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The Effect of the PhET Simulation Media-based PjBL Learning Model on Improving Learning Outcomes

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Abstract

This study aims to examine the effect of the Project-Based Learning (PjBL) model, integrated with PhET Interactive Simulations, on improving the science learning outcomes of fifth-grade elementary school students in magnetism, electricity, and technology in everyday life. A quasi-experimental design with a pretest-posttest control group was employed, involving 60 fifth-grade students from SDN 21 Sijuk, divided into an experimental class (n=30) receiving PjBL-PhET instruction and a control class (n=30) receiving conventional instruction. Data were collected through a validated 23-item multiple-choice test (KR-20 = 0.82), a structured observation sheet for student activities (Cohen's κ = 0.85), and a student response questionnaire (Cronbach's α = 0.91). Results showed that the experimental class achieved a significantly higher mean posttest score (85.67) than the control class (73.33), with a higher N-Gain of 0.71 compared to 0.25 in the control group. An independent sample t-test confirmed a statistically significant difference (p = 0.000) with a large effect size (Cohen's d = 1.70). Student learning activities in the experimental class achieved an average engagement of 87.5% (very active), with engagement gradually increasing across meetings. Student responses toward the learning approach were highly positive (89.3%), particularly regarding its benefits for conceptual understanding (91.0%). These findings demonstrate that integrating PjBL with PhET simulations enhances cognitive learning outcomes, active participation, and affective responses in elementary science education.

Keywords: Learning Outcomes, Magnetism and Electricity, PhET Simulation, Project-Based Learning.

Abstrak

Penelitian ini bertujuan untuk mengkaji pengaruh model *Project-Based Learning* (PjBL) yang diintegrasikan dengan media PhET *Interactive Simulation* terhadap peningkatan hasil belajar IPA siswa kelas V sekolah dasar pada materi kemagnetan, kelistrikan, dan teknologi dalam kehidupan sehari-hari. Desain kuasi-eksperimen dengan *pretest-posttest control group design* digunakan, melibatkan 60 siswa kelas V SDN 21 Sijuk yang dibagi menjadi kelas eksperimen (n=30) yang mendapat pembelajaran PjBL-PhET dan kelas kontrol (n=30) yang mendapat pembelajaran konvensional. Data dikumpulkan melalui tes hasil belajar berbentuk pilihan ganda sebanyak 23 butir yang telah tervalidasi (KR-20 = 0,82), lembar observasi aktivitas siswa (Cohen's κ = 0,85), dan angket respons siswa (Cronbach's α = 0,91). Hasil penelitian menunjukkan bahwa kelas eksperimen memperoleh rata-rata nilai *posttest* yang lebih tinggi secara signifikan (85,67) dibandingkan kelas kontrol (73,33), dengan nilai N-Gain tinggi sebesar 0,71 berbanding 0,25 pada kelas kontrol. Uji *independent sample t-test* mengonfirmasi perbedaan yang

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signifikan secara statistik (p = 0,000) dengan *effect size* sangat besar (Cohen's d = 1,70). Aktivitas belajar siswa di kelas eksperimen mencapai rata-rata keterlibatan 87,5% (kategori sangat aktif) dengan peningkatan progresif pada setiap pertemuan. Respons siswa terhadap pendekatan pembelajaran ini sangat positif (89,3%), khususnya terkait manfaatnya bagi pemahaman konsep (91,0%). Temuan ini membuktikan bahwa integrasi PjBL dengan simulasi PhET secara efektif meningkatkan hasil belajar kognitif, partisipasi aktif, dan respons afektif siswa dalam pembelajaran IPA di sekolah dasar.

Kata Kunci: Hasil Belajar, Magnet Dan Listrik, Project-Based Learning, Simulasi PhET.

INTRODUCTION

Natural science (IPA) examines natural phenomena through systematic observation, empirical investigation, and logical reasoning to produce scientifically valid conclusions. Through science learning, students are introduced to the processes of inquiry that allow them to understand how knowledge about the natural world is developed and validated (Lestari et al., 2024; Safkolam et al., 2024). In elementary education, science learning plays a fundamental role in shaping students' basic scientific literacy by developing their conceptual understanding, scientific skills, and attitudes toward inquiry (Auralia & Juliani, 2024). Therefore, it should emphasize the acquisition of factual knowledge, foster students' ability to explore, investigate, and interpret natural phenomena through meaningful learning experiences (Ansori et al., 2026; Corrigan et al., 2025; Morris, 2025).

In Indonesia, the implementation of the Independent Curriculum aims to give teachers greater flexibility to design learning experiences that accommodate students' needs, interests, and learning characteristics (Limiansi et al., 2023; Nurhidin & Habibah, 2024). However, despite these curriculum reforms, science learning outcomes in elementary schools still face significant challenges. Several studies indicate that students' conceptual understanding in science remains relatively low, particularly when learning abstract concepts (Cai et al., 2022; Melati et al., 2025). This situation is often characterized by limited variation in instructional strategies, low student engagement in classroom activities, and insufficient use of learning media to illustrate complex scientific phenomena (Atmojo et al., 2025). Consequently, there is an increasing need for innovative instructional approaches that can create more engaging, interactive, and meaningful learning environments for elementary school students (Sirait et al., 2025).

Initial observations conducted at Public Elementary School (SDN) 21 Sijuk revealed several challenges in science learning, particularly in magnetism, electricity, and everyday technology. First, many students struggle to understand abstract scientific concepts related to magnetic forces, electric circuits, and electromagnetic phenomena.

Second, the learning media used in the classroom have not fully supported active student engagement or conceptual visualization. Third, the learning process often relies on teacher-centered instruction, which often leads to decreased student motivation and limited participation in classroom activities. These conditions are reflected in the relatively low achievement of students' learning outcomes. Based on school evaluation data, only about 47% of students met the minimum competency criteria, indicating that a considerable proportion still struggle to master the expected science competencies.

This situation highlights the importance of designing learning experiences that are more interactive, contextual, and supportive of students' conceptual understanding. In this regard, it is essential to select appropriate instructional models, as they serve as a framework that guides teachers in effectively organizing learning activities (Amalda et al., 2023). One instructional approach that has gained significant attention recently is Project-Based Learning (PjBL). This approach allows students not only to acquire theoretical knowledge but also to develop higher-order thinking skills, creativity, and collaborative competencies (Krajcik & Czerniak, 2018). The PjBL, as a learning model, encourages students to engage in inquiry processes such as planning investigations, collecting information, analyzing data, and presenting project results (Handayani et al., 2025).

Previous studies have demonstrated that implementing PjBL can enhance students' critical thinking, collaboration skills, and learning motivation, ultimately contributing to improved learning outcomes (Mardin et al., 2024; Putri et al., 2025), student engagement, and promote deeper conceptual understanding compared to traditional instructional approaches (Puspitasari et al., 2025). A growing body of research has investigated the effectiveness of the PjBL in learning outcomes when combined with YouTube (Pratomo & Reffiane, 2024), blended learning (Tika & Agustiana, 2021), and the Wordwall application (Isnanto et al., 2024). These findings suggest that integrating PjBL with appropriate learning technologies could further strengthen its effectiveness in science education.

In recent years, digital simulation-based learning media have become increasingly popular in science education due to their ability to visually and interactively represent complex and abstract phenomena. One widely used simulation platform is PhET Interactive Simulations, which offers dynamic, interactive virtual experiments that allow students to explore scientific concepts through direct manipulation of variables (Diab et al., 2024). The platform is developed by the University of Colorado Boulder and supported by various educational institutions and organizations worldwide (Rayan et al., 2023). By interacting with these simulations, students can conduct virtual experiments, test

hypotheses, and observe cause-and-effect relationships, thereby promoting deeper conceptual understanding (R. Arifin et al., 2024; Falloon, 2019). Previous studies have reported that using PhET simulations can enhance conceptual understanding, creativity, and increase students' engagement in elementary school (S. Arifin et al., 2023; Diab et al., 2024; Kukuh et al., 2025), and combining visual representation and interactive exploration is suitable for teaching abstract science topics (Azis & Ariani, 2025).

Although research on Project-Based Learning (PjBL) and PhET simulations is expanding, significant gaps persist. Most studies focus on cognitive outcomes, neglecting other learning dimensions. Furthermore, PjBL and PhET simulations are often investigated separately rather than as an integrated instructional approach. Research on combining PjBL and PhET simulations in elementary science, particularly within Indonesia's Independent Curriculum, remains scarce. It is especially relevant for abstract topics such as magnetism and electricity, which require both conceptual inquiry and visual representation. Addressing these gaps, this study examines three interrelated aspects: students' cognitive outcomes, learning activities, and affective responses to technology-supported instruction. Through integrated PjBL and PhET simulations, students engage in project tasks, explore simulations, conduct virtual experiments, test hypotheses, and collaborate in interpreting results. These experiences support a deeper understanding of abstract scientific concepts through active, experiential learning.

Beyond cognitive outcomes, this study examines students' affective responses, including learning interest, perceived usefulness of PhET simulations, engagement in collaborative activities, and overall satisfaction with the learning process. By analyzing cognitive results, learning activities, and affective measures together, this research offers a comprehensive view of the effectiveness of integrating PjBL with interactive simulations in elementary science. Specifically, the study investigates how the combined approach influences fifth-grade students' learning in magnetism, electricity, and technology in daily life. The findings aim to inform the development of technology-enhanced science instruction and offer practical insights for teachers designing engaging and meaningful science experiences.

RESEARCH METHODS

This study uses a quantitative approach. Data were collected with standardized instruments and analyzed using statistical methods to generate objective, numerical findings. The aim is to provide an empirical overview and test the validity of

predetermined hypotheses. A quasi-experimental design with a pretest-posttest control group was employed. This design was selected because true experimental random sampling is rarely feasible in school settings, as students are already assigned to existing classes (Creswell & Creswell, 2018). The research design can be described in Table 1.

Table 1. Pretest-Posttest Control Group Design

Group	Pretest	Treatment	Posttest
Experiment	O_1	X	O_2
Control	O_3	-	O_4

The research population in this study comprised all fifth-grade students at SDN 21 Sijuk in the 2025/2026 academic year, totaling 120 students distributed across 4 parallel classes. The sampling technique used was a purposive sampling technique with the following considerations: (1) equality of initial academic ability based on the average grade of the previous semester; (2) taught by the same teacher; and (3) having equivalent facilities to access PhET simulation. Of the four existing classes, two were randomly selected as the experimental class (Class V-A, 30 students) and the control class (Class V-B, 30 students), for a total research sample of 60 students.

Three instruments were used to collect data in this study: a learning outcome test, an observation sheet for student learning activities, and a student response questionnaire. The main instrument used to measure students' conceptual understanding was a multiple-choice test of learning outcomes comprising 25 items, developed based on the curriculum indicators for magnetism, electricity, and technology in everyday life. The indicators measured included explaining the properties of magnets, demonstrating magnetization processes, understanding the flow and transformation of electrical energy, analyzing simple electrical circuits, and explaining the application of magnetism and electricity in technological contexts. Each correct answer was assigned 4 points, for a maximum possible score of 100.

Before use in the main study, the test instrument underwent standardization to ensure validity and reliability. Content validity was first assessed through expert judgment involving three validators: two science education lecturers and one senior elementary school teacher. The evaluation yielded a Content Validity Ratio (CVR) of 0.89, indicating that the instrument was highly valid and appropriate for measuring students' learning outcomes. To further examine the quality of the items, the instrument was piloted with 35 sixth-grade students from a neighboring school who had previously studied similar material. This pilot testing aimed to obtain empirical evidence regarding item validity and

reliability through statistical item analysis. The item validity test was conducted using the Pearson Product-Moment correlation, which measures the correlation between each item's score and the total test score. An item was considered valid if the calculated correlation coefficient (r-count) exceeded the critical value of the r-table at a significance level of $\alpha = 0.05$.

For the pilot sample size of 35 students, the r-table value was 0.334. The analysis revealed that 23 of the initial 25 items met the validity criterion, while 2 (items 4 and 19) did not meet the required correlation threshold and were therefore excluded from the final instrument. Consequently, 23 valid items were retained and used as the learning outcome test in the main study. After establishing item validity, the instrument's reliability was examined using the Kuder–Richardson Formula 20 (KR-20), which is suitable for dichotomously scored tests such as multiple-choice items. The reliability analysis yielded a coefficient of 0.82, placing it in the high-reliability category, indicating strong internal consistency and reliable measurement of students' learning outcomes.

In addition to validity and reliability testing, further item analysis was conducted to evaluate the difficulty level and discrimination power of each item. The item difficulty index (P) was calculated as the proportion of students who answered each item correctly. Based on established criteria, items were categorized as difficult ($P < 0.30$), moderate ($0.30 \leq P \leq 0.70$), and easy ($P > 0.70$). The analysis showed that 19 of the 23 valid items fell within the moderate difficulty category, while 2 items were categorized as difficult and 2 as easy. This distribution indicates that the instrument had a balanced level of difficulty and could measure a range of student abilities.

Furthermore, the discrimination index (D) was calculated to assess each item's ability to distinguish between students with high and low achievement levels. The discrimination index was calculated by comparing the proportions of correct responses between the upper (top 27%) and lower (bottom 27%) groups. The results indicated that 18 items had good discrimination power ($0.40 \leq D < 0.70$), while 5 items fell into the sufficient category ($0.20 \leq D < 0.40$). No item was categorized as poor. These results confirm that the final 23-item instrument possesses acceptable psychometric quality and is appropriate for use in the main research.

The second instrument used in this study was an observation sheet designed to assess student learning activities during the implementation of the PhET simulation-based PjBL model. The observation focused on five aspects of student engagement: participation in group discussions, active exploration of PhET simulations, collaboration during project

activities, creativity in project design, and presentation skills when communicating project results. Each aspect was evaluated on a 4-point Likert scale from 1 (less active) to 4 (very active). Two trained observers conducted observations to maintain objectivity and consistency. The level of agreement between observers was analyzed using Cohen's Kappa, yielding a coefficient of $\kappa = 0.85$, indicating very high inter-rater reliability.

The third instrument was a student response questionnaire designed to capture students' perceptions of the learning process. The questionnaire consisted of 20 statements, measured on a four-point Likert scale from strongly disagree to agree strongly. The statements were designed to evaluate several aspects, including students' interest in learning, the perceived ease of using PhET simulations, the usefulness of the learning activities for conceptual understanding, and overall satisfaction with the learning experience. The Kaiser-Meyer-Olkin (KMO) measure of construct validity yielded a value of 0.87, indicating that the data were suitable for factor analysis. The reliability analysis using Cronbach's Alpha yielded a coefficient of 0.91, indicating excellent reliability.

Data analysis in this study was conducted through several stages. First, descriptive statistical analysis was performed to characterize students' learning outcomes, learning activities, and responses. The descriptive analysis included calculating the mean, standard deviation, minimum, and maximum scores, as well as the percentage distribution of student activities and responses during the learning process. To measure the magnitude of the increase in learning outcomes, the N-Gain index was used with the formula:

$$g = \frac{\text{Score Posttest} - \text{Skor Pretest}}{\text{Score Maximum} - \text{Skor Pretest}}$$

The N-Gain values were interpreted using the following criteria: high ($g \geq 0.70$), moderate ($0.30 \leq g < 0.70$), and low ($g < 0.30$). Before conducting hypothesis testing, prerequisite tests were performed to ensure that the data met the assumptions required for parametric statistical analysis. The normality test was conducted using the Shapiro–Wilk test, which is appropriate for sample sizes of 50 or fewer per group. The homogeneity of variance was tested using Levene's Test. Data that satisfied the assumptions of normality and homogeneity were subsequently analyzed using inferential statistics.

Hypothesis testing involved two types of t-tests. A paired sample t-test was used to determine whether there were significant differences between pretest and posttest scores within each group. Meanwhile, an independent-samples t-test was conducted to examine differences in learning outcomes between the experimental and control groups, using both

posttest scores and N-Gain values. All statistical tests used a significance level of $\alpha = 0.05$, where p-values less than 0.05 indicate a statistically significant difference.

To complement the significance analysis, the effect size was calculated using Cohen's d, which provides information about the magnitude of the treatment effect. The effect sizes were interpreted using the following criteria: small ($d = 0.2$), moderate ($d = 0.5$), and large ($d \geq 0.8$). Through this analysis, the study not only examined whether differences existed between groups but also evaluated the strength of the PhET simulation-based PjBL model's influence on students' learning outcomes. All statistical analyses were conducted using IBM SPSS Statistics version 29, while Microsoft Excel 2021 was used for initial data processing and visualization.

RESULTS AND DISCUSSION

Results

Student Learning Outcomes, Activities, and Responses in Learning

This study presents descriptive statistics to provide an initial overview of the distribution and trends in student learning outcomes across groups before conducting inferential analysis. These statistics include the mean, standard deviation, and minimum and maximum scores at the pretest and posttest stages for both the experimental and control groups. This presentation identifies initial patterns of change in learning outcomes and compares the initial and final conditions across groups. The complete descriptive statistics are presented in Table 2.

Table 2. Descriptive Statistics of Student Learning Outcomes

Group	Test	N	Mean	Std. Deviation	Min	Max
Experiment	Pretest	30	65,33	8,42	52	80
Experiment	Posttest	30	85,67	6,15	72	96
Control	Pretest	30	64,67	8,91	48	80
Control	Posttest	30	73,33	7,82	60	88

Source: Research Data 2025

Table 2 shows a comprehensive profile of student learning outcomes in both research groups before and after the treatment. The average pretest scores of the experimental (65.33) and control (64.67) classes showed very little difference (0.66 points), indicating that students' initial abilities in both groups were relatively homogeneous. This condition is very important for ensuring the internal validity of the study, because differences that emerge after the treatment can be attributed to the learning intervention rather than to differences in initial abilities.

After the treatment was implemented, the average posttest score in the experimental class increased to 85.67, with a smaller standard deviation (6.15) than the pretest (8.42), indicating higher scores and greater consistency of improvement across students in the group. Meanwhile, the control class also showed an increase, though of much lower magnitude, with an average posttest score of 73.33 and a standard deviation of 7.82, indicating that conventional learning still has a positive impact but is less effective than PjBL-PhET-based learning. The difference in score ranges reflects the quality of learning: the experimental class showed a higher minimum posttest score (72 versus 60), indicating that even the lowest-ability students in the experimental class achieved better results than those in the control class.

Table 3. N-Gain Analysis of Learning Outcomes

Group	*N-Gain*	Category
Experiment	0,71	High
Control	0,25	Low

Source: Research Data 2025

The N-Gain analysis in Table 3 provides a more in-depth overview of learning effectiveness by normalizing the score increase to the available room for improvement for each group. The experimental class showed an N-Gain value of 0.71, which falls within the high category ($g \geq 0.7$), indicating that PjBL-PhET-based learning utilized 71% of the available improvement potential to achieve the maximum score. This achievement is very impressive, considering the complexity of magnetism, electricity, and technological materials, which are often considered abstract and challenging for elementary school students.

In contrast, the control class achieved an N-Gain of 0.25, which falls in the low category ($g < 0.3$), indicating that conventional learning utilized only 25% of the available improvement potential. The stark difference between the two groups (0.46) indicates the superiority of the PhET simulation-based PjBL learning model in facilitating deep, meaningful mastery of science concepts. This finding strengthens the argument that integrating interactive simulation technology with a constructivist pedagogical approach can create transformative learning experiences for elementary school students.

Table 4. Data Normality Test (Shapiro-Wilk)

Group	Test	Statistic	*df*	*Sig.*	Decision
Experiment	Pretest	0,961	30	0,327	Normal
Experiment	Posttest	0,968	30	0,489	Normal

Group	Test	Statistic	*df*	*Sig.*	Decision
Control	Pretest	0,957	30	0,258	Normal
Control	Posttest	0,964	30	0,392	Normal

Source: Research Data 2025

Table 4 indicates that all research data distributions meet the assumption of normality, which is an important prerequisite for parametric statistical analysis. All four data groups (pretest and posttest for the experimental and control classes) show p-values greater than $\alpha = 0.05$, ranging from 0.258 to 0.489, indicating that the data are normally distributed and exhibit no significant deviation from the theoretical normal distribution. The Shapiro-Wilk statistic, which ranges from 0.957 to 0.968, also indicates excellent agreement with the normal distribution, as values approaching 1.0 indicate a more normal distribution. Fulfillment of this normality assumption is crucial because it legitimizes the use of t-tests (paired-samples and independent-samples t-tests) in inferential analysis. The appropriate use of parametric tests ensures that conclusions drawn from data analysis are highly statistically valid and can be generalized to broader contexts.

Table 5. Homogeneity Test (Levene's Test)

Variables	F	*df1*	*df2*	*Sig.*	Decision
Pretest	0,128	1	58	0,722	Homogen
Posttest	2,453	1	58	0,123	Homogen

Source: Research Data 2025

The homogeneity-of-variance test using Levene's Test in Table 5 shows that the variances of both research groups are homogeneous for both the pretest and posttest data. The significance values for the pretest ($p = 0.722$) and posttest ($p = 0.123$) are both significantly greater than the significance level of $\alpha = 0.05$, indicating no significant difference in variance between the experimental and control classes. The relatively low F-statistics (0.128 for the pretest and 2.453 for the posttest) also confirm the homogeneity of variance between the groups.

Fulfilling the assumption of homogeneity of variance is crucial because it is one of the main prerequisites for using the independent sample t-test to compare the learning outcomes of the two groups. Homogeneity of variance indicates that the variability of scores within each group is comparable, allowing valid comparisons of group means without bias caused by differences in internal variability. The combination of fulfilling the assumptions of normality and homogeneity provides a solid statistical foundation for conducting inferential analysis and drawing valid conclusions about the effectiveness of the learning model being tested.

Table 6. Paired Sample t-test Results

Group	Pair	Mean Difference	*Std. Deviation*	*t*	*df*	Sig. (2-tailed)	Decision
Experiment	Posttest-Pretest	20,34	6,89	16,178	29	0,000	Significant
Control	Posttest-Pretest	8,66	5,12	9,261	29	0,000	Significant

Source: Research Data 2025

The paired-samples t-test results in Table 6 provide strong statistical evidence of learning effectiveness within each group, as pretest and posttest scores are compared within the same group. Both groups showed a statistically significant difference between the pretest and posttest ($p = 0.000 < 0.05$), indicating that both PjBL-PhET-based and conventional learning improved student learning outcomes. However, the magnitude of the increase showed a very substantial difference between the two groups. The experimental class showed an average increase of 20.34 points, with a t-value of 16.178, which was significantly higher than the control class, which showed an average increase of 8.66 points, with a t-value of 9.261.

The higher t-value in the experimental class indicates that the increase occurred not only greater in absolute terms, but also more consistent and statistically significant. The larger standard deviation in the experimental class (6.89 versus 5.12) indicates a higher variability in improvement, which can be interpreted as varying responses to innovative learning, but this does not diminish the significance of the findings, given the significantly greater average improvement. This finding strengthens the argument that the PhET simulation-based PjBL model not only provides a significant impact but also a substantially greater impact than conventional learning in the context of science learning in elementary schools.

Table 7. Independent Sample t-test Results

Variables	*t*	*df*	Sig. (2-tailed)	Mean Difference	Cohen's d	Category
Posttest	6,589	58	0,000	12,34	1,70	Very large

Source: Research Data 2025

Table 7 provides very strong empirical evidence for the superiority of PjBL-PhET-based learning over conventional learning. The t-value of 6.589 and p-value of 0.000 ($p < 0.001$) indicate that the difference in posttest learning outcomes between the experimental and control classes is highly statistically significant, with a probability of error approaching zero. The average difference of 12.34 points between the two groups is substantial in the context of learning, given the 0-100 scoring scale.

More importantly, Cohen's d effect size of 1.70 falls in the "very large" category (d ≥ 0.8), indicating that the treatment effect is not only statistically significant but also practically and pedagogically meaningful. Cohen's d value of 1.70 indicates that the average student in the experimental class is at the 95.5th percentile of the control class's distribution, meaning that students with average abilities in the experimental class will outperform approximately 95.5% of students in the control class. This finding provides a strong justification for adopting the PhET simulation-based PjBL learning model as an effective alternative for magnetism, electricity, and technology materials in elementary schools, given its significant impact on student learning outcomes.

Table 8. Results of Observations of Student Activities in the Experimental Class

Observed Aspects	Meeting 1-2 (%)	Meeting 3-4 (%)	Meeting 5-6 (%)	Average	Category
Involvement in group discussions	82,5	86,7	90,0	86,4	Very Active
PhET exploration activity simulation	85,0	88,3	91,7	88,3	Very Active
Collaboration skills	80,0	85,0	88,3	84,4	Very Active
Creativity in project design	83,3	86,7	90,0	86,7	Very Active
Presentation skills	78,3	83,3	92,5	84,7	Very Active
Total Average	**81,8**	**86,0**	**90,5**	**87,5**	**Very Active**

Source: Research Data 2025

Observation data on student activity in Table 8 shows very high and consistent engagement during the implementation of PjBL-PhET-based learning. The average student activity reached 87.5%, placing it in the "very active" category, indicating that this learning model successfully fostered high engagement in the learning process. What is interesting is the pattern of progressive increase from the initial meeting (81.8%) to the final meeting (90.5%), indicating an adaptive learning curve in which students become more skilled and comfortable with the project-based learning approach and simulation technology over time. The exploration activity aspect of the PhET simulation showed the highest percentage (88.3%), indicating that the simulation media successfully attracted interest and facilitated active student engagement in exploring the concepts of magnetism and electricity.

The interactive, visual, and game-like characteristics of PhET are very much in line with the learning preferences of the digital-native generation, thereby helping maintain student focus and motivation. Consistent improvements in all aspects of observation ranging from group discussion engagement (82.5% to 90.0%), collaboration (80.0% to 88.3%), creativity (83.3% to 90.0%), to presentation skills (78.3% to 92.5%) indicate that

the PjBL-PhET model is not only effective for one particular aspect of learning, but provides a holistic impact on various essential 21st-century skills for students. These findings strengthen the argument that well-designed technology-based learning can enhance active learning and encourage students to become independent, creative, and collaborative learners.

Table 9. Experimental Class Student Response Questionnaire Results

Aspect	Average Score	Percentage (%)	Category
Interest in learning	3,62	90,5	Very Positive
Ease of use of the PhET simulation	3,48	87,0	Very Positive
Benefits of understanding concepts	3,64	91,0	Very Positive
Satisfaction with learning	3,52	88,0	Very Positive
Average Score	**3,57**	**89,3**	**Very Positive**

Source: Research Data 2025

The results of the student response questionnaire in Table 9 indicate very positive acceptance of PjBL-PhET-based learning, with an average of 89.3%, which is categorized as "very positive." This finding is very important because students' affective responses to learning are strongly correlated with learning motivation, persistence in facing challenges, and willingness to engage in in-depth learning. The benefits for conceptual understanding received the highest response (91.0%), indicating that students consciously felt the real impact of this learning on mastering concepts in magnetism, electricity, and technology that were previously considered abstract and difficult to understand. It aligns with Vygotsky's social constructivist theory, which emphasizes scaffolding and mediation in learning, and with the PhET simulation, which serves as a cognitive tool that supports students' understanding of complex scientific phenomena.

The ease of use of the PhET simulation, which received a positive response (87.0%), indicates that the intuitive PhET interface design and adherence to Universal Design for Learning (UDL) principles successfully accommodate the characteristics and abilities of elementary school students. The simple yet powerful interface allows students to focus on exploring concepts without being burdened by the technical complexity of operating the software. The very high interest in learning (90.5%) and satisfaction with learning (88.0%) indicate that the PjBL-PhET model successfully creates an engaging, meaningful, and enjoyable learning experience. According to Self-Determination Theory,

students' intrinsic motivation will increase when learning fulfills three basic psychological needs: autonomy (freedom in designing projects), competence (success in exploration through PhET), and relatedness (collaboration in groups). PjBL-PhET learning has been proven to address these three aspects comprehensively.

Discussion

PhET Simulation-Based PjBL Model Effectiveness in Improving Learning Outcomes

The study found that the PjBL learning model based on PhET simulations was effective in improving fifth-grade students' learning outcomes in magnetism, electricity, and technology for life. The experimental class's learning outcomes, with an N-Gain of 0.71 (high category), were much higher than those of the control class, with an N-Gain of 0.25 (low category). The presence of a significant difference ($p < 0.05$) with a very large effect size (Cohen's $d = 1.70$) confirmed the effectiveness of this learning model. In line with previous research that shows changes and improvements in elementary school students' activities and learning outcomes through PjBL (Atmojo et al., 2025; Hannah et al., 2024; Mardin et al., 2024).

Various studies have shown that using PhET simulations significantly improves student learning outcomes. Research by Arifin et al. (2023) and Sirait et al. (2025) found that students who learned using PhET achieved significantly higher posttest scores than those who participated only in lecture-based learning. The interactive simulation environment in PhET allows students to conduct repeated experiments without risk or expense, allowing them to explore cause-and-effect relationships in the science learning process in greater depth. These exploratory activities encourage independent learning and increase students' motivation to participate in the learning process actively. Furthermore, the animations and visualizations provided by PhET can overcome the limited laboratory facilities that remain a major obstacle in many schools, enabling students to observe abstract concepts virtually, as if they were in a real laboratory (Corrigan et al., 2025).

In line with these findings, various studies have also shown that implementing the PjBL model, supported by interactive learning media, has a positive impact on student learning outcomes. The PjBL model not only helps students understand concepts more deeply but also trains critical thinking, problem-solving, and collaboration skills relevant to the demands of 21st-century learning (Montessori et al., 2024). Furthermore, the PhET-based PjBL model has consistently proven effective in improving learning outcomes through active, collaborative, and contextual learning, particularly on topics such as

magnetism, electricity, and technology in everyday life, with literature supporting this by increasing learning motivation, higher-order thinking skills, and long-term conceptual mastery (Efliana et al., 2022). Therefore, this research enriches science education practices by presenting a replicable learning model that optimizes the use of interactive technology, particularly for implementation at the elementary school level (Namira et al., 2024).

In this research, students can manipulate variables in the simulation, such as changing the strength of a magnet, reversing its poles, designing electrical circuits with various configurations, and observing electromagnetic induction in real time. This virtual, hands-on experience is crucial for elementary school students who are still in the concrete operational stage, where they need concrete representations to understand abstract phenomena. The synergy between PjBL and PhET simulations creates an optimal learning environment for science learning. PjBL provides a pedagogical framework that encourages inquiry, collaboration, and authentic problem-solving. In contrast, PhET simulations provide technological tools that enable in-depth exploration of concepts without the limitations of a physical laboratory. This combination allows students to experiment without risk, repeat observations as many times as necessary, and build a strong understanding through guided discovery (Sukmawati et al., 2025).

Student Activities in PhET Simulation-Based PjBL Learning

Highly active student engagement (87.5%) in PhET simulation-based PjBL learning indicates that this learning model effectively fosters high student engagement. The progressive increase in activity from the first meeting (81.8%) to the last meeting (90.5%) indicates the process of adaptation and improvement of student skills in using this learning model. The highest level of active exploration of PhET simulations (88.3%) indicates that the simulation media successfully attract interest and facilitate active student engagement. The interactive, visual, and game-like characteristics of PhET are highly aligned with the learning preferences of the digital-native generation. Recent studies have shown that simulation-based learning increases student engagement by providing direct control over the learning process and instant feedback. High collaboration skills (84.4%) reflect the effectiveness of the group learning structure in PjBL.

Through group project work, students learn to communicate, share ideas, negotiate, and resolve conflicts, which are essential 21st-century skills. Creativity in project design (86.7%) indicates that PjBL provides students with space to express their understanding in unique and personal ways rather than simply reproducing the teacher's knowledge. This

finding aligns with the research by Alvarez & Webb (2025), which showed a significant difference between the experimental group that used PhET simulation media in the PjBL model and the control group that did not, at the 95% confidence level. The experimental group demonstrated higher academic learning outcomes, particularly in the ability to analyze how changes in relevant variables affect the design and performance of the learning system. This further strengthens the evidence that integrating PhET simulations into PjBL not only increases learning engagement but also positively affects the quality of conceptual understanding and overall student learning outcomes.

Students' Positive Response to Learning

The very positive student response (89.3%) to the PhET simulation-based PjBL learning indicates high satisfaction and motivation to learn. The highest score for benefits for conceptual understanding (91.0%) confirms that students feel a real impact of this learning on their understanding of magnetism, electricity, and technology. The ease of use of the PhET simulation (87.0%) indicates that the PhET intuitive user interface design suits the characteristics of elementary school students. PhET uses the Universal Design for Learning (UDL) design principle, which ensures accessibility for students at various ability levels (Priscilia & Haryani, 2025).

The simple yet powerful interface allows students to focus on exploring concepts without being burdened by technical complexity. High interest in learning (90.5%) indicates that the PhET simulation-based PjBL successfully creates an engaging and meaningful learning experience. Self-Determination Theory emphasizes that students' intrinsic motivation will increase when learning meets basic psychological needs: autonomy (freedom in project design), competence (successful exploration through PhET), and relatedness (collaboration in groups). This learning addresses all three aspects, thereby fostering high learning motivation (Alya et al., 2025).

Theoretical and Practical Implications

Theoretically, this study provides empirical evidence on the effectiveness of integrating technology (PhET simulations) into a constructivist learning model (PjBL) for science learning in Indonesian elementary schools, particularly in the context of the Independent Curriculum implementation. These findings reinforce constructivist learning theory, which emphasizes active learning, exploration, and students' construction of knowledge (Li et al., 2025). This study also contributes to the development of

Technological Pedagogical Content Knowledge (TPACK) for elementary school science learning (Khairani & Rosita, 2025). The effective integration of content knowledge (magnetism, electricity, technology), pedagogy (PjBL), and technology (PhET simulation) demonstrates that all three must be developed synergistically to create optimal learning.

In practice, this study provides a concrete learning model that elementary school science teachers can adopt to improve learning quality, particularly for material involving abstract phenomena. This model also addresses the challenge of limited science laboratories in many Indonesian elementary schools by utilizing freely accessible virtual laboratories (Manalu et al., 2025). This learning model also supports the implementation of the Independent Curriculum, which emphasizes project-based learning, learning differentiation, and the development of the *Pancasila Student Profile*: critical reasoning, creativity, independence, and cooperation (Habibah & Nurhidin, 2023). The integration of digital literacy into the digital poster project also supports the development of students' digital competencies, essential in the digital age.

Theoretical and Empirical Contributions

This study provides both theoretical and empirical contributions to the field of science education in elementary schools. From a theoretical perspective, the findings support the constructivist learning theory, which emphasizes that meaningful learning occurs when students actively construct knowledge through exploration, experimentation, and social interaction. The integration of Project-Based Learning with PhET simulation demonstrates how technology-enhanced learning environments can facilitate conceptual understanding of abstract scientific phenomena such as magnetism and electricity. The study also strengthens the theoretical perspective that combining inquiry-based learning activities with interactive digital simulations can enhance both cognitive and affective dimensions of learning.

From an empirical perspective, this study contributes to the growing body of research on technology-assisted science learning by providing evidence that integrating PjBL pedagogy with PhET interactive simulations significantly improves student learning outcomes compared with conventional instruction. In addition, this research highlights the importance of examining not only cognitive achievement but also student learning activities and affective responses, which are often overlooked in previous studies. The results demonstrate that technology-supported project-based learning can create more engaging and meaningful learning experiences for elementary school students. In practice,

the findings have important implications for teachers and educational practitioners by offering an innovative instructional approach that integrates project-based pedagogy with digital simulation tools to improve the quality of science learning in elementary schools.

Research Limitations and Recommendations

Although this study shows positive results, several limitations need to be considered. First, the study was conducted at only one school with a small sample size (60 students), so generalizing the results should be done with caution. Further research with larger, more diverse samples across various school contexts (urban-rural, public-private) is needed for external validation. Second, this study measured only cognitive learning outcomes and did not specifically assess science process skills or other 21st-century skills. Future research could develop instruments to measure critical thinking, creativity, collaboration, and digital literacy as additional dependent variables. Third, the limited duration of the study (6 meetings) does not allow for measuring long-term knowledge retention. Longitudinal studies that measure students' conceptual understanding after several months or years would provide information on the long-term impact of this learning. For practical implementation, teachers need adequate training in PjBL syntax and the use of PhET simulations (Alya et al., 2025; Kukuh et al., 2025). Technological support, such as the availability of devices (computers/tablets) and stable internet access, is also an important prerequisite. Schools and the government need to invest in technological infrastructure and teacher professional development to support the sustainable implementation of technology-based learning (Aldogiher et al., 2025).

CONCLUSION

This study concludes that integrating the Project-Based Learning (PjBL) model with PhET simulations significantly improves fifth-grade students' science learning outcomes in magnetism, electricity, and technology in everyday life. Students who participated in the PhET simulation-based PjBL learning demonstrated higher posttest scores and greater learning gains than those who experienced conventional instruction, indicating that the learning model effectively supports students' conceptual understanding of abstract science concepts.

In addition to improving cognitive learning outcomes, implementing the PjBL model, supported by PhET simulations, encourages active student participation during the learning process and elicits positive responses toward science learning. The integration of

project-based pedagogy with interactive simulation technology enables students to explore concepts through experimentation, collaboration, and problem-solving, creating more engaging and meaningful learning experiences.

Overall, the findings suggest that the PhET simulation-based PjBL model can serve as an effective instructional alternative for elementary science learning, particularly for topics involving abstract phenomena that require visualization and experimentation. This study, therefore, contributes to the development of technology-supported science learning models that facilitate the implementation of innovative, student-centered learning practices in elementary education.

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