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The influence of project-based learning using PhET on fifth-grade scientific literacy in electrical circuits

Saras Dwi Putri Maulida*, Mubarak Ahmad

Universitas Muhammadiyah Prof. Dr. Hamka, Indonesia

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Abstract: This study aims to investigate the effect of the Project Based Learning (PjBL) model assisted by PhET simulations on the scientific literacy skills of fifth-grade elementary school students, specifically on the topic of electrical circuits. The study employed a quasi-experimental method with a nonequivalent control group pretest-posttest design, conducted at a public elementary school in East Jakarta. The sample consisted of 61 fifth-grade students divided into two groups: the experimental group and the control group. The instrument used was a scientific literacy test developed based on the four components of scientific literacy according to PISA, namely context, content, competency, and attitude, and it had undergone validity and reliability testing. Data were analyzed using descriptive statistics and an independent t-test. The results showed a significant difference in scientific literacy scores between the experimental and control groups, indicating that the application of the PjBL model with PhET simulations is effective in enhancing the scientific literacy of elementary school students.

Keywords: PhET, project-based learning, scientific literacy

Abstrak: Penelitian ini bertujuan untuk mengevaluasi pengaruh model *pembelajaran Project Based Learning* (PjBL) yang didukung simulasi PhET terhadap kemampuan literasi sains siswa kelas V SD, khususnya pada materi rangkaian listrik. Metode yang digunakan adalah kuasi eksperimen dengan desain *nonequivalent control group pretest-posttest* yang dilakukan di sebuah sekolah dasar negeri di Jakarta Timur. Sampel terdiri dari 61 siswa kelas V yang dibagi menjadi dua kelompok, yaitu kelompok eksperimen dan kelompok kontrol. Alat ukur yang digunakan berupa tes literasi sains yang dikembangkan berdasarkan empat komponen literasi sains menurut PISA, yaitu konteks, konten, kompetensi, dan sikap, serta sudah diuji validitas dan reliabilitasnya. Data dianalisis menggunakan statistik deskriptif dan uji-t independen. Hasil penelitian memperlihatkan perbedaan bermakna antara nilai literasi sains siswa di kelompok eksperimen dan kontrol, yang mengindikasikan bahwa penerapan model PjBL dengan simulasi PhET efektif dalam meningkatkan literasi sains siswa SD

Kata kunci: PhET, pembelajaran berbasis proyek, literasi sains

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*Corresponding author: srsputri16@gmail.com

INTRODUCTION

Education serves as a foundation for preparing students to meet the demands of the future by developing their knowledge, skills, and character. As formal education providers, schools carry the duty to deliver effective learning opportunities (Mustofa et al., 2024; Nasir et al., 2024). Nevertheless, educational standards in Indonesia remain below expectations. This is especially evident in the continued low literacy rates among students, most notably at the elementary school level (Amelia et al., 2024). According to the PISA 2022 assessment, Indonesia ranked 69th out of 80 participating countries (Pusat Asesmen Pendidikan, 2022). This situation highlights how important it is to improve students' skills in understanding and using scientific literacy, such as shallow understanding of key concepts, a lack of strong critical thinking, and mostly teacher-focused teaching methods (Fuadi et al., 2020).

Logical and critical thinking are key aspects of scientific literacy because they are closely related to students' cognitive abilities, which help them grasp scientific concepts and tackle problems effectively (Sanjiartha et al., 2024). In the context of 21st-century education, scientific literacy has become increasingly important; it involves not just understanding scientific ideas, but also applying these ideas in daily life and making informed choices based on scientific facts and evidence. At the elementary level, scientific literacy is reflected in how actively students participate in learning, their willingness to read, and their skills in expressing their thoughts both verbally and in writing (Lorenza, 2025; Nurpratiwi et al., 2023). Unfortunately, many students still struggle to show these characteristics. This situation is concerning because literacy is the cornerstone for learning all other subjects, including scientific (Fitriani, 2024).

Scientific literacy among elementary school students is still lacking, in part because classroom learning often doesn't give children the chance to truly explore scientific ideas in practical, meaningful ways. As noted by Efendi et al. (2021) Many primary classrooms continue to depend on conventional, teacher-led lessons, which leave little room for students to actively engage with real-world word scientific problems. Ramdani (2023) points out that this environment frequently leads students to simply memorize facts, rather than actually understanding what they learn or seeing how it applies in daily life, resulting in weak mastery of key concepts. Nuriyah et al. (2024) found that misconceptions about simple electrical circuits are widespread among young students, indicating gaps in both their content knowledge and ability to reason scientifically. In contrast, research by Nurpratiwi et al. (2023) shows that when students experience inquiry-based approaches like the RADEC model, their scientific literacy improves noticeably, outcomes very different from what's seen with passive learning methods. Fauziyah et al. (2024) also demonstrated that virtual labs, such as those provided by PhET, can spark curiosity and boost comprehension in science. Furthermore Fitriani (2024) discovered a strong relationship between students' literacy abilities and how well they understand scientific content, suggesting that building literacy skills is a vital foundation for scientific learning success.

Insights from observing fifth-grade elementary classrooms show that students' abilities in scientific literacy are still falling short. This is apparent across a number of areas. On the content side, many struggle to clearly describe simple scientific ideas like what a battery does or how electricity moves in a circuit. When it comes to context, students often have difficulty using what they've learned in everyday situations-such as operating switches and lamps at home. Their reasoning skills are another weak point; many students can't predict what might happen if something in a circuitchanges, nor can they justify their thought process, and often give up quickly on challenges during scientific lessons. These patterns were noticed during classroom activities about passive listening, rather than engaging actively.

Furthermore, learning activities remain dominated by teacher-centered methods and rarely provide opportunities for exploration or project-based tasks. This aligns with findings from Nasir et al. (2024), which indicate that fifth-grade elementary students struggle to grasp scientific concepts deeply and contextually apply them. One of the most prominent issues identified was the topic of electrical circuits—an idea that is both fundamental and directly connected to daily life, such as when using lamps, batteries, or electronic devices. However, students often fail to understand how electrical components interact or how current flows within a circuit (Nuriyah et al., 2024). These difficulties indicate low levels of scientific literacy in content, context, and competency domains. Previous studies also support this, showing that students rely more on memorization than conceptual reasoning and often cannot express scientific ideas using appropriate terminology (Efendi et al., 2021; Ramdani, 2023). Therefore, this study focuses on the topic of electrical circuits as a meaningful entry point to improve scientific literacy by integrating Project-Based Learning with PhET simulations.

Project-based learning (PjBL) gives students real and meaningful challenges, allowing them to apply scientific ideas directly in everyday life (Sujud et al., 2024). This approach is known to build important skills, such as scientific investigation, critical thinking, and clear communication of scientific concepts (Putri et al., 2021). Through PjBL, students start to truly understand content because lessons are tied to hands-on activities and real-world situations they recognize (Lavado-Anguera et al., 2024) . PjBL also develops students' ability to think in context, encouraging them to analyze problems, interpret data, and make predictions or hypotheses (Zulkarnaen et al., 2025). Working together on a project further supports the growth of scientific attitudes like curiosity, persistence, and openness to new perspectives, by fostering these skills and mindsets, PjBL meets the core needs of 21st-century learning, which values students' curiosity, active participation, and deep understanding of concepts (Nasril & Desyandri, 2023).

Although project-based learning has many benefits, its use in elementary classrooms is still met with several obstacles. A key challenge is that students often struggle to make sense of abstract scientific ideas-especially those related to electricity, which the microscopic and not visible to the naked eye. Ramdani (2023) points out that, without enough guidance, some students may get lost during projects and miss out on deep understanding. Success with PjBL also depends heavily on having sufficient resources and teachers who are skilled at leading inquiry, which aren't always available in typical classroom settings (Fitriani, 2024). To overcome these barriers, schools need learning tools that help students grasp scientific concepts while providing an interactive experience. One such tool is PhET simulations, which bring scientific to life by letting students explore, experiment with variables, and get instant feedback through vivid visuals. According to Fauziyah et al. (2024) using virtual media like PhET boosts students' motivation and helps them understand scientific better, showing its promise for making PjBL even more effective.

To make PjBL even more effective, it can be very helpful to integrate interactive tools such as PhET simulations-especially during the stages when students are exploring and experimenting as part of their projects. With PhET, learners access online simulations that make challenging scientific concepts more understandable and engaging; these simulations turn abstract ideas into something students can easily see and interact (Noverma et al., 2024). By adjusting variables and getting immediate feedback, students are free to try things out themselves, which helps them better understand topics like electrical circuits (University of Colorado Boulder, 2024). This approach fits perfectly with the principles of project-based learning, where students actively investigate, build new knowledge, and use scientific reasoning throughout each project (Nasril & Desyandri, 2023). Including PhET in PjBL lessons keeps students more interested and deeply supports the growth of their conceptual understanding. Agustina et al. (2024) found that PhET-based e-worksheets provide interactive visualizations that help students better understand complex scientific concepts and inscrease their engagement.

Based on the explanation, it is evident that students' low scientific literacy, particularly in understanding and applying concepts related to electrical circuits, remains a significant challenge in elementary education. Conventional, teacher-centered learning models are insufficient in addressing students' needs for conceptual understanding, critical thinking, and contextual application. Project-based learning offers a promising solution by fostering active engagement and inquiry; however, its effectiveness can be further enhanced through the integration of interactive simulations such as PhET. The combination of PjBL and PhET aligns with the characteristics of 21st-century learning, emphasizing student autonomy, real-world relevance, and scientific reasoning. Therefore, this study aims to investigate the effectiveness of project-based learning, supplemented by PhET simulations, in enhancing the scientific literacy of fifth-grade elementary school students on the topic of electrical circuits.

METHOD

This study took place at a public elementary school in East Jakarta and used a quasi-experimental design with a pretest-posttest control group to examine how the PjBL, supported by PhET simulations, affects students' scientific literacy. This method is often preferred in educational settings because it allows researchers to explore cause-and-effect relationships in real classroom environments where random assignment isn't always possible (Abraham & Supriyati, 2022). The participants were fifth-grade students from two classes at the school, totaling 6 students- 31 students in the experimental group and 30 in the control group. The researchers applied saturated sampling by including all fifth graders from those two classes, which fits well since they studied the entire population of that grade. The instrument used to assess students' scientific literacy was an essay test consisting of 10 items developed based on the PISA scientific literacy indicators. The test measured five core dimensions: conceptual understanding, analytical comparison, contextual application, problem solving, and scientific communication.

The scientific literacy assessment rubic was developed following the guidelines presented in the book "Pengembangan Instrumen Penilaian Berbasis Literasi Sains," which was published by the Indonesian Ministry of Education (Direktorat Jenderal Pendidikan Anak Usia Dini, 2021) This framework is based on the PISA model of scientific literacy, highlighting four main areas: content, context, competency, and attitude. The rubic was designed to evaluate students' skills in these areas, whit special attention to conceptual inderstanding, analytical thinking, applying knowledge in context, solving problems, and communicating scientific ideas (Table 1). By aligning with this framework, the assessment tool is well-grounded in theory and suitable for measuring scientific literacy in elementary school students.

Before the instrument was employed for data collection, it underwent validation using the Pearson product-moment correlation method, and its reliability was assessed through Cronbach's Alpha. Additionally, expert reviews were conducted during the development phase to ensure its alignment with the intended learning objectives and curriculum standards. The validation process involved two specialists: a university lecturer with expertise in primary scientific education and an active elementary school scientific teacher. Their feedback contributed to refining the content, structure, and scoring rubric to guarantee content validity and contextual relevance. The outcomes of the instrument's validity and reliability tests are presented in the Tables 2.

Table 1. Rubric for scientific literacy essay assessment

Criteria	**Score 4 (Very Good)**	**Score 3 (Good)**	**Score 2 (Fair)**	**Score 1 (Poor)**
Conceptual Understanding	Demonstrates in-depth understanding of series and parallel circuits, including current, voltage, and resistance; accurately explains relationships between components.	Understands series and parallel circuits reasonably well, but with minor inaccuracies.	Demonstrates basic understanding but with several conceptual inaccuracies.	Does not demonstrate adequate understanding of electrical circuits
Analytical Comparison	Provides a comprehensive analysis of differences between series and parallel circuits, including current flow, voltage, and failure consequences; compares advantages and disadvantages clearly.	Identifies differences and compares them, though explanations lack depth	Identifies only some fundamental differences; analysis is limited.	Fails to identify or analyze differences between the two circuit types
Contextual Application	Connects circuit concepts to real-life applications in a relevant and creative way; provides strong reasoning for appropriate use in context	Provides real-life examples, but with less elaboration or weak relevance	Mentions examples without clearly linking them to the concept	Does not provide examples or connections to real-life situations

Problem Solving	Offers innovative solutions to complex problems related to electrical circuits, based on a deep conceptual understanding; explains each step in detail.	Provides adequate solutions to simple problems	Attempts to solve problems, but the solutions are incorrect or incomplete.	Fails to provide a solution or apply concepts
Scientific Communication	Explains concepts and analysis using clear, logical, and structured scientific language	Mostly clear communication with minor structural issues	Communicates with vague or unclear language	Unable to communicate ideas or analysis meaningfully

Table 2. Item validity results

Item No	**Validity**			**Reliability**	
	r-count	**r-table**	**Result**	**Method**	**r-count**
1	0.451	0.388	Valid	Cronbach's Alpha	0.623
2	0.524				
3	0.535				
4	0.588				
5	0.409				
6	0.409				
7	0.458				
8	0.535				
9	0.409				
10	0.553				

The implementation procedure began with coordination with the school and teachers, followed by pretests for both groups to determine baseline scientific literacy. The experimental group underwent learning through the PjBL model assisted by PhET simulations, following six phases: presenting a driving question, planning the project, organizing tasks and collaboration, investigation and mentoring, product presentation and reflection, and final feedback. PhET simulations were primarily used in the inquiry and mentoring phase, where students explored how electric current flows through various circuit configurations, tested virtual components such as switches, bulbs, and batteries, and visualized the effects of changes in resistance and connections. These simulations allowed students to experiment and revise their project plans before constructing the physical models. The control group received conventional instruction. After the intervention, both groups were given a posttest using the same instrument.

Data analysis involved both descriptive and inferential statistics. Normality was tested using the Shapiro-Wilk test, and homogeneity of variance was tested using Levene's test. Once assumptions were met, hypothesis testing was performed using an independent samples t-test with a 0.05 significance level. The effect size of the treatment was further measured using Cohen's d, Hedges' g, and Glass's delta.

RESULTS AND DISCUSSION

This study involved fifth-grade pupils enrolled in a primary school setting. Prior to commencing the main experiment, a series of preliminary data analyses were executed. These included a Shapiro-Wilk test to ascertain normality and Levene's test to check for homogeneity. Provided the data conformed to these normality and homogeneity assumptions, an independent samples t-test was subsequently employed to facilitate a comparison between the two group means. The core research data were gathered from the post-test scores of students' scientific literacy on electrical circuit concepts, administered to two distinct groups: an experimental cohort and a control cohort. The experimental group, comprising 31 learners, engaged with a project-based learning model. In contrast, the control group, composed of 30 students, underwent instruction through a direct learning approach. Following the collection of post-test outcomes from both cohorts, a comprehensive data distribution table was constructed to enable subsequent analytical procedures.

Table 3. Student scientific literacy scores data in experimental and control classes

Class	N	Mean	Std Deviation
Experimental	31	71.90	7.560
Control	30	62.67	6.504

Table 3 presents the result showing that the average post-test score for scientific literacy in the project-based learning class was 71.90 with a standard deviation of 7.560. Meanwhile, the conventional class had an average score of 62.67 with a standard deviation of 6.504. To verify if this mean difference was caused by the treatment, prerequisite tests including normality and homogeneity were performed prior to analysis.

Table 4. Student scientific literacy scores data for the normality test

	Class	Shapiro-Wilk
		Sig.
Result	Pre scientific literacy experimental	0.590
	Post scientific literacy experimental	0.300
	Pre scientific literacy control	0.543
	Post scientific literacy control	0.182

Table 4 shows the significance values from the normality test, with 0.590 for the experimental group's pre-test, 0.300 for its post-test, 0.543 for the control group's pre-test, and 0.182 for the control group's post-test. Since all these values are above 0.05, the data from each group can be considered normally distributed, indicating no significant deviation from normality. With the normality assumption satisfied, the analysis then proceeded to assess homogeneity.

Table 5. Student scientific literacy data for the homogeneity test

	Test of Homogeneity of Variance	Sig.
Result	Based on the Mean	0.311

Table 5 shows the result of the test used to check if the variation between the experimental group and the control group is about the same. In this study, we used Levene's test, which says the data is similar enough if the significance value is over 0.05. Here, we got 0.311 for the significance value, which is higher than 0.05, so the difference in variation between the two groups is small enough. Since this condition of having similar variances is met, we can continue the analysis with confidence. After making sure that the normality and homogeneity conditions are fulfilled, the t-test was carried out to compare the average scientific literacy scores of students in the two groups.

Table 6. Student scientific literacy data for t-test

		T	Df
Result	Equal variances assumed	5.108	59

Following the results presented in Table 6, and after satisfying the required tests for normality and homogeneity, hypothesis testing was performed utilizing an independent sample t-test to evaluate the posttest scores. An independent sample t-test was conducted to determine if there was a significant difference in posttest scientific literacy scores between the experimental and control groups. The results yielded a significance value (Sig. 2-tailed) of less than 0.001, accompanied by a t-value of 5.108 and 59 degrees of freedom (df). The significance value, being substantially below 0.05, indicates a statistically significant difference between the two groups. These results demonstrate that the intervention administered, namely the implementation of the PjBL model added with PhET simulations, positively impacted student learning outcomes.

This test result confirms that the difference in learning outcomes between the experimental and control groups was not due to chance, but rather a direct result of the different learning approaches employed. Therefore, the implementation of the PjBL model, supported by PhET simulation media, has been proven to have a significant effect on improving the scientific literacy of fifth-grade primary school students.

Table 7. Significant impact of treatment on scientific literacy

Independent Samples Effect Sizes				
		Point Estimate	95% Confidence Interval	
			Lower	Upper
Result	Cohen's d	1.308	0.749	1.858
	Hedges' correction	1.291	0.740	1.834
	Glass's delta	1.420	0.792	2.032

Based on the result in Table 7, effect size calculations were conducted to determine the magnitude of the treatment's impact on student scientific literacy, utilizing three indicators: Cohen's d, Hedges' g, and Glass's delta. The finding revealed Cohen's d at 1.308, Hedges' g at 1.291, and Glass's delta at 1.420. Each of these values falls within the "large" effect category (> 0.8), demonstrating that the intervention had a strong and meaningful effect on improving scientific literacy. This indicates that the learning model applied is not only statistically significant but also feasible as an alternative instructional method. indicating that the given treatment had a substantial and practically significant impact on. The presence of a size effect signifies that the learning applied influences student performance (Nasir et al., 2020; Nunaki et al., 2020; Nusantari et al., 2021).

Before testing the hypothesis, prerequisite analyses were performed, including tests for normality and homogeneity. The Shapiro-Wilk normality test result showed that all groups-pretest and posttest, both experimental and control-were normally distributed, with significance values exceeding 0.05. Then, Levene's Test for homogeneity showed a significance value of 0.311, confirming that the variances among groups were equal. Since these assumptions were met, the data were analyzed with a parametric independent t-test.

To compare the learning outcomes between the experimental and control groups, an independent two-sample t-test was carried out. The analysis yielded a t-value of 5.108 with a significance level less than < 0.001. The experimental group's average posttest score was 71.90, outperforming the control group's average of 62.67. These results support the conclusion that the Project-Based Learning model enhanced with PhET simulations is more effective in increasing students' scientific literacy than conventional teaching methods.

The research findings demonstrate that the learning approach employed in the experimental class significantly enhanced student scientific literacy . This achievement is due to a more dynamic and organized learning approach that fosters enhanced student involvement in the educational process. This study identified a notable disparity in scientific literacy outcomes between the experimental and control groups. The experimental class exhibited greater average posttest results than the control class. The t-test produced a significance value below 0.05, demonstrating that the PjBL model, facilitated by PhET simulations, significantly enhanced students' scientific literacy. The effect size estimate produced a Cohen's d value of 1.308, categorizing it as "huge," which signifies that the applied learning model had a substantial and practically significant impact.

The research demonstrates that the PjBL model is capable of significantly improving students' scientific literacy because it places students at the center of learning, where they are actively involved in designing projects, analyzing data, and presenting results. This aligns with the opinions of Usboko et al. (2021), who state that PjBL is effective in building conceptual understanding, enhancing collaborative skills, and promoting active student participation. Additionally, the application of PhET simulations in the learning process allows students to visualize abstract electrical circuit concepts, thereby supporting deeper understanding. Research by Tolas et al. (2024) indicates that the utilization of PhET media in education substantially influences student learning results, corroborating the findings of this study. Studies on the use of PhET simulations in elementary classrooms have shown that these interactive tools can significantly improve students' conceptual understanding and learning motivation (Sopari et al., 2024). Furthermore, these research results reinforce the findings of Fauziyah et al. (2024) that the use of virtual laboratories, such as PhET, increases student motivation and conceptual understanding. According to Firmansyah et al. (2024) Interactive PhET simulations can improve students' cognitive learning outcomes in abstract subjects.

Thus, the implementation of the PjBL model assisted by PhET simulations is proven to influence scientific thinking, information analysis, and independent and collaborative problem-solving in scientific. This research confirms that the combination of a project-based learning approach and the use of interactive digital learning media is highly relevant and practical for application with primary school students, particularly in scientific subjects such as electrical circuits.

CONCLUSION

The results of this study indicate that the application of the project-based learning (PjBL) model, assisted by PhET simulations, has a significant influence on the improvement of scientific literacy among fifth-grade primary school students in the area of electrical circuits. Statistical analysis revealed a substantial difference in the average posttest scores between the experimental and control classes, with the effect size falling into the "huge" category. This research demonstrates that students' active involvement in learning projects, combined with the use of interactive simulation media, contributes to an increase in conceptual understanding, scientific thinking abilities, and overall scientific literacy. Therefore, the integration of PjBL and PhET simulations is a viable alternative learning strategy to strengthen scientific literacy at the primary school level.

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