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Integrating Inquiry-Based Learning with PHET Simulations: A Strategy to Enhance Higher-Order Thinking Skills

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Abstract – *Enhancing Higher-Order Thinking Skills (HOTS) is essential in physics education to prepare students for analyzing and solving real-world problems. However, in under-resourced regions such as Flores, Indonesia, the development of HOTS is hindered by limited access to laboratories and traditional teacher-centered approaches. This study investigates the effectiveness of integrating Inquiry-Based Learning (IBL) with PhET simulations as an instructional strategy to improve HOTS among university students. Using a one-group pretest-posttest experimental design, the study involved 36 students from the Physics Education Program at Universitas Flores. Students were exposed to four simulation-based inquiry sessions on alternating current (AC) circuits. HOTS were assessed through a 15-item test targeting analysis, evaluation, and creation dimensions, with data analyzed using a paired-sample t-test. The results revealed a significant improvement in students' HOTS, as indicated by the increase in average scores from 70.67 to 79.64 ($p < 0.001$), with the most notable gain observed in the 'Create' category. The integration of IBL with PhET provided an interactive, contextual, and student-centered learning experience that supported conceptual understanding and cognitive engagement. Despite challenges related to infrastructure and teacher readiness, the findings highlight the potential of this approach in promoting critical and creative thinking. This study contributes to physics education by offering a scalable and cost-effective instructional model that aligns with 21st-century learning demands, particularly in resource-constrained environments.*

Keywords: *AC electricity; HOTS; inquiry-based learning; PhET simulations*

I. INTRODUCTION

In an era of rapidly advancing technology and an increasingly complex global landscape, the demand for educational strategies that foster Higher-Order Thinking Skills (HOTS) has become more critical than ever. HOTS, which encompasses the abilities to analyze, evaluate, and create, is essential for students to navigate and solve real-world problems (Andriani et al., 2024). HOTS involves cognitive abilities that extend beyond simple memorization or recall, encompassing skills such as analysis, evaluation, and creation based on one's knowledge (Rachma et al., 2025).

In physics education, these skills are particularly relevant due to the abstract and conceptual nature of the subject. Students are expected not only to understand and memorize formulas but also to apply them critically to phenomena they encounter in their daily lives (Esra & Şükrü, 2017). However, the development of HOTS in physics remains a significant challenge across various educational settings in Indonesia, particularly in resource-limited regions. HOTS are crucial for training students to foster their creative thinking skills during the learning process and to effectively respond to HOTS-based test items (Liline et al., 2024).

In general, physics education in Indonesia faces several systemic challenges that hinder effective learning (Irawan et al., 2024). These challenges include the predominance of teacher-centered instruction, insufficient laboratory facilities, and low student engagement. Studies have shown that many students struggle with conceptual understanding and the application of physics principles due to traditional pedagogical approaches that emphasize rote memorization over inquiry and exploration (Yuliati et al., 2021). These issues are exacerbated in under-resourced and remote areas such as Flores, where schools often lack access to well-equipped laboratories and technological tools. Observations conducted at the Physics Education Program of Faculty of Teacher Training and Education, Universitas Flores highlight a noticeable gap in student achievement and motivation, linked to limited opportunities for hands-on experiments and interactive learning experiences.

To address these challenges, educators have explored various pedagogical innovations aimed at promoting student-centered and inquiry-driven learning. One such strategy is the integration of Inquiry-Based Learning (IBL) with interactive technology tools, such as Physics Education Technology (PhET) simulations (Sudirman & Qaddafi, 2023). IBL encourages students to ask questions, design and conduct experiments, and derive conclusions through exploration and critical reflection (Ulker & Ali, 2023). When paired with PhET simulations, which offer dynamic and visual representations of physical phenomena, this model enables students to engage in virtual experiments that mimic real-life laboratory conditions (Wieman et al., 2010). This integration helps bridge the gap between theoretical knowledge and practical application, especially in environments where traditional labs are unavailable (Susilawati et al., 2022).

The PhET project provides useful simulations for teaching and learning physics and makes them freely available through its website (Perkins et al., 2006). Technology can significantly enhance student learning in physics when it is properly aligned with teaching objectives and fully integrated into a learning module (Anselmo et al., 2024). Recent studies have validated the effectiveness of combining IBL with PhET simulations to enhance conceptual understanding and foster HOTS. For example, it was found that community college students who used PhET-assisted inquiry learning significantly improved their scientific reasoning and problem-solving skills

(Taibu et al., 2021). Similarly, it was reported that student engagement and performance in science subjects increased when digital simulations were embedded within inquiry-based frameworks (Premthaisong & Srisawasdi, 2024). In Indonesia, it has been demonstrated that senior high school students showed notable gains in critical thinking when taught using guided inquiry supported by PhET simulations (Fitriani et al., 2024). These studies suggest that integrating inquiry models with digital simulations can provide a powerful learning experience that enhances both cognitive and affective domains.

PhET simulations illustrate the connection between scientific concepts and real-life phenomena, serving as a foundation for interactive, constructive, and creative learning approaches (Laila & Anggaryani, 2021). Despite these promising findings, several gaps remain in the current literature. First, most research has been conducted in urban or technologically advanced regions, providing limited insight into the effectiveness of this model in underserved areas like Flores (Cyr et al., 2019). Second, while many studies affirm the cognitive benefits of PhET-assisted inquiry learning, fewer explore its practical implementation challenges, such as teacher readiness, infrastructure limitations, and adaptation to local curricula (Dy et al., 2024). Third, there is a need for more experimental studies with robust research designs to validate the impact of this approach on HOTS development across different educational contexts (Ragab et al., 2024).

The integration of IBL with PhET simulations presents a viable solution to address the specific challenges faced in physics education in Flores. Given the limited physical infrastructure, PhET simulations provide an alternative platform for students to conduct virtual experiments, compensating for the lack of physical laboratories (Kumar, 2024). Additionally, the inquiry-based model empowers students to take ownership of their learning, promoting deeper engagement and motivation. This combination is particularly relevant in Flores, where the need for innovative, low-cost, and scalable instructional models is paramount.

Previous studies on the use of PhET simulations, such as improving the understanding of Hooke's Law concepts through the use of PhET-based student worksheets (Sudirman & Qaddafi, 2023), developing an inquiry-based PhET worksheet aimed at improving students' understanding of the physics concept of the particle-in-a-box model (Bouchée et al., 2024), exploring the effect of interactive PhET simulations on students' conceptual understanding of chemical equilibrium (Rahmawati et al., 2022), and examining how PhET simulations improve conceptual understanding in various physics topics, have identified best practices for integrating the tool into active learning environments. Moreover, studies have also examined the effect of PhET-based learning on science process skills and students' understanding of temperature and heat (Haryadi & Pujiastuti, 2020).

Based on this rationale, the present study aims to investigate the integration of IBL with PhET simulations as a strategy to enhance HOTS Skills among students in the Physics Education Program at Universitas Flores. Specifically, this research seeks to answer the following question: How effective is the integration of IBL with PhET simulations in improving students' HOTS? Through this study, it is expected that empirical evidence will be provided to support the broader implementation of PhET-assisted inquiry learning in physics education, particularly in schools and higher education institutions facing infrastructural and pedagogical constraints.

II. METHODS

This study employs an experimental design with a one-group pretest-posttest framework, as illustrated in Figure 1. The figure depicts a one-group pretest-posttest design, involving a single group of 36 students who undergo a pre-test, followed by an intervention, and then a post-test, with data analysis conducted thereafter. This design is used to examine whether an intervention leads to a change in the outcome of interest within the same group, by measuring the outcome before and after the intervention to observe any differences (Dimitrov & Rumrill, 2003).

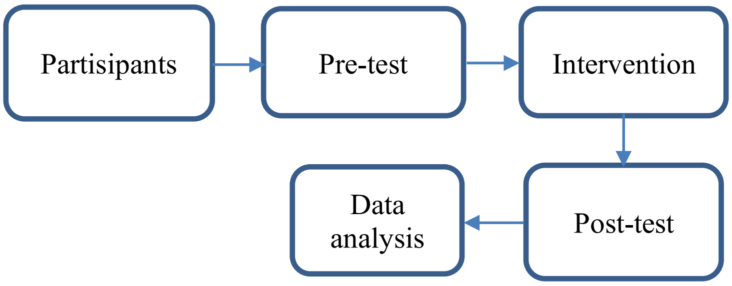

Figure 1. The flowchart for the data collection steps in this study

The data collection procedure involved several key steps: initially, 36 students from the Physics Education Program at FKIP Universitas Flores were selected through purposive sampling. Subsequently, a pretest was administered to assess students' initial HOTS, specifically in understanding AC electricity. Following the pre-test, the students received instruction integrating IBL with PhET simulations. After the intervention, a post-test was conducted to measure changes in students' HOTS. Finally, both the pre-test and post-test data were statistically analyzed using a paired-sample t-test to assess the effectiveness of the instructional approach.

This study aims to examine the impact of integrating IBL with PhET simulations on enhancing HOTS specifically analysis, evaluation, and creation among university students. Purposive sampling was used to select the sample, consisting of 36 students. The focus of this research is to assess students' HOTS, particularly in the context of understanding AC electricity. The topic of AC electricity was chosen because it involves complex and abstract concepts that require students to apply higher-order thinking skills, such as analysis, evaluation, and synthesis, to fully understand and solve related problems.

The research involved four treatment sessions, each incorporating the use of PhET simulations within the inquiry-based learning framework. The first session focused on AC electricity involving resistor circuits, guiding students to explore and understand the behavior of resistors in alternating current through simulation-based inquiry activities. The second session addressed AC electricity with capacitor circuits, where students investigated the characteristics and response of capacitors in AC systems using PhET tools. The third session concentrated on inductor circuits, allowing students to discover how inductors interact with AC signals through structured inquiry steps. The fourth and final session culminated with parallel RLC circuits, enabling students to integrate their understanding of resistors, capacitors, and inductors in a parallel configuration, again facilitated by interactive PhET simulations and inquiry-driven tasks.

Data were collected through a written test consisting of 15 items: 5 analysis questions, 5 evaluation questions, and 5 creation questions. The test instrument was evaluated for quality, yielding a validity coefficient of 0.67, indicating that it is quite valid, and a reliability coefficient of 0.77, suggesting that it is reliable for assessing students' HOTS (Jugessur, 2022). The collected data were analyzed using a paired-sample t-test with the help of SPSS software, at a 95% confidence level. The formula for the paired-sample t-test is as follows (Afifah et al., 2022):

$$t_{cal} = \frac{\bar{D}}{\frac{SD}{\sqrt{n}}} \qquad (1)$$

t = calculated t value
$\bar{D}$ = average difference between measurements 1 and 2
SD = standard deviation of the difference between measurements 1 and 2
N = number of samples.

The paired-sample t-test was used because it aims to determine whether there is a significant difference in participants' performance before and after the intervention within the same group. Since the data consists of two related measurements typically pre-test and post-test scores from the same participants the paired-sample t-test is appropriate for analyzing mean differences while accounting for the dependency between the two sets of scores. The comparison of pretest and post-test average scores will help determine whether the integration of IBL and PhET simulations leads to a significant improvement in students' HOTS.

III. RESULTS AND DISCUSSION

This study investigated the effectiveness of IBL with PhET simulations in enhancing students' HOTS in the context of AC circuits. A total of 36 undergraduate students participated in the intervention. As presented in Table 1, students' average post-test score was higher than their pre-test score, indicating a gain in conceptual understanding and cognitive abilities after the instructional treatment.

Table 1. Results of the descriptive statistics

Paired samples statistics					
		Mean	**N**	**Std. deviation**	**Std. error mean**
Pair 1	Post-test	79.64	36	10.710	1.785
	Pre-test	70.67	36	11.484	1.914

The data presented in Table 1 shows the results of a statistical analysis comparing students' pre-test and post-test scores. The mean score for the pretest was 70.67 with a standard deviation of 11.484, while the posttest mean score increased to 79.64 with a standard deviation of 10.710. These results indicate an improvement in student achievement following the intervention or learning treatment, as indicated by the higher average post-test score. These findings are supported by research conducted by Nur Maesaroh, which demonstrated that integrating PhET simulations with songs can improve students' HOTS (Maesaroh & Sutikno, 2025).

The graph illustrates a comparison of critical thinking indicator scores between the experimental and control classes. It visually represents the percentage achieved by each class across five critical thinking indicators: analysis, problem recognition, and solving, evaluation, inference, and synthesis. The experimental class, which utilized song-assisted PhET simulations, consistently outperformed the control class in all indicators. Notably, the synthesis indicator showed the most substantial difference in scores between the two groups. Overall, the graph effectively highlights the impact of the instructional approach on enhancing students' critical thinking skills.

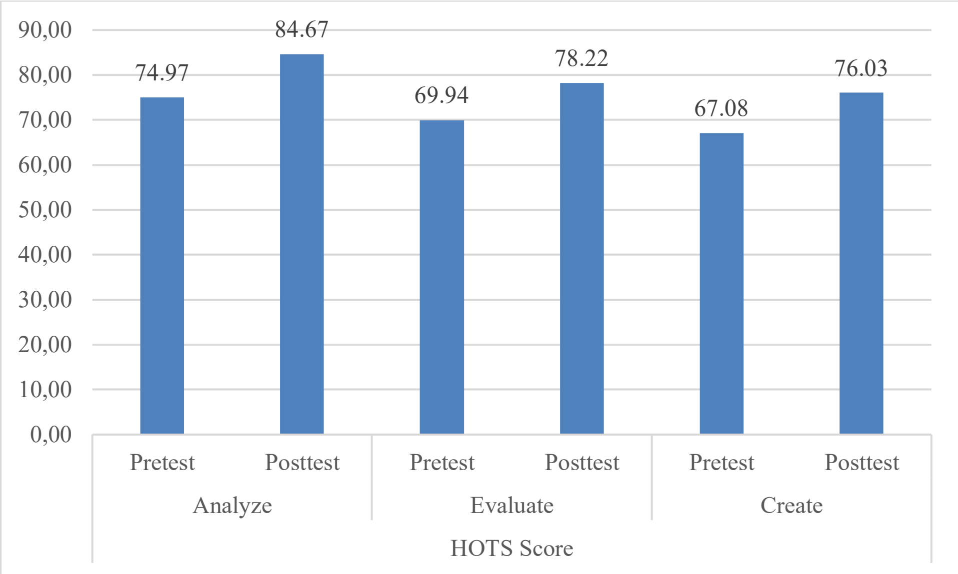

Figure 2. The graphic of the HOTS score

Figure 1 presents the pre-test and post-test scores for students' HOTS in three categories: analyze, evaluate, and create. The data indicate improvements across all categories after the learning intervention. The mean score for Analyze increased from 74.97 to 84.67, Evaluate from 69.94 to 78.22, and create from 67.08 to 76.03. This improvement spans the aspects of Analysis, Evaluation, and Creation, showcasing the effectiveness of the STEM approach with PhET simulations in improving students' HOTS in physics learning (Yusuf & Widyaningsih, 2019). These results suggest that the instructional approach effectively enhanced students' HOTS, with the most significant gain observed in the Create category, reflecting an improved ability to generate original ideas or solutions. Consistent improvements in all dimensions indicate a positive impact on students' critical and creative thinking skills. These findings align with research by Dy et al. (2024), which found that PhET interactive tools are effective in improving learners' performance in science. The Problem-Based Hybrid Learning (Pro-BHL) model assisted by OLabs has also been shown to significantly improve students' HOTS in heat and heat transfer topics (Rachma et al., 2025), while student worksheets based on PhET simulations effectively improve students' conceptual understanding of Hooke's Law (Sudirman & Qaddafi, 2023).

The table presents a comparison of pretest and posttest scores between experimental and control groups, showcasing the average scores for each group and providing a clear view of the students' performance before and after the intervention. These scores serve as the basis for analyzing the effectiveness of the teaching methods employed in each group. The data highlight the impact of different instructional strategies on students' learning outcomes. Ultimately, the table facilitates a quantitative evaluation of the study's findings.

Table 3. Paired samples test analysis results

Paired samples test									
		Paired differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Posttest - Pretest	8.972	5.690	.948	7.047	10.897	9.462	35	.000

The data in Table 3 presents the results of a paired-sample t-test comparing students' post-test and pretest scores. The analysis shows a mean difference of 8.972, with a standard deviation of 5.690 and a standard error of 0.948. The 95% confidence interval for the mean difference ranges from 7.047 to 10.897, and the t-value is 9.462 with 35 degrees of freedom. The significance value ($p = 0.000$) indicates that the difference is statistically significant. Based on these findings, it can be concluded that the integration of IBL with PhET simulations significantly improves students' HOTS.

The results of this study reveal that integrating IBL with PhET simulations significantly enhances students' HOTS in physics education. Statistical analysis using a paired-sample t-test showed a substantial mean difference of 8.972 between post-test and pretest scores, indicating a clear improvement in students' analytical, evaluative, and creative thinking skills. Additionally, supporting tests confirmed the normal distribution and homogeneity of the data, ensuring the reliability of the results. These findings demonstrate that combining IBL and PhET simulations provides students with effective cognitive stimulation and supports conceptual understanding of complex physics topics.

PhET simulations align with the development of the Industrial Revolution 4.0, enabling students to improve their technological literacy and become proficient in using these tools (Sarwoto et al., 2020). The improvement in students' HOTS can be attributed to the interactive and student-centered nature of the IBL model, which encourages inquiry, experimentation, and reflection. PhET simulations further enhance this process by allowing students to visualize abstract physics concepts and conduct virtual experiments that would be difficult or impossible in a conventional classroom. This dual approach provides a dynamic learning environment in which students construct knowledge through discovery, analyze data, test hypotheses, and collaborate with peers, ultimately strengthening their critical thinking, problem-solving, and conceptual comprehension.

The results align with prior studies that report the effectiveness of PhET simulations and inquiry models in science education. For instance, Susilawati et al. (2022), found that PhET simulations significantly increased student motivation and problem-solving abilities. Similarly, it was confirmed that PhET media supported HOTS development in STEM-based learning environments (Yusuf & Widyaningsih, 2019). These findings reinforce the present study's conclusions, supporting the view that technology-enhanced inquiry learning not only improves academic performance but also boosts students' engagement and motivation. No contradictory findings were noted in the reviewed literature, suggesting a strong consensus on the value of this integrated approach. Previous studies have shown that the use of PhET simulation-based worksheets significantly improved students' conceptual understanding of Hooke's Law (Sudirman & Qaddafi, 2023). Students have also perceived that PhET simulations aid in both content and process learning, with the majority expressing positive attitudes toward their usage (Guden et al., 2024).

Theoretically, this study contributes to the growing body of evidence supporting constructivist approaches in physics education, particularly the effectiveness of combining digital simulations with inquiry strategies to foster higher-order cognitive development. Practically, it emphasizes the need for educational institutions to adopt technology-rich and inquiry-oriented instructional models to meet the demands of 21st-century education. However, challenges such as limited technological infrastructure and insufficient teacher training must be addressed to ensure widespread implementation. Educators and policymakers should prioritize investments in digital tools and professional development to fully harness the benefits of PhET-assisted inquiry learning in physics classrooms.

IV. CONCLUSION AND SUGGESTION

This study demonstrated that integrating the IBL model with PhET simulations significantly enhances students' HOTS in physics education, particularly in understanding complex concepts such as alternating current electricity. The statistically significant improvement in students' posttest scores (from 70.67 to 79.64) indicates a marked development in analysis, evaluation, and creative problem-solving abilities. The interactive and student-centered nature of the IBL model, coupled with dynamic visualizations from PhET simulations, provided meaningful cognitive engagement and conceptual clarity, making physics learning more accessible and effective.

Despite these promising findings, several limitations should be noted. The study was limited to a single group of students from one university program, restricting the generalizability of the results. Additionally, the lack of a control group limits the ability to make broader causal claims. Challenges such as technological infrastructure and teacher readiness in underserved areas also remain significant barriers to implementation. Therefore, future research should involve larger and more diverse samples to validate and expand these findings. Comparative studies with control groups and long-term assessments are also recommended to evaluate the retention and transferability of HOTS. Moreover, research into teacher professional development programs for integrating inquiry and simulation tools is essential. This study contributes to the advancement of physics education by offering an evidence-based instructional approach that is both scalable and contextually adaptive. It highlights the potential of technology-supported inquiry learning to transform HOTS development, especially in resource-limited educational environments.

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