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The Effectiveness of Guided Inquiry Learning Model with Digital Simulations to Enhance Students' Critical Thinking Skills in Physics

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ABSTRACT

Objective: *This study aims to determine the effectiveness of the guided inquiry learning model integrated with digital simulation in enhancing students' critical thinking skills on the topic of harmonic oscillation.* ***Method:*** *A quasi-experimental method with a pretest-posttest control group design. The participants were two Grade XI classes at SMAN 1 Pacet: the experimental group received guided inquiry learning with digital simulations, while the control group received guided inquiry learning without simulations. Instruments used included critical thinking skill tests (pre-test and post-test), classroom implementation observation sheets, and student response questionnaires.* ***Results:*** *The results showed that the implementation of learning in the experimental class was in the "outstanding" category, with an average score of 3.62 (89.5%). The paired t-test analysis indicated a significant improvement between pre-test and post-test scores in both the experimental (p=0.000) and control (p=0.003) classes, with mean score differences of 32.90 and 20.20, respectively. The N-Gain value of the experimental class was 0.68 (medium category), which was higher than the control class's N-Gain of 0.39 (medium category). Student responses toward the learning approach were highly positive, with an overall average 0f 82% in the "outstanding" category.* ***Novelty:*** *This study highlights the novelty of integrating PhET digital simulations into guided inquiry learning to foster critical thinking in physics education, specifically in understanding harmonic oscillation.*

INTRODUCTION

In the era of globalization and rapid technological advancement, 21st-century skills have become essential competencies for every student. One of the most important skills to be developed is critical thinking. Critical thinking can be defined as the ability to analyze ideas in detail, distinguish them clearly, identify, evaluate, and further develop them into more mature forms (Eka et al., 2024). This skill is crucial to ensure that students are prepared to compete in the future and capable of solving complex problems.

In science education, particularly in physics, critical thinking is not only vital for understanding abstract concepts but also for fostering scientific reasoning in addressing real-life challenges. Developing critical thinking requires the integration of multiple components of higher-order thinking, which allows students to approach problem-solving better (Saputra, 2020). Students' low critical thinking skills are currently influenced by various factors, such as teacher-centered learning patterns that tend to emphasize memorization (Fitriani et al., 2024; Lintangesukmanjaya et al., 2024). The lack of stimulus through questions or activities that encourage analysis and problem-solving, and a learning culture that prioritizes quick and correct answers over in-depth thinking (Angwaomaodoko, 2024).

Furthermore, the habit of accessing information instantly through technology makes students less accustomed to filtering, studying, and critically processing data. Social

environmental factors also play a role, where asking questions or arguing is sometimes still considered impolite, so students are reluctant to criticize ideas. Furthermore, limited teacher training in developing higher-order thinking skills-based learning results in a less-than-optimal learning process in building a culture of critical thinking in the classroom (Kwangmuang et al., 2021).

However, physics instruction in schools is still predominantly conventional, teacher-centered, and lacks active student participation. As a result, students' critical thinking skills have not been optimally developed. Therefore, an instructional model that encourages students to think critically, explore, and discover concepts through scientific processes is needed (Sutiani, 2021; Zulyusri et al., 2023). One such relevant model is the guided inquiry learning model.

According to Marzuki (2023), guided inquiry consists of a series of learning activities that emphasize the development of students' critical thinking and analytical abilities to explore and find solutions to problems. Through guided inquiry, students can identify and formulate problems, generate hypotheses, conduct experiments, and draw conclusions, while the teacher acts as a facilitator (Nurmayani et al., 2018). To enhance the effectiveness of this approach, digital simulations such as PhET can be integrated.

PhET (Physics Education and Technology) is a virtual laboratory developed at the University of Colorado, USA, designed to support physics learning by helping students understand abstract concepts. PhET simulations aim to increase student engagement, support active exploration, and enhance conceptual understanding through interactive activities (Rizaldi et al., 2020).

RESEARCH METHOD

Types of Research

This study employed a quasi-experimental research design using a pretest-posttest control group. A quasi-experiment is a research design similar to an actual experiment, but without the use of complete randomization in group selection (Lam & Wolfe, 2022). Researchers still compare treatment and control groups through pretests and posttests to determine the effect of an intervention. The advantage of this design is that it is more practical in educational settings, although it has limitations in controlling external variables that could influence the results.

The participants consisted of two Grade XI classes at SMAN 1 Pacet, recommended by the physics teacher. The experimental group was taught using guided inquiry learning with PhET digital simulations, while the control group received guided inquiry learning without simulations. The research design is presented as follows in Table 1:

Tabel 1. Research design

Class	*Pre-test*	Treatment	*Post-test*
Experimental	O_1	X_1	O_2
Control	O_1	C	O_2

This study used a quasi-experimental design with a pretest-posttest control group pattern, where X_1 is the experimental group given treatment in the form of Guided Inquiry Learning with the help of digital simulation. At the same time, C is the control group that only uses Guided Inquiry Learning without simulation. Both groups were given O_1 as a pre-test before treatment to determine students' initial abilities. After treatment, O_2 was given as a post-test to measure the improvement in abilities. Thus, a comparison of the pre-test and post-test results in both groups can show the effectiveness of using digital simulation in guided inquiry learning.

Instruments of Research

The instruments used in this study include observation sheets to evaluate the implementation of the learning process, critical thinking tests consisting of pre-tests and post-tests to measure the improvement of students' critical thinking skills, and student response questionnaires used to analyze students' perceptions of the learning process that has been implemented.

Data Analysis

The research data were analyzed using several techniques, namely the implementation of learning was analyzed using an average score which was then categorized into four levels, namely very poor, poor, good, and very good; the increase in students' critical thinking skills was measured through a paired t-test and normalized gain (N-gain) calculation; while student responses were analyzed using percentages and categorized from very poor to very good.

RESULTS AND DISCUSSION

Results

The evaluation was conducted by assessing various indicators of teaching performance, and the scores were converted into mean values, percentages, and categorical ratings. This analysis aims to provide a comprehensive overview of the consistency and quality of learning implementation throughout the observed sessions. The results of classroom observation on the implementation of learning across three meetings as shown in Table 2.

Tabel 2. Observation results of learning implementation

Meeting	Mean Score	Percentage (%)	Category
1	3.62	89.5	Very Good
2	3.55	88.0	Very Good
3	3.70	92.55	Very Good
Average	3.62	89.0	Very Good

Observation over the course of three meetings revealed that the experimental class achieved an overall average score of 3.62 (89.5%), which was categorized as *very good*. Among the three sessions, the highest implementation score was recorded in the third meeting, with a mean of 3.70 (92.55%), while the second meeting obtained the lowest score of 3.55 (88%). These findings suggest that the application of the guided inquiry

learning model assisted by digital simulations was carried out consistently with high quality. The steady improvement across meetings, culminating in the highest score during the final session, also reflects the adaptability of both teachers and students in optimizing the use of digital simulations to support inquiry-based learning. This consistency indicates not only the effectiveness of the instructional design but also its potential to be sustainably integrated into classroom practices to enhance learning engagement and outcomes.

The results of the critical thinking test showed a significant improvement in the experimental group, with the mean score increasing from 52.1 in the pre-test to 85.0 in the post-test, yielding a mean difference of 32.9. In contrast, the control group experienced a smaller gain, improving from 50.9 to 71.1, with a mean difference of only 20.2.

Tabel 3. Critical thinking test results (pre-test and post-test)

Group	Pre-test	Post-test	Difference (Δ)
Experimental	52.1	85.0	32.9
Control	50.9	71.1	20.2

These findings as shown in Table 3 is indicate that students who were taught using the guided inquiry learning model supported by digital simulations demonstrated greater progress compared to those who experienced guided inquiry without simulations. The substantial improvement in the experimental group suggests that the integration of digital simulations not only facilitated students' conceptual understanding but also provided opportunities to analyze, evaluate, and draw conclusions from simulated phenomena—skills that are essential indicators of critical thinking. Thus, the use of digital simulations within guided inquiry learning can be seen as an effective strategy to foster the development of students' critical thinking abilities in physics learning.

The results of the statistical analysis showed that the data fulfilled the assumptions for parametric testing based on normality and homogeneity tests. The paired t-test revealed significant differences ($p < 0.05$) between the pre-test and post-test scores in both groups, with the experimental group obtaining a higher t-value, which indicates a more substantial improvement compared to the control group. Furthermore, the N-gain analysis demonstrated that the experimental class achieved an N-gain score of 0.68, categorized as medium, which was notably higher than the control class's N-gain of 0.39, also in the medium category. These results confirm that guided inquiry learning with digital simulations was more effective in enhancing students' critical thinking skills than guided inquiry learning without simulations. The response questionnaire revealed that students reacted positively to the integration of digital simulations. The overall percentage reached 82% ("perfect"), with the highest rating in learning interest (85%) and the lowest in active involvement (78%). These results indicate that PhET simulations not only enhanced conceptual understanding but also increased learning motivation.

Discussion

The findings confirm that integrating digital simulations into guided inquiry learning enhances students' critical thinking skills. The results align with previous studies (Nurmayani & Doyan, 2018; Rizaldi et al., 2020), which demonstrated that guided inquiry combined with interactive tools supports better engagement and understanding. The improvement in the experimental group compared to the control group also supports the

claim that PhET simulations bridge the gap between abstract concepts and real-world visualization, leading to deeper conceptual understanding.

Students' critical thinking skills are enhanced by the use of virtual simulations, which present physical phenomena in a more concrete and interactive way. Through digital simulations, students can observe variables that are difficult to visualize in real-life experiments and then analyze the resulting cause-and-effect relationships (Lintangesukmanjaya et al., 2025). This process requires students to ask questions, evaluate data, and draw conclusions based on observed evidence, thus fostering the development of critical thinking skills such as analysis, interpretation, and evaluation (Plummer et al., 2022).

The use of virtual simulations aligns well with guided inquiry learning models, as both emphasize exploration and discovery of concepts through active learning experiences. In guided inquiry, teachers provide general direction but still allow students to develop investigation strategies and find answers. Digital simulations support this by providing a flexible, safe experimental environment that allows for repeated experiments without time or equipment constraints. Thus, virtual simulations enhance the inquiry stages, such as formulating problems, conducting experiments, analyzing data, and concluding conclusions.

The implications of this research emphasize the importance of utilizing technology, particularly virtual simulations, as an effective learning medium to enhance students' critical thinking skills. Integrating digital simulations into science learning not only strengthens conceptual understanding but also develops 21st-century skills relevant to the demands of the digital era (Putra et al., 2025). This demonstrates that the use of technology in a pedagogical context is not merely a visualization tool, but rather a strategic part of creating a more meaningful, interactive learning experience oriented toward developing higher-order thinking skills.

CONCLUSION

Fundamental Finding: Guided inquiry learning integrated with digital simulations is effective in enhancing students' critical thinking skills in physics, particularly in the topic of harmonic oscillation. **Implication:** This study implies that incorporating interactive simulations such as PhET into inquiry-based learning can increase student engagement, improve conceptual understanding, and strengthen higher-order thinking skills in physics education. **Limitation:** The study was limited to two classes at a single school with a relatively small sample size, which restricts the generalizability of the results. **Future Research:** Further research should involve larger and more diverse samples, investigate other physics topics, and explore the long-term effects of integrating digital simulations into inquiry-based learning models.

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AUTHOR CONTRIBUTIONS

Mahdalysa Dayu contributed to the conceptual framework, research design, and validation process; **Rahmatta Thoriq Lintangesukmanjaya** was sourcing references, and drafting the manuscript; **Lindsay N. Brgsma** handled data management, methodology development and project coordination. All listed authors have reviewed and approved the final version of this submission.

CONFLICT OF INTEREST STATEMENT

No conflict interest.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

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