



Improving Elementary Students' Learning Outcomes and Critical Thinking Skills through the Implementation of the PBL Model with PhET

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ABSTRACT

Learning in elementary schools is still largely dominated by memorization and basic comprehension, which hinders the optimal development of students' critical thinking skills. In fact, critical thinking skills support a deeper and more meaningful learning process, thereby directly contributing to improved learning outcomes. This study aims to examine the effectiveness of implementing the Problem Based Learning (PBL) model assisted by PhET in improving learning outcomes and critical thinking skills of fourth-grade students in the IPAS subject. The research employed a quantitative approach with a quasi-experimental design. The participants were 60 fourth-grade students of SDN Ditotrunan 01 Lumajang, consisting of class IV A (30 students) as the control group and class IV C (30 students) as the experimental group. The research instruments were post-test sheets consisting of essay questions on learning outcomes and critical thinking tests. The collected data were analyzed using an independent sample t-test with the aid of SPSS. The results showed significant differences ($p < 0.05$) between the experimental and control groups in both learning outcomes and critical thinking skills. These findings indicate that the implementation of the PBL model assisted by PhET has a significant effect on improving elementary students' learning outcomes and critical thinking skills. The application of PBL assisted by PhET can serve as an alternative learning model for IPAS, foster students' critical thinking, and support the integration of technology into elementary school learning.

Keywords: Problem Based Learning; PhET; Learning Outcomes; Critical Thinking Skills; Elementary School

ABSTRAK

Pembelajaran di sekolah dasar masih didominasi oleh hafalan dan pemahaman, sehingga keterampilan berpikir kritis siswa belum berkembang secara optimal. Padahal keterampilan berpikir kritis mendukung proses pembelajaran yang lebih mendalam dan bermakna, sehingga berdampak langsung pada peningkatan hasil belajar. Penelitian ini bertujuan menguji efektivitas penerapan model *Problem Based Learning* (PBL) berbantuan PhET dalam meningkatkan hasil belajar dan keterampilan berpikir kritis siswa kelas IV pada mata pelajaran IPAS. Penelitian menggunakan pendekatan kuantitatif dengan desain kuasi-eksperimen. Subjek penelitian terdiri atas 60 siswa kelas

395

IV SDN Ditotrunan 01 Lumajang, terdiri dari kelas IV A (30 siswa) sebagai kelas kontrol dan IV C (30 siswa) sebagai kelas eksperimen. Instrumen penelitian berupa lembar *post-test* berisi soal uraian hasil belajar dan tes keterampilan berpikir kritis. Data nilai yang diperoleh kemudian dianalisis menggunakan uji *t-test* dengan bantuan SPSS. Hasil penelitian menunjukkan adanya perbedaan signifikan ($p < 0,05$) antara kelas eksperimen dan kelas kontrol, baik pada hasil belajar maupun keterampilan berpikir kritis. Temuan ini membuktikan bahwa penerapan model PBL berbantuan PhET berpengaruh signifikan terhadap peningkatan hasil belajar dan keterampilan berpikir kritis siswa sekolah dasar. Penerapan model *PBL* berbantuan PhET dapat menjadi alternatif model pembelajaran IPAS, melatih berpikir kritis siswa, dan sebagai integrasi teknologi di pembelajaran sekolah dasar.

Kata Kunci: Problem Based Learning; PhET; Hasil Belajar; Keterampilan Berpikir Kritis; Sekolah Dasar

INTRODUCTION

Thinking is a complex cognitive process that involves not only the generation of ideas but also the application of those ideas to enhance metacognition and self-regulation in learning (Raj et al., 2022). In the context of 21st-century education, critical thinking and student learning outcomes are intrinsically linked, serving as essential components in preparing learners to navigate complex, real-world challenges. Learning outcomes serve as a crucial measure of educational achievement. They include not only the cognitive aspects, like gaining knowledge, but also cover affective and psychomotor areas that represent students' attitudes, values, and practical skills cultivated throughout the learning experience (Purnamasari et al., 2025). Furthermore, critical thinking is recognized as a key determinant of academic success, both in the short and long term, as it enables students to analyze information objectively and make rational decisions based on evidence and logic. Particularly in science education, critical thinking is indispensable in fostering the understanding of complex scientific phenomena and their practical application in real-life scenarios (Jamil et al., 2024).

International research indicates that while teacher-centered methods maintain classroom order and content coverage, overreliance can hinder students' curiosity and skills. In contrast, student-centered learning, with teachers as facilitators, fosters an interactive environment that supports autonomy, engagement, and higher-level cognitive outcomes (Ma-Ui & Phrakhrusutheejariyawattana, 2025). Globalization has shifted the role of educators from knowledge transmitters to facilitators who foster 21st-century skills such as critical thinking, collaboration, communication, and creativity (Arifin & Mu'id, 2024). Teachers are therefore

required to adapt their strategies by integrating student-centered models. One such approach is *Problem-Based Learning* (PBL), which engages students in real-world problem solving and has been proven to enhance critical thinking and academic performance (Liu & Pásztor, 2022). PBL has been shown to significantly enhance students' critical thinking abilities and academic performance by promoting reflective inquiry, logical evaluation, and independent decisionmaking (Raharjo et al., 2025). When combined with digital technologies such as simulations, PBL becomes even more effective in deepening conceptual understanding (Rosyida & Prahani, 2025). Observations at SDN Ditotrunan 01 Lumajang reveal that science learning in elementary schools remains teacher-centered through lectures, leaving students passive, less engaged, and with limited opportunities to develop critical thinking and problem-solving skills. In contrast, student-centered learning promotes collaboration, inquiry, and hands-on activities that enhance motivation and deepen understanding (Mladenovici et al., 2024).

Problem-Based Learning (PBL) was specifically designed to help students enhance their thinking abilities, problem-solving skills, and intellectual capacities. Several researchers have found that PBL successfully improves both the academic and non-academic achievements of students. This learning model utilizes contextual problems, providing students with opportunities to sharpen, develop, and enhance their problem-solving abilities, as well as to better face challenges in their daily lives (Rorimpandey et al., 2023). The Problem-Based Learning (PBL) model is implemented through five core stages: (1) Introducing students to the problem; (2) Organizing learners to engage in learning tasks; (3) Guiding students as they conduct investigations, either individually or collaboratively; (4) Supporting the development and presentation of their findings; and (5) Leading the analysis and evaluation of the problemsolving process (Simamora et al., 2025).

Interactive platforms like PhET simulations provide a dynamic learning environment that not only visualizes abstract scientific phenomena but also enhances students' motivation, engagement, and critical thinking (Salame & Makki, 2021). These tools simulate realistic scientific experiments in a safe and accessible format, often offering experiences that are unavailable in conventional classroom laboratories. Furthermore, such simulations help improve knowledge retention, support inquiry-based learning, and promote students' creativity and interest in science (Almadrones & Tadifa, 2024). Empirical studies have consistently confirmed that integrating PBL with tools like PhET leads to improved learning outcomes and a more meaningful learning experience in science education.

Several international studies have proposed strategies to develop critical thinking skills in young learners. For example, Kelvin in (Calma & Davies, 2021), recommended dialogic teaching, cognitive-based learning, and strategic partnerships as effective ways to improve students' thinking dispositions. The *Students-as-Researchers* approach has also been suggested to help students express arguments and build knowledge. However, despite their importance, studies on the use of *Problem-Based Learning* (PBL) and PhET simulations are still mostly conducted at the middle and high school settings where cognitive readiness and curriculum design more readily support inquiry-based approaches. Factors such as limited teacher training, concern over age-appropriate content, and rigid curriculum structures often hinder the implementation of such innovative methods in primary education (Li et al., 2025). In addition, most existing studies remain conceptual and small-scale, with practical classroom

implementation limited by the relatively low cognitive development of elementary school students and their tendency to rely on surface-level information (Daryanes et al., 2023). This underscores a research gap, namely the lack of empirical studies on the effectiveness of implementing PBL supported by PhET in the context of elementary education in Indonesia, particularly in improving learning outcomes and critical thinking skills (Fuentes et al., 2025).

Responding to those gaps, this study supports previous findings confirming the effectiveness of both Problem-Based Learning (PBL) and PhET interactive simulations in enhancing student learning and engagement, particularly in science education (Salame & Makki, 2021). However, it also expands the scope of application by implementing these approaches in a different educational context—namely, elementary education, where such integration is still relatively underexplored (Li et al., 2025). The study makes a valuable contribution by demonstrating that combining PBL and PhET simulations can be effectively applied in primary science learning (IPAS), where learners typically require more structured and interactive learning models. The innovation of this approach lies in merging these two powerful strategies into a single instructional design tailored for the cognitive level of elementary students—providing a dynamic and student-centered learning environment. More importantly, this research is significant for its dual focus: improving both students' academic performance and their critical thinking skills, which are essential components of 21st-century education (Liu & Pásztor, 2022).

The novelty of this study lies in its context of application. Most previous research has focused primarily on secondary and higher education levels, while implementation at the elementary school level has rarely been explored. By integrating PBL supported by PhET in elementary education, this study provides empirical evidence that such an approach is not only feasible but also effective in improving learning outcomes and critical thinking skills at the primary level. Furthermore, this study expands its contribution by highlighting the link between the integration of PBL+PhET and the development of 21st-century skills, which has received little attention in the elementary education literature. Thus, this study addresses the research gap by demonstrating that the combination of these two approaches can simultaneously enhance learning outcomes and foster critical thinking skills that are highly relevant to the needs of future generations.

Therefore, the present study specifically aims to examine the effect of implementing the Problem-Based Learning (PBL) model assisted by PhET simulation media on elementary students' learning outcomes and their critical thinking skills. This research focuses on the Science and Social Studies (IPAS) subject in a fourth-grade classroom, where the integration of student-centered learning and digital simulations offers a promising approach. By analyzing the differences between students taught using the PBL model with PhET support and those receiving conventional instruction, this study seeks to determine the effectiveness of innovative teaching strategies in enhancing conceptual understanding and promoting critical, independent thinking in younger learners.

METHODS Type and Design

This study employed a quantitative approach with a quasi-experimental design, specifically a post-test only control group design. The participants were 60 fourth-grade

students from SDN Ditotrunan 01 Lumajang, consisting of class IV A (30 students) as the control group and class IV C (30 students) as the experimental group. The classes were selected using purposive sampling based on comparable numbers of students and daily test results. Prior to the study, the researcher obtained school approval and parental/guardian consent through informed consent.

The control group received conventional instruction, while the experimental group was taught using the Problem-Based Learning (PBL) model supported by PhET simulations in the Integrated Science and Social Studies (IPAS) subject on the topic "Energy and Its Transformations" during the first semester of the 2024/2025 academic year. Both groups were then administered post-tests on learning outcomes and critical thinking skills, each consisting of 10 essay questions. The learning outcomes test was assessed using indicators of conceptual understanding, concept application, problem-solving, and logical reasoning. Meanwhile, the critical thinking skills test was assessed using indicators of analysis, evaluation, and interpretation. The instruments were validated through expert judgment (two science education lecturers and one experienced science teacher). Reliability testing showed that the post-test on learning outcomes ($\alpha = 0.70$) and the critical thinking skills post-test ($\alpha = 0.75$) met the criteria, indicating both were valid and reliable for use in the study.

After the test scores were obtained, the next step was normality tested using the Kolmogorov-Smirnov test in SPSS version 26 ($\alpha = 0.05$), with data considered normal if the significance value was > 0.05 . Homogeneity was assessed using Levene's Test for Equality of Variances, with data deemed homogeneous if the significance value was > 0.05 . When both assumptions were met, an Independent Samples t-test was conducted. Hypotheses were tested using the criterion that Sig. (2-tailed) < 0.05 indicated rejection of H_0 (a significant difference exists), while Sig. ≥ 0.05 indicated acceptance of H_0 (no significant difference).

Data and Data Sources

The research data were divided into primary data and secondary data. The primary data consisted of post-test results used to measure the effect of the treatment on the learning outcomes and critical thinking skills of the control and experimental groups. Meanwhile, the secondary data were obtained from various sources such as books, journals, and other literature to support the theoretical framework used in the study.

Data collection technique

We controlled the variables in this study by modifying the steps proposed by (Moazami et al., 2014) to produce the following approaches:

1. The educational level was limited to fourth-grade elementary school students.
2. Students' academic ability was controlled based on their previous semester report card scores.
3. To ensure equal access to technology tools, all students in the experimental group received training on the basic use of digital devices and the PhET simulation.
4. None of the students had previously studied the topic "Energy and Its Transformations."
5. The same teacher taught both the experimental and control groups.
6. Both groups completed the learning within the same time frame.

7. Both groups received the same learning content, which included basic competencies, learning objectives, and student worksheets.

In this study, the main variable under investigation was the instructional method: the experimental group used the Problem-Based Learning (PBL) model assisted by PhET simulation, while the control group received conventional teaching. Students' learning outcomes and critical thinking skills were evaluated through a post-test instrument that had been previously validated.

Data analysis

The post-test data on students' learning outcomes were analyzed using the following formula:

$$Mastery Learning (\%) = \left(\frac{\text{Number of students with score} < 70}{\text{Total number of student}} \right) \times 100\%$$

The results of this calculation were then categorized according to Table 1 below to facilitate the assessment of students' learning achievement.

Table 1. Student Learning Outcomes Assessment Criteria

Criteria	Score Range
Excellent	89 < A ≤ 100
Good	79 < B ≤ 89
Fair	< C ≤ 79
Need Guidance	D < 70

Sumber: (Putri & Desyandri, 2025)

Assessment of students' critical thinking skills in IPAS learning was based on post-test result sheets, processed using the following formula:

$$Score = \left(\frac{\sum \text{Raw Score}}{\sum \text{Maximum Score}} \right) \times 100\%$$

After obtaining the individual student scores, the next step was to calculate the overall average using the following formula:

$$Average Score = \left(\frac{\sum \text{Total Student Scores}}{\sum \text{Number of Students}} \right) \times 100\%$$

This average was then categorized using the standard presented in Table 2.

Table 2. Critical Thinking Skills Assessment Criteria

Percentage (%)	Category
86-100	Highly Critical
76-85	Critical
60-75	Fairly Critical
55-59	Less Critical
<55	Very Poor Criticality

Sumber: (Nurhidayati & Asmah, 2025)

A normality test was conducted to evaluate whether the pre-test and post-test data followed a normal distribution. This analysis was performed using SPSS version 26, applying either the Kolmogorov-Smirnov or Shapiro-Wilk method depending on the sample size. The data were considered normally distributed if the significance value (p-value) was greater than 0.05. Conversely, if the significance value was below 0.05, the data were considered not normally distributed.

A homogeneity test was also conducted to ensure that the variances between the groups (experimental and control classes) were equal or homogeneous. This test was also performed using SPSS version 26. The results were considered homogeneous if the significance value was greater than 0.05, indicating that both groups had equal variance. If the significance value was less than 0.05, it was concluded that there were differences in variance between the groups (non-homogeneous).

Finally, hypothesis testing was conducted to determine the effectiveness of the Problem Based Learning (PBL) model assisted by PhET simulation on students' learning outcomes and critical thinking skills.

Hypothesis 1:

There is a difference in learning outcomes between the experimental and control classes after implementing the PBL model with PhET.

- H_0 (Null Hypothesis):
There is no significant difference in learning outcomes between students in the experimental and control groups.
- H_1 (Alternative Hypothesis):
There is a significant difference in learning outcomes between students in the experimental and control groups.

Hypothesis 2:

There is an effect of implementing the PBL model with PhET simulation on students' critical thinking skills.

- H_0 (Null Hypothesis):
The implementation of the PBL model with PhET simulation has no significant effect on students' critical thinking skills.
- H_1 (Alternative Hypothesis):
The implementation of the PBL model with PhET simulation has a significant effect on students' critical thinking skills.

RESULTS AND DISCUSSION Learning Outcomes

Based on the post-test data analysis presented in Table 3, there is a significant difference in the learning outcomes between the control class and the experimental class. This finding indicates that the application of the Problem-Based Learning (PBL) model assisted by PhET simulations has a positive impact on students' understanding of IPAS (Science) material, thereby resulting in differing learning achievements between the two groups.

Table 3. Recapitulation of Students' Learning Outcome Scores

Component	Control Class	Experimental Class
Number of Students	30	30
Highest Score	75	95

Lowest Score	60	78
Mean Score	68.23	86.4
Standard Deviation	4.49	4.5

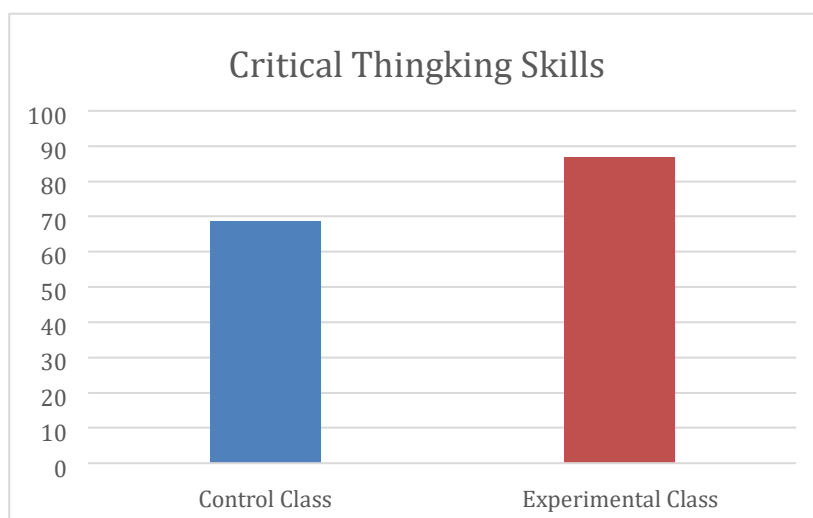


Figure 1. Comparison chart of students' learning outcomes.

As seen in Table 3, the mean post-test score of the experimental class reached 86.4, while the control class obtained an average of only 68.23. This considerable difference indicates that the use of the PBL model integrated with PhET interactive simulations significantly improves students' learning outcomes. PBL encourages active student engagement during the learning process, fosters critical thinking skills, and deepens conceptual understanding. At the same time, PhET, as an interactive simulation tool, allows students to explore material directly in a fun and engaging manner. Abstract science concepts that are typically difficult to visualize and understand become easier to grasp (Risnanto, 2021). Overall, these results demonstrate that integrating PBL with PhET simulations has a meaningful impact on improving students' academic achievement. This approach is recommended for implementation in other classroom settings to promote more optimal learning outcomes (Nurhamidah, 2022).

The next step was to perform a normality test using both the Kolmogorov-Smirnov and Shapiro-Wilk methods, with the results shown in Table 4.

Table 4. Normality Test Results

Description	Kolmogorov-Smirnov (Sig.)	Shapiro-Wilk (Sig.)
Post-test Experimental	0.091	0.210
Post-test Control	0.078	0.195

The significance values for both classes are greater than 0.05, indicating that the data meet the assumption of normal distribution. This satisfies a fundamental requirement for further statistical analysis. Homogeneity of variance results presented in Table 5.

Table 5. Homogeneity Test Results

Based on	Kolmogorov-Smirnov (Sig.)	Shapiro-Wilk (Sig.)
Means	0.480	0.698
Median	0.510	0.675

The significance value is greater than 0.05, which suggests that the data variances between the two groups are homogeneous. Thus, the assumption of equal variance in parametric statistical testing is met. Finally, a t-test was conducted to compare the average scores of the two classes and determine whether the differences were statistically significant. This study used the Independent Samples t-test, with results shown in Table 6.

Table 6. Independent Samples t-test Results

Variable	t	df	Sig. (2-tailed)
Experimental vs Control	-18.750	58	0.000

The t-test result shows a significance value of 0.000, which is less than 0.05. Therefore, the alternative hypothesis (H_1) is accepted, meaning that there is a statistically significant difference in learning outcomes between the experimental and control groups after the implementation of the PBL model with PhET simulation.

Statistical analysis results, as presented in Table 4 (normality test), Table 5 (homogeneity test), and Table 6 (t-test), show that the significance value (2-tailed) is 0.000 (< 0.05), indicating that the alternative hypothesis (H_1) is accepted. This means based on the data obtained from this study implementation of the PBL model supported by PhET media has a significant effect on students' learning outcomes. The combination of these two components creates a more interactive, meaningful, and enjoyable learning experience. These findings are consistent with prior research by (Marianus & Umboh, 2020), which confirmed that the simultaneous application of the PBL model and PhET media is effective in enhancing the learning process, student engagement, and overall academic performance. Therefore, integrating a problem-based learning model with interactive simulation technology such as PhET can serve as a relevant and adaptive instructional strategy to meet 21st-century students' learning needs.

The instructional model and supporting media used during the learning process play a crucial role in students' academic success. PBL has proven to be one of the effective models in promoting students' active engagement. This is in line with the findings of Rambe ((2024), who stated that the PBL model facilitates students' ability to independently solve problems through active participation in learning. In this model, students are presented with contextual problems as a starting point for learning, encouraging them not only to receive information passively but also to actively search for and process information. Thus, PBL enhances students' conceptual understanding in a more in-depth and applicable manner (Sukarso & Lestari, 2024). The use of simulation-based learning media such as PhET also contributes to presenting abstract concepts in a concrete and interactive way, which triggers improvements in learning outcomes. This aligns with Suhardiman et al. (2022), who found that the use of PhET media encouraged students to engage more actively in learning through various activities such as observation, experimentation, and direct interaction with the learning material. Furthermore, Rahma (2021) emphasized that PhET media makes learning more enjoyable and challenging, helping

students develop mathematical logic, which ultimately leads to a significant increase in learning outcomes compared to classes that do not use the media.

Critical Thinking Skills

Critical thinking skills play a crucial role in the learning process, as they not only support students' understanding of information but also foster the development of abilities to analyze, evaluate, and interpret information more deeply. With strong critical thinking capabilities, students are able to scrutinize information thoroughly, assess different arguments or perspectives, and interpret data or concepts in more meaningful ways. The detailed post-test data of students' critical thinking skills are presented in Table 7 and Figure 2. Table 7. Students' Critical Thinking Skills Achievement

Component	Control Class	Experimental Class
Number of Students	30	30
Highest Score	75	95
Lowest Score	58	75
Mean Score	68.57	86.77
Standard Deviation	4.35	5

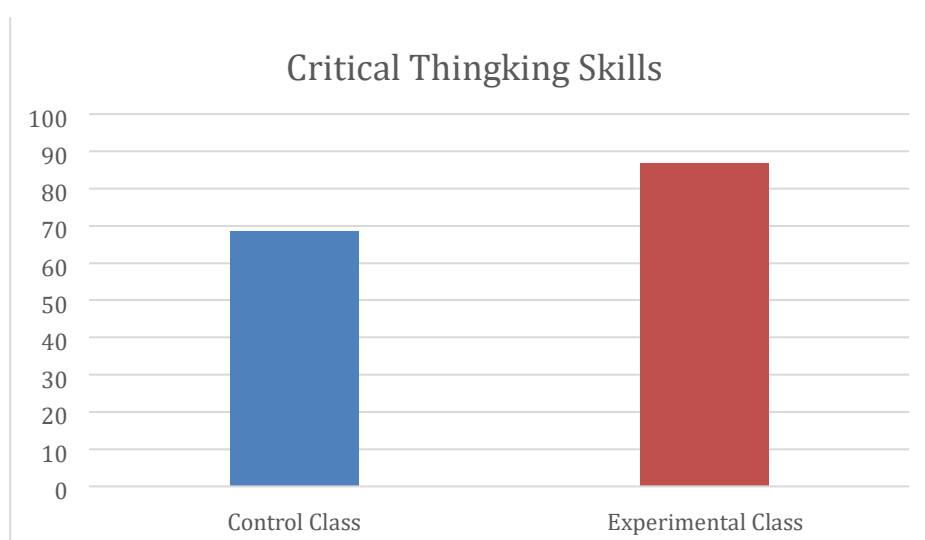


Figure 2. Comparison Chart of Critical Thinking Skills Achievement.

Based on Table 7, the post-test average score for critical thinking skills assessment shows that the experimental class, which implemented the PBL model supported by PhET simulations, achieved a significantly higher average score of 86.77, compared to 68.57 in the control class. The next step was to test for the normality of the critical thinking scores, as presented in Table 8.

Table 8. Normality Test Results

Class	Kolmogorov-Smirnov (Sig.)	Shapiro-Wilk (Sig.)
Control Post-test	0.068	0.190
Experimental Post-test	0.088	0.205

The data are normally distributed, as both the Kolmogorov-Smirnov and Shapiro-Wilk tests show significance values greater than 0.05. This confirms that the distribution does not differ significantly from a theoretical normal distribution, fulfilling the assumption of normality required for further parametric testing.

Table 9. Homogeneity Test Results

Based on	Levene Statistic	Sig.
Means	0.520	0.650

Table 9 shows the result of Levene's Test for equality of variances, which yielded a significance value of 0.650 (> 0.05) and a test statistic of 0.520. This indicates that the data are homogeneous and there is no significant difference in variance between the groups. Therefore, the assumption of homogeneity is met, validating the use of further parametric analyses such as the t-test.

Table 10. Independent Samples t-test Results

Variable	T	Df	Sig. (2-tailed)
Experimental vs Control	-19.200	58	0.000

A t-test was conducted to determine whether the differences in mean critical thinking scores between the two classes were statistically significant. The results indicate a highly significant difference between the experimental class (PBL with PhET) and the control class ($t = -19.200$; $df = 58$; $p = 0.000 < 0.05$). Therefore, in testing Hypothesis 2, the alternative hypothesis (H_1) is accepted, meaning PBL model supported by PhET media has a significant effect on students' critical thinking skills. Based on the data obtained from this study that the observed difference is highly statistically significant and unlikely to be due to chance, thereby confirming the effectiveness of the implemented instructional intervention.

These findings are consistent with the research conducted by Zulianti (2024), who also reported a significant difference in critical thinking skills between students engaged in problem-based learning (PBL) using PhET simulations and those receiving conventional instruction. The study found that integrating the PBL model with interactive simulations like PhET creates a learning environment that encourages students to be more active in analyzing problems, constructing arguments, and drawing logical conclusions. While PBL facilitates deeper conceptual exploration, PhET provides visual and experimental support that helps clarify students' understanding of abstract scientific concepts. This combination has proven to be more effective in enhancing students' critical thinking skills compared to traditional teacher-centered approaches with minimal student interaction.

Furthermore, Firdaus et al (2021) emphasized that the way teachers implement learning strategies greatly influences the development of students' critical thinking skills. The choice of instructional models plays a vital role in shaping students' thinking processes and their comprehension of the subject matter. The teacher's approach not only determines student engagement but also affects how students construct knowledge and reasoning. Similarly, Ariawan and Kadek (Ariawan & Kadek, 2024), asserted that PBL is effective in developing critical thinking through contextual problem-solving. In PBL, students are not merely

memorizing content but are required to analyze, evaluate, and formulate solutions independently – thereby fostering critical, logical, and systematic thinking.

This study has several limitations. First, the sample size was relatively small (60 students) and drawn from only one elementary school, which limits the generalizability of the findings. Second, the research instruments consisted of only ten essay questions, which may not fully represent the overall scope of learning outcomes and critical thinking skills. In addition, external factors such as motivation, learning interest, and the teacher's role may also have influenced the results of this study.

CONCLUSION

Based on the findings and analysis, it can be concluded that: (1) The implementation of the PBL model supported by PhET simulations significantly improved the learning outcomes of fourth-grade students at SDN Ditotrunan 01 Lumajang in the IPAS subject, with average post-test scores of 68.23 for the control class and 86.4 for the experimental class ($p = 0.000 < 0.05$), thereby confirming the acceptance of the alternative hypothesis (H_1). (2) This model was also effective in enhancing students' critical thinking skills, as shown by the average post-test scores of 68.57 for the control class and 86.77 for the experimental class ($p = 0.000 < 0.05$), which further confirmed the acceptance of the alternative hypothesis (H_1). However, this study has certain limitations, such as the relatively small sample size and the fact that participants were drawn from only one school, which restricts the generalizability of the findings. Nevertheless, this research is expected to serve as a consideration for adopting more problem-based and technology-integrated learning models in primary science education (IPAS), in order to effectively enhance students' learning outcomes and critical thinking skills.

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