying (C3), analyzing (C4), evaluating (C5), and creating (C6) according to the revised Bloom's Taxonomy. The instrument consists of questions with easy, medium, and difficult levels of difficulty, thereby being able to comprehensively measure the cognitive abilities of the students.

Before being used in the research, the instrument was first tested for content validity thru an assessment by an expert lecturer in the field of Science Education. Subsequently, empirical validity and reliability tests were conducted using IBM SPSS Statistics. The validity test results showed that 28 out of 30 items were declared valid, while 2 items were declared invalid and thus not used in the research. The results of the reliability test indicate that the instrument meets the reliability criteria, making it suitable for measuring students' learning outcomes.

Data collection

Data were collected thru learning outcome tests. A pretest was given before the learning process to determine the students' initial abilities, while a posttest was given after the learning process to measure the learning outcomes after the treatment.

Procedure

The research was conducted over three meetings in each class. The first meeting was used to conduct a pretest to determine the initial abilities of the students. The second meeting was used to implement the Project-Based Learning (PjBL) model assisted by PhET Simulation on the topic of light and its properties. The third meeting was used to conduct a posttest to determine the students' learning outcomes after the treatment was given. Each meeting lasts for 2 × 35 minutes.

Learning in the experimental class is conducted using the Project-Based Learning (PjBL) model, which consists of six stages: (1) determining the fundamental question, (2) planning the project, (3) scheduling the project implementation, (4) monitoring project progress, (5) testing or assessing project results, and (6) evaluating the learning experience. At the project implementation stage, PhET Simulation is used as a learning medium to help students observe the concept of light and its properties thru virtual experiments. Students explore the phenomena of reflection, refraction, propagation, and absorption of light, then discuss their observations with the group and use them as a basis for completing the assigned project. Meanwhile, the learning in the control class was conducted using conventional methods thru lectures, question-and-answer sessions, and assignments.

Data analysis

Data analysis was conducted using IBM SPSS Statistics version 29 software. The analysis began with a normality test using the Kolmogorov–Smirnov test and a homogeneity test using Levene's Test. Since the data did not follow a normal distribution, hypothesis testing was conducted using the nonparametric Mann–Whitney U test. All statistical tests were performed at a significance level of 5% ($\alpha = 0.05$). Next, the magnitude of the treatment effect was calculated using Rank-Biserial Correlation (r) as the effect size.

RESULT AND DISCUSSION

Result Clear Parameters

To determine the effect of implementing the Project-Based Learning (PjBL) model assisted by PhET Simulation on students' learning outcomes, a descriptive analysis was conducted on the pretest and posttest scores in the control and experimental classes. This analysis aims to provide an overview of the changes in students' learning outcomes before and after the treatment was given. The results of the descriptive analysis are presented in Table 1.

Table 1. Descriptive Statistics of Pretest and Posttest Scores

Group	Pretest (Mean ± SD)	Pretest (Mean ± SD)	Δ Score
Control Class Posttest	17.55 ± 6.26	25.33 ± 1.96	7.78
Experimental Class Posttest	18.31 ± 5.42	26.60 ± 1.73	8.29

Based on Table 1, the average pretest score of the control class was 17.55, while the experimental class was 18.31. After treatment, the average posttest score of the control class increased to 25.33, while the experimental class increased to 26.60. The Δ score indicates that the control class experienced an increase of 7.78 points, while the experimental class experienced an increase of 8.29 points. The results indicate that both groups experienced an improvement in learning outcomes, with a higher increase in the experimental class after the implementation of the Project-Based Learning (PjBL) model assisted by PhET Simulation. Next, before hypothesis testing is conducted, the learning outcome data is first tested using normality and homogeneity tests to determine the appropriate statistical analysis technique. The results of the normality test are presented in Table 2.

Normality Test

The normality test is conducted to determine whether the students' learning outcomes in the experimental class and the control class are normally distributed or not. The results of the normality test serve as the basis for determining the type of statistical test used to test the research hypothesis. In this study, the normality test was conducted using the Kolmogorov–Smirnov method with a significance level of 0.05.

Table 2. Result of the Normality Test

Group	Statistic *Kolmogorov-Smirnov*	Sig.	Interpretation
Control Class Posttest	0.163	0.002	Not normally distributed
Experimental Class Posttest	0.135	0.019	Not normally distributed

Based on Table 2, the results of the normality test show that the control group obtained a Kolmogorov–Smirnov statistic of 0.163 with a p-value of 0.002, while the experimental group obtained a statistic of 0.135 with a p-value of 0.019. Since both p-values are less than 0.05, the learning outcome data for both groups are not normally distributed. Therefore, hypothesis testing was continued using a nonparametric test, namely the Mann–Whitney U test.

Homogeneity Test

A homogeneity test was conducted to determine whether the variances of the learning outcome data in the experimental and control classes were homogeneous. The test was performed using Levene's Test with a significance level of 0.05. Based on Table 3, the Levene's statistic was found to be 0.170 with a p-value of 0.681. Since the p-value is greater than 0.05, it can be concluded that the variances of the learning outcomes data in the experimental and control classes are homogeneous.

Table 3. Result of the Homogeneity Test

Levene Statistic	df1	df2	Sig.	Interpretation
0.170	1	101	0.61	Homogeneous

Mann–Whitney Test

Since the results of the normality test indicated that the data were not normally distributed, hypothesis testing was conducted using the Mann–Whitney U test. This test aimed to determine whether there was a significant difference in learning outcomes between students who learned using the Project-Based Learning model aided by PhET Simulation and those who learned using conventional instruction. Based on Table 4, the control class consists of 51 students, while the experimental class consists of 52 students. The mean rank of the control class is 50.36, while the experimental class is 53.61. In addition, the sum of ranks in the experimental class (2787.50) is slightly higher than in the control class (2568.50). The difference in scores indicates a descriptive difference in initial abilities, but it needs to be further proven thru significance testing results.

Table 4. Results of the Mann-Whitney U Test (Pretest Rank)

Group	N	Mean Rank	Sum of Ranks
Control Class Pretest	51	50.36	2568.50
Experimental Class Pretest	52	53.61	2787.50

Table 5. Results of the Mann-Whitney U Test (Pretest Test Statistics)

Mann-Whitney U	Z	Asymp. Sig. (2-tailed)	Interpretation
1242.500	-0.552	0.581	No significant difference

Based on Table 5, a Mann–Whitney U value of 1242.500, Z = -0.552, and Asymp. Sig. (2-tailed) of 0.581 were obtained. Because the significance value is greater than 0.05 (0.581 > 0.05), H_0 is accepted. The results indicate that there is no significant difference between the initial abilities of students in the experimental class and the

control class. Thus, both groups had relatively equal initial abilities before being given the treatment.

Table 6. Results of the Mann-Whitney U Test (Posttest Rank)

Group	N	Mean Rank	Sum of Ranks
Control Class Posttest	51	43.27	2207.00
Experimental Class Posttest	52	60.56	3149.00

Based on Table 6, the control class had a sample size of 51 students, while the experimental class had 52 students. The mean rank for the experimental class was 60.56, higher than that of the control class, which was 43.27. In addition, the sum of ranks for the experimental class was 3149.00, greater than that of the control class, which was 2207.00. These results indicate that, in general, student learning outcomes in the experimental class were higher than those in the control class.

Table 7. Results of the Mann-Whitney U Test (Posttest Test Statistics)

Mann-Whitney U	Z	Asymp. Sig. (2-tailed)	Interpretation
881.00	-2.997	0.003	There is a significant difference

Based on Table 7, the Mann–Whitney U statistic was 881.000, the Z-score was -2.977, and the Asymp. Sig. (2-tailed) was 0.003. Since this significance value is less than 0.05, H_0 is rejected and H_1 is accepted. Thus, there is a significant difference in learning outcomes between students who learned using the Project-Based Learning (PjBL) model supported by PhET Simulation and those who learned using conventional instruction. These results indicate that the implementation of the Project-Based Learning (PjBL) model supported by PhET Simulation has a positive effect on students' learning outcomes regarding light and its properties.

Rank-Biserial Correlation Test

The Rank-Biserial Correlation (r) test was conducted to measure the effect size of the implementation of the Project-Based Learning (PjBL) model assisted by PhET simulations on students' learning outcomes. Because the hypothesis testing uses the nonparametric Mann–Whitney U test, the effect size used is the Rank-Biserial Correlation (r). The results of the Rank-Biserial Correlation (r) calculations are presented in Table 8.

Table 8. Result of the Rank-Biserial Correlation Test

Effect Size Type	Value (r)	Category
Rank-Biserial Correlation (r)	0.684	Moderate

Based on Table 8, a Rank-Biserial Correlation (r) value of 0.336 was obtained, which falls into the moderate category. The results indicate that the implementation of the Project-Based Learning (PjBL) model assisted by PhET simulations has a moderate effect on students' learning outcomes in the topic of light and its properties. Thus, in addition to producing a significant difference based on the Mann–Whitney test (Asymp. Sig. = 0.003), the application of this learning model also has a considerable impact on improving students' learning outcomes.

Discussion

The results of this study indicate that the implementation of the Project-Based Learning (PjBL) model, supported by PhET simulations, has a positive effect on students' learning outcomes regarding light and its properties. The improvement in learning outcomes in the experimental class occurred because the Project-Based Learning (PjBL) model encourages students to actively engage in the learning process through inquiry, discussion, problem-solving, and project completion. This learning process provides students with the opportunity to construct their own knowledge based on learning experiences, thereby making the concepts they learn more meaningful. These findings are consistent with the research by Taupik & Fitria (2021), which states that the implementation of the Project-Based Learning model can improve elementary school students' science learning outcomes. Similar results were also reported by Budiarti & Putri (2022), who showed that project-based learning provides contextual learning experiences that have a positive impact on student learning outcomes. These findings are also supported by the research of Theresia et al., (2024), which states that Project-Based Learning can enhance student engagement during lessons, leading to improved learning outcomes. Additionally, Ketan et al., (2025) reported that the implementation of Project-Based Learning on the properties of light in elementary schools has a positive impact on students' learning outcomes.

In addition to the instructional model used, the use of PhET simulations also contributed to improving student learning outcomes. Interactive simulations help students visualize abstract concepts related to light, such as reflection and refraction, making these concepts easier to understand. Through these simulations, students can explore independently, observe the changes that occur, and connect concepts to the phenomena studied during project activities. This makes the learning process more engaging, increases student participation, and strengthens conceptual understanding. The results of this study align with those of Aji et al., (2023), who found that the use of interactive media in science education can improve students' conceptual understanding and learning outcomes. Research by Simbolon & Silalahi (2023) also shows that PhET-based virtual laboratories provide a more interactive learning experience, thereby increasing student engagement and learning outcomes. Additionally, Aina & Hariyono (2023) report that the use of PhET can improve students' science literacy through the presentation of concepts that are more concrete and easier to understand. The findings are also supported by Wahyuningsih & Pramasty (2024), who state that the use of PhET Simulation in elementary school science education can improve learning outcomes because the material is presented in a more engaging and interactive manner.

The findings of this study are also supported by Agustina et al., (2024), who state that the implementation of a Project-Based Learning model aided by PhET simulations can enhance students' critical thinking skills. The results are in line with the research by Sugiyartini et al., (2024), which shows that the application of the Project-Based Learning model can enhance elementary school students' understanding of science concepts and scientific attitudes thru active student involvement in the learning process. Research by Narulita et al., (2024) also shows that the use of PhET simulation media in elementary school science instruction can improve learning outcomes by presenting concepts in a more engaging and easily understandable way.

These findings are further reinforced by the research of Suarmika et al., (2024), which states that PhET interactive media can improve students' science literacy through active exploration activities. The study by Rahma et al., (2024) also shows that the use of PhET simulations has a positive impact on the understanding of science concepts because students can observe phenomena that are difficult to replicate through standard laboratory experiments. Furthermore, Sirait et al., (2025) reported that the use of PhET media in science instruction has a positive impact on student learning outcomes and engagement. A systematic review conducted by Komang et al., (2025) also concluded that virtual laboratories, including PhET Simulation, effectively enhance conceptual understanding, student engagement, and the quality of science learning. Based on the research findings and supported by various previous studies, it can be concluded that the implementation of the Project-Based Learning (PjBL) model assisted by PhET Simulation is an effective learning alternative to improve student learning outcomes on the topic of light and its properties.

Based on the results of this study and supported by previous research, it is evident that combining the Project-Based Learning (PjBL) model with PhET simulations can create an active, interactive, and student-centered learning environment. Through project-based activities and exploration using simulations, students gain a more concrete learning experience, which enhances their conceptual understanding and leads to better learning outcomes compared to conventional instruction.

CONCLUSION

Based on the research results, the application of the Project-Based Learning (PjBL) model assisted by PhET simulations has a positive effect on the learning outcomes of elementary school students on the topic of light and its properties. The results of the Mann–Whitney test showed a significant difference between the experimental class and the control class with a Mann–Whitney U value of 881.000, Z = -2.977, and an Asymp. Sig. (2-tailed) of 0.003 ($p < 0.05$). Additionally, the Rank-Biserial Correlation (r) calculation of 0.336 indicates that the implementation of the Project-Based Learning (PjBL) model assisted by PhET simulations has a moderate effect on students' learning outcomes. The scientific contribution of this research is to provide empirical evidence regarding the effectiveness of integrating the Project-Based Learning (PjBL) model with PhET simulations in improving elementary school students' science learning outcomes, particularly on the topic of light and its properties.

The novelty of this research lies in the application of a combination of the Project-Based Learning (PjBL) model and PhET simulations in elementary school science education, using a quasi-experimental design and non-parametric Mann–Whitney U analysis complemented by Rank-Biserial Correlation as an effect size measure. These findings are expected to serve as a reference for teachers in designing more interactive, contextual, and technology-based science education. This research still has limitations, as it was only conducted on the topic of light and its properties, involving two elementary schools, and focused on measuring cognitive domain learning outcomes. Therefore, it is recommended that future research involve a larger sample size, examine other science subjects, and add variables such as learning motivation, critical thinking skills, creativity, science literacy, and science process skills to obtain a more comprehensive picture.

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