

The Effect of a Guided Inquiry Learning Model Assisted by a Virtual Laboratory on Students' Cognitive Learning Outcomes

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Abstract

This study aimed to investigate the impact of a guided inquiry learning model supplemented by a virtual laboratory on students' cognitive learning outcomes. The study was motivated by low cognitive achievement and limited laboratory facilities in schools. A quantitative approach was employed using a quasi-experimental pretest–posttest control group design. The sample comprised two Grade X classes at SMA Negeri 2 Labuapi, selected through cluster random sampling. Research instruments included a cognitive learning outcomes test and an observation sheet related to cognitive learning outcomes. Data were analyzed using the normalized gain (N-Gain) test and ANCOVA. The results showed that the N-Gain of the experimental class (0.50) was higher than that of the control class (0.36), and the ANCOVA produced a significance value of 0.000 (< 0.05), indicating a significant effect of the learning model on improving cognitive learning outcomes. These findings suggest that guided Inquiry assisted by a virtual laboratory is more effective than conventional instruction in developing cognitive outcomes, including the ability to analyze information, construct arguments, and draw logical conclusions. This model is relevant for 21st-century science learning, especially in schools with limited laboratory facilities.

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Introduction

Education is a key determinant of a nation's progress and development. As a strategic sector, education plays a crucial role in enhancing human resource quality; therefore, continuous efforts to improve educational quality are consistently expected (Jahudin et al., 2025; Pertiwi, 2018). Nevertheless, low cognitive learning outcomes are still frequently found. This condition is partly caused by the use of inappropriate teaching methods or learning models, as well as students' limited thinking skills and conceptual understanding. The situation is exacerbated by teacher-centered learning processes in which the teacher dominates classroom activities. Moreover, conventional instructional approaches may ultimately contribute to low student achievement (Desi & Hani, 2020).

Preliminary observations indicated a similar pattern. Students at SMA Negeri 2 Labuapi still exhibited limitations in utilizing their skills, particularly those related to cognitive learning outcomes. This limitation arose because the learning process did not provide students with sufficient opportunities to participate actively. In addition, school facilities and infrastructure—especially laboratory equipment—were limited and thus rarely used in instruction. The lack of learning activities based on projects, case studies, or simulations further hindered the development of students' cognitive abilities. As a result,

students received information more often passively, which affected their ability to express opinions and contributed to lower cognitive outcomes.

Cognitive learning outcomes refer to the ability to understand, analyze, and apply information in various contexts. More broadly, learning outcomes can be understood as relatively permanent changes in an individual's behavior resulting from interaction with the learning environment (Gunandi, 2020). Thus, cognitive learning outcomes can be interpreted as a set of abilities related to thinking processes and understanding within the cognitive domain. Learning processes involving cognition encompass receiving external stimuli through the senses, storing and processing information in the brain, and retrieving information when needed to connect and integrate ideas, methods, or procedures that have been learned for problem-solving (Pranyoto & Geli, 2020).

Given the importance of cognitive competence in learning, efforts are needed to increase student involvement so that their thinking processes develop optimally. Addressing these problems requires effective learning models that make materials more engaging while encouraging active participation and the development of students' critical thinking abilities. One alternative considered suitable is the guided inquiry learning model, which can help overcome low activeness and cognitive ability (Azra et al., 2025). Guided Inquiry is an instructional approach that helps students connect concepts they learn (Rasyidah, 2018). In this model, the teacher provides examples and guides students in observing phenomena, formulating hypotheses, and drawing conclusions, thereby encouraging independent learning and deeper conceptual understanding.

Through guided Inquiry, students can be directed to develop their cognitive abilities more optimally. Observation activities in the inquiry process enable students to draw independent conclusions, allowing them to discover and understand concepts scientifically. Active involvement in learning also helps knowledge remain in memory for a more extended period (Wulansari & Dewi, 2022). However, guided Inquiry has limitations: it may be challenging to implement when students are accustomed to conventional learning patterns; it can require more instructional time and thus be less flexible; and successful learning depends heavily on students' mastery of the material (Mursali et al., 2023).

Barriers to implementing guided Inquiry can be addressed through the use of technology. Rapid technological development in the 21st century has great potential to improve learning quality (Saleh et al., 2024). One form of such technology is a virtual laboratory, i.e., software that runs virtually on a computer to simulate laboratory functions as if experiments were conducted in real conditions. This medium not only presents materials through engaging visual and audio formats but also enables teachers to design activities that encourage active student involvement in thinking processes, concept exploration, and problem solving (Rizka et al., 2025). Virtual laboratories are more effective and efficient in supporting instruction because they allow students to conduct experiments virtually. One widely used virtual laboratory is PhET (Physics Education Technology), which enables students to observe phenomena virtually and manipulate variables that are difficult to manage directly in real environments (Chotimah et al., 2023).

PhET simulations are selected because they offer high flexibility in supporting various learning models and strategies, particularly inquiry approaches (Defianti et al., 2021). PhET can be used online or offline and is specifically designed to help students understand complex and abstract science concepts through interactive and attractive visual representations (Fatimah et al., 2020). With these simulations, students are directed to observe scientific phenomena, formulate questions, develop hypotheses, conduct virtual experiments, and

interpret simulation results to draw logical conclusions (Defianti et al., 2021). Therefore, PhET provides a conducive learning environment for developing authentic scientific reasoning aligned with the core principles of inquiry-based learning. Accordingly, PhET virtual laboratories play a crucial role in enhancing students' cognitive learning outcomes in science education (Basuki, 2023).

PhET is highly suitable when combined with inquiry learning models because it offers several advantages: (1) it helps students understand basic concepts and essential ideas more effectively; (2) it strengthens retention of newly learned material; (3) it encourages intuitive thinking and independent hypothesis formulation; (4) it provides intrinsic learning satisfaction; and (5) it creates more engaging learning experiences (Simbolon, 2015). Previous findings by Gunawan et al. (2019) also show that guided Inquiry supported by a virtual laboratory significantly improves students' skills. Similarly, guided inquiry learning that utilizes a virtual laboratory can enhance students' understanding of difficult concepts (Hermansyah et al., 2019).

Based on the above, guided Inquiry assisted by a virtual laboratory is expected to be effective in improving students' cognitive learning outcomes. This is because such a combination can increase active participation and student independence in identifying information sources through technology-supported investigative activities. Accordingly, this study aimed to enhance the cognitive learning outcomes of students at SMA Negeri 2 Labuapi by implementing a guided inquiry learning model supported by a virtual laboratory. Thus, the study hypothesized that guided Inquiry assisted by a virtual laboratory has a significant effect on students' cognitive learning outcomes.

Research Method

This study employed a quantitative approach using a quasi-experimental design to manipulate the independent variable, control other variables, and observe its impact on the dependent variable to assess causal relationships among variables (Rukminingsih et al., 2020). The study used a pretest–posttest control group design, as shown in Table 1.

Table 1. Pretest-Posttest Control Group Design

Group	Pretest	Treatment	Posttest
Experimental	O ₁	X ₁	O ₁
Control	O ₂	X ₂	O ₂

(Cohen et al., 2018)

Notes:

O₁: Initial measurement administered before treatment in each group.

O₂: Final measurement administered after treatment is completed.

X₁: Treatment using the guided inquiry model assisted by a virtual laboratory in the experimental group.

X₂: Treatment using conventional learning in the control group.

The study was conducted at SMA Negeri 2 Labuapi, Labuapi District, West Lombok Regency, during the second semester of the 2024/2025 academic year. The population consisted of all Grade X students in the second semester (four classes). The sample was determined using cluster random sampling. Class X-B (n = 26) served as the experimental

group, while class X-C ($n = 24$) served as the control group, yielding a total of 50 students. This sample size meets the standards for the present study (Cohen et al., 2018; Mursali et al., 2024).

Research instruments are tools used to collect data. In this study, the instrument was a cognitive learning outcomes test. A cognitive learning outcomes test is an assessment tool used to evaluate students' level of understanding, mastery, and application of concepts or material that has been taught. The instrument was designed to measure cognitive aspects based on Bloom's taxonomy, ranging from basic skills, such as remembering (C1), to more complex skills, including evaluating (C5) and creating (C6). The test comprised six essay items administered at the end of the study. Data for each indicator were categorized based on cognitive concept criteria.

Data analysis was conducted after pretest and posttest scores were collected. The analysis involved comparing pretest and posttest results. Student scores were calculated using the standard formula $\text{Final Score} = (\text{Obtained Score} / \text{Maximum Score}) \times 100$.

N-Gain Test

The gain test was conducted to determine the improvement in learning outcomes before and after instruction using the normalized gain score formula (Simbolon, 2015). In general, the normalized gain can be expressed as $g = (\text{posttest} - \text{pretest}) / (\text{maximum score} - \text{pretest})$.

Table 2. N-Gain Score Categories

Category	Score
High	$g > 0.7$
Moderate	$0.3 < g < 0.7$
Low	$g \leq 0.3$

Hypothesis Testing

Hypothesis testing in this study used Analysis of Covariance (ANCOVA). ANCOVA is a statistical model used to test group differences by combining regression analysis and analysis of variance. ANCOVA helps determine whether the hypothesis regarding the effect of the guided inquiry learning model on students' cognitive learning outcomes is accepted or rejected. The treatment effect is interpreted by comparing the obtained significance value with an alpha level of 0.05.

Research Results and Discussion

This section presents the findings derived from a comprehensive analysis of data examining the effect of the guided inquiry learning model, supported by the use of a virtual laboratory, on students' cognitive learning outcomes. The data analyses include the N-Gain test, which was employed to measure the extent of students' learning improvement after the implementation of the learning model. In addition, normality and homogeneity tests were conducted to ensure that the data met the required statistical assumptions for further analysis. Furthermore, an Analysis of Covariance (ANCOVA) was applied to evaluate the effectiveness of the guided inquiry learning model while controlling for differences in students' pretest scores. Overall, these findings serve as a fundamental basis for understanding the impact of the learning model on the enhancement of students' cognitive development.

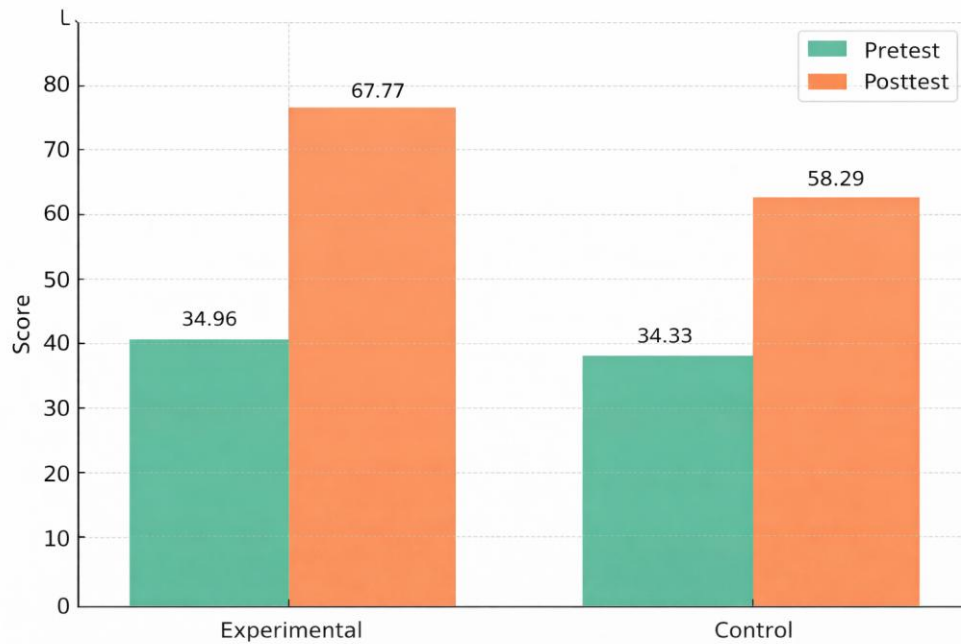


Figure 1. Cognitive Learning Outcomes

The bar chart in Figure 1 compares the mean pretest and posttest scores of students in the experimental and control classes. This comparison evaluates the effectiveness of the implemented learning model in improving cognitive learning outcomes. In the experimental class, the mean pretest score of 34.96 increased markedly to 67.77 on the posttest, indicating that guided Inquiry supported by a virtual laboratory had a positive impact on students' academic achievement. In contrast, the control class increased from a mean pretest score of 34.33 to a posttest mean of 58.29. Although improvement occurred, it was smaller than that of the experimental class. Overall, these results suggest that guided Inquiry—primarily when supported by technology such as a virtual laboratory—provides more effective and meaningful learning experiences for improving students' cognitive outcomes.

Table 3. N-Gain Test Results

Group	Pretest (Mean)	Posttest (Mean)	N-Gain	Category
Control	34.33	58.29	0.36	Moderate
Experimental	34.96	67.77	0.50	Moderate

Table 3 compares the mean pretest and posttest scores, as well as the N-Gain values, of the control and experimental classes. The N-Gain serves as an indicator of instructional effectiveness by measuring the extent of students' cognitive improvement after treatment. In the control class, the mean score increased from 34.33 (pretest) to 58.29 (posttest), producing an N-Gain of 0.36 (moderate). This indicates that conventional instruction improved understanding, although the effect was limited. In the experimental class, the mean score increased from 34.96 to 67.77, yielding a higher N-Gain of 0.50 (moderate). Although both groups were classified in the same category, the experimental group showed greater improvement, highlighting the advantage of a technology-supported guided inquiry strategy.

Table 4. Normality Test Results

Learning Model (Posttest)	Kolmogorov–Smirnov Sig.	Shapiro–Wilk Sig.
Guided Inquiry + Virtual Lab	0.070	0.171
Conventional	0.010	0.089

A normality test was conducted to determine whether posttest data for cognitive learning outcomes were normally distributed, which is a prerequisite for parametric analyses such as ANCOVA. Based on the Kolmogorov–Smirnov test, the experimental group showed a significance value of 0.070 (normal), whereas the control group showed 0.010 (not normal). However, the Shapiro–Wilk test, which is more appropriate for small sample sizes, yielded significance values of 0.171 (experimental) and 0.089 (control). Because both Shapiro–Wilk values exceed 0.05, posttest data for both groups can be considered normally distributed based on this more suitable criterion; thus, the normality assumption was met for subsequent parametric analysis.

Table 5. Homogeneity of Variance Test Results (Levene's Test)

F	df1	df2	Sig.
1.091	1	48	0.301

A homogeneity of variance test was conducted to determine whether variances across the experimental and control groups were equivalent. This assumption is required for ANCOVA. Levene's test produced a significance value of 0.301 ($p > 0.05$), indicating no statistically significant difference in variance between groups. Therefore, the data met the homogeneity assumption and could be analyzed using ANCOVA.

Table 6. ANCOVA Results

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1123.533	2	561.766	7.146	0.002	0.233
Intercept	3352.541	1	3352.541	42.643	0.000	0.476
Pretest	2.526	1	2.526	0.032	0.859	0.001
Cognitive learning outcomes (model effect)	1108.839	1	1108.839	14.104	0.000	0.231
Error	3695.047	47	78.618			
Total	204657.000	50				
Corrected Total	4818.580	49				

ANCOVA was used to test the effect of the learning model on students' cognitive learning outcomes while controlling for pretest scores as a covariate. The ANCOVA results indicate a significant effect of the learning model on cognitive learning outcomes (Sig. = 0.000 < 0.05; F = 14.104; Partial Eta Squared = 0.231). This suggests that approximately 23.1% of the variance in posttest cognitive outcomes can be attributed to the learning model, representing a moderate-to-strong effect size. In contrast, the pretest covariate was not significant (Sig. = 0.859 > 0.05), indicating that baseline differences did not significantly predict posttest scores when the model effect was taken into account. Overall, these results confirm that guided

Inquiry assisted by a virtual laboratory has a significant and positive effect on improving students' cognitive learning outcomes compared with conventional learning.

The significant ANCOVA result ($0.000 < 0.05$) addresses the research problem and achieves the study objective, demonstrating that guided Inquiry supported by PhET can improve cognitive learning outcomes more effectively than conventional instruction. This effectiveness is closely linked to the guided inquiry characteristics that encourage students to actively explore, analyze, and draw conclusions about concepts through direct learning experiences, even when conducted virtually (Mursali et al., 2024). The model is also aligned with 21st-century learning competencies in science (Saleh et al., 2024).

Guided Inquiry supported by a virtual laboratory places students at the center of learning activities (Gunawan et al., 2019). Students can optimize their existing abilities and utilize their learning resources effectively. Their prior knowledge serves as a foundation for understanding and solving problems presented through interactive simulations (Mursali et al., 2023). In this context, the teacher acts as a motivator by posing prompting questions (e.g., "Can you predict the simulation outcome based on your prior understanding?") and as a facilitator who assists students in exploring PhET features, provides guidance when difficulties arise, and encourages collaborative discussion to analyze experimental outcomes critically (Rahayu et al., 2023).

As a facilitator, teachers need to design learning activities holistically, select appropriate strategies and models, and create a safe, comfortable, and responsive classroom environment that accommodates learners' diverse needs. Such efforts aim to make learning more meaningful and have long-term impacts (Basyori, 2025). This is consistent with Utami et al. (2025), who emphasize that students' active involvement in designing and implementing learning activities increases relevance and depth of learning. Through such involvement, students not only understand theoretical concepts but also apply them to collaborative problem-solving and improve their oral and written communication. This approach fosters essential life skills, including cognitive competence, interpersonal communication, and inclusive attitudes, which are needed for the modern workplace and diverse social environments.

Virtual laboratories offer broader opportunities for students to engage in scientific exploration, which is often constrained in real settings by physical and logistical limitations (Gunawan et al., 2019). Through guided Inquiry, students do not receive content passively; instead, they participate actively in structured learning processes requiring higher-order thinking. These processes include observation, problem identification, hypothesis formulation, virtual experimentation, and evidence-based conclusion drawing (Mursali et al., 2024). This approach supports knowledge construction through guided, reflective, and independent learning. Hermansyah et al. (2019) reported that integrating a virtual laboratory in guided Inquiry deepens students' conceptual understanding. However, many prior studies were conducted in relatively ideal contexts; thus, findings may not fully represent schools with limited facilities.

Responding to such limitations, this study contributes to the literature by demonstrating that guided Inquiry can still be implemented effectively in constrained learning environments when simulation-based technologies, such as PhET, are optimally integrated. Technology functions not merely as a supplement but as a strategic solution to laboratory-facility constraints (Rizka et al., 2025). Thus, this study not only reinforces prior evidence on the effectiveness of guided inquiry but also illustrates its adaptability and scalability within digital learning ecosystems with minimal infrastructure requirements. Nevertheless, this study has limitations: (1) the implementation period was relatively short; (2) PhET use requires adequate technological devices that may not be evenly available across

schools; and (3) measured cognitive outcomes were limited to aspects assessable through written tests, whereas cognition is also intertwined with affective and collaborative skills requiring deeper investigation. These limitations present opportunities for further studies that focus on more holistic learning approaches and more inclusive technology use.

Conclusion

This study confirms that a guided inquiry learning model assisted by a virtual laboratory significantly improves students' cognitive learning outcomes. This conclusion is supported by the ANCOVA result, which shows a significance value of 0.000 ($p < 0.05$), indicating that the model is more effective than conventional learning. Learning activities involving scientific stages—from problem formulation and hypothesis development to experimentation and interpretation—encourage students to think systematically, analytically, and reflectively. The integration of guided Inquiry with simulation technology through a virtual laboratory provides a learning environment that better supports cognitive competencies relevant to 21st-century science education.

Recommendations

Based on the results, teachers are encouraged to implement guided Inquiry assisted by a virtual laboratory to support instruction and improve students' cognitive learning outcomes. Future research is recommended to test this model across broader topics and contexts to obtain more comprehensive findings. Further studies should also explore other innovative and creative learning media to provide alternative solutions that are increasingly effective in improving student learning outcomes.

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