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# Virtual vs Real Lab: A Comparative Study on the Effectiveness of Laboratory-Based Physics Learning on Students' Critical Thinking Skills

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**ABSTRACT**

***Objective:*** *This study aims to compare the effectiveness of guided inquiry learning using worksheets (SW) based on Virtual Lab (PhET) and Real Lab in enhancing students' critical thinking skills in physics learning.* ***Method:*** *This study employed a quasi-experimental method with a non-equivalent pretest–posttest design involving two experimental classes in a public senior high school in Surabaya during the even semester of the 2024/2025 academic year. A saturated sampling technique was applied, in which all 11th-grade science students were included as the research sample. The first class used SW integrated with PhET simulations, while the second class used SW based on real laboratory activities. The instrument used was a critical thinking skills test developed based on Facione's five indicators, and the data were analyzed using gain score analysis, paired sample testing, independent sample testing, and effect size analysis.* ***Results:*** *The findings showed that both experimental classes experienced significant improvement in students' critical thinking skills after the implementation of guided inquiry learning, with no significant difference found between the two groups, indicating that both approaches are comparably effective.* ***Novelty:*** *The novelty of this study lies in its direct comparative design, demonstrating that both virtual and real laboratory modalities can equally support the development of critical thinking skills and provide flexible alternatives for physics learning in schools with different laboratory facilities.*

## INTRODUCTION

Critical thinking skills are one of the key competencies that every individual must possess in order to compete in an ever-evolving environment in the 21st century (Mumtaziah & Majid, 2023). The presence of this skill is crucial, considering that information is now abundant and spreads rapidly (Fauziah, 2024). The world of education positions critical thinking skills not only as a tool to help students understand their lessons, but also as essential preparation for facing challenges in an ever-evolving work environment (Hayati & Nuriyah, 2023). Mastering these skills provides students with the capacity to identify the root causes of problems and enables them to design and implement practical solutions to overcome the challenges they face (Yuliani, 2024). The systematic reinforcement of critical thinking skills has become an essential need to prepare the younger generation to face the complexity of global challenges in an adaptive and solution-oriented manner.

Along with technological advancements and the rapid flow of information in the 21st century, the systematic reinforcement of critical thinking skills has become increasingly urgent to implement in the field of education. It is hoped that through strong mastery of critical thinking skills, students will be able to deeply analyze problems, evaluate and solve them systematically, and make appropriate decisions both in learning and in everyday life. The world of education not only demands that students understand theoretical material, but also encourages them to apply that knowledge contextually in real-life situations. Beyond the educational setting, the workplace has also become more adaptive to change and increasingly demands individuals who are capable of critical and analytical thinking. Critical thinking skills are essential competencies in 21st-century education. It enables students to analyze problems, evaluate information, and make reasoned decisions. Therefore, the development of critical thinking skills should become a primary focus in the learning process to foster a generation that is intelligent, creative, and globally competitive.

However, the current conditions in many schools indicate that students' critical thinking skills have not yet developed optimally. For example, many students in Kenya struggle to solve exam that requires critical thinking skills (Ongesa, 2020). This situation highlights the need for instructional approaches that intentionally promote higher-order thinking and actively engage students in meaningful learning processes. Despite being widely recognized as an essential aspect of 21st-century education, students' critical thinking skills remain relatively low in practice. Research by Masitah et al. (2022) showed that only 56.25% of 32 students demonstrated adequate critical thinking proficiency. Similarly, Mardiana et al. (2022) reported that the lack of appropriate teaching methods is a major factor contributing to the low level of students' critical thinking skills. Ideally, the application of effective learning methods should significantly enhance these skills. Another contributing factor is that the practice questions provided often do not meet the necessary standards to accurately assess students' critical thinking abilities. Moreover, students are still insufficiently engaged in constructing understanding through their own reasoning processes (Putri et al., 2023). The low results in critical thinking skills are consistent with the findings of a preliminary study conducted at SMA Negeri 22 Surabaya, which showed that students' critical thinking levels were still relatively low, with an average achievement score of 61.77 classified as low. A significant number of students scored in the low (49.48) and very low (34.38) categories, with 41.38% and 34.48%, respectively, out of 106 students. Therefore, an appropriate learning model is needed, one that can provide students with direct experiences to help them thoroughly understand the subject matter.

In this context, inquiry-based learning becomes highly relevant as a student-centered approach that emphasizes the processes of questioning, investigating, analyzing evidence, and drawing conclusions through systematic reasoning. Inquiry learning encourages students to construct their own understanding through exploration and evidence-based thinking rather than passively receiving information from the teacher. This characteristic makes inquiry particularly suitable for fostering critical thinking skills, as students are required to interpret information, evaluate evidence, formulate explanations, and make reasoned judgments.

Based on this inquiry framework, a more structured form, namely guided inquiry, is considered appropriate for classroom implementation, especially in physics learning where students still require teacher facilitation during the investigation process (Goodwin, 2024). One of the learning models that can be used to address this issue is guided inquiry, in which students are encouraged to actively seek various information related to the problems presented by the teacher, with the help of guidance, allowing them to find solutions through investigation or experimentation. The guided inquiry learning model is a teaching approach that emphasizes the process of discovering concepts and the relationships between them, in which the teacher acts as a facilitator who guides students in the right direction. This model offers various advantages that make it highly relevant to today's educational landscape, as it focuses on the development of knowledge, attitudes, and skills, while also allowing students to learn according to their individual learning styles.

A learning model that develops critical and analytical thinking patterns in students will be more effective when accompanied by supportive learning materials, such as practice questions and worksheets. One such learning material is the Student Worksheet (SW). The Student Worksheet (SW) is a learning tool that contains tasks or activity guides designed by teachers to help students understand the material through individual or group activities (Andriyani et al., 2020; Sari et al., 2020). In a student-centered learning approach, SW plays an important role in enhancing active engagement, encouraging effective interaction between teachers and students, and helping learners independently discover the concepts of the subject matter (Abdillah & Astuti, 2021).

As an extension of the guided inquiry approach, SW in this study is implemented in two different experimental settings, namely virtual laboratories and real laboratories, which constitute the focus of this research. With the advancement of technology, the use of digital-based SW has become increasingly relevant, as it can make the learning process more engaging, interactive, and adaptable to the needs of modern education. Technology also serves as an important tool to help explain abstract concepts in a more concrete manner (Elvi et al., 2021).

One form of technology integration in SW is the use of virtual laboratories such as PhET. PhET is an interactive learning medium that provides research-based simulations of physical phenomena and is freely accessible. These simulations are designed to resemble simple games, allowing students to explore visually and practically within a safe virtual environment. The use of PhET in physics learning has been proven to enhance conceptual understanding and train students' critical thinking skills (Masita et al., 2020; Sadidah & Irvani, 2021), making it one of the most effective supporting tools in inquiry-based and virtual experiment learning.

Previous studies have demonstrated the effectiveness of both virtual laboratories and real laboratories in improving students' critical thinking skills. Research by Listiantomo & Dwikoranto (2023), showed a significant improvement in students' critical thinking skills after the implementation of the guided inquiry model supported by a virtual lab on the topic of light waves. Similarly, Mat et al. (2023), reported that the guided inquiry learning model supported by a virtual lab can enhance students' critical thinking skills. On the other hand, Sarifah & Nurita (2023) found that the use of the guided inquiry learning model through real laboratories improved students' critical thinking and collaboration skills. Rahmati & Sari (2024) also stated that the laboratory-based inquiry model using real labs can significantly enhance students' critical thinking skills.

However, although previous studies have independently confirmed the effectiveness of virtual laboratories and real laboratories, there is still a clear research gap regarding the comparative effectiveness of these two types of SW within the same guided inquiry framework, particularly in the context of physics learning and critical thinking development. Most prior studies tend to focus on only one type of laboratory setting, making it difficult to determine which approach provides greater pedagogical benefits for fostering critical thinking skills. This gap indicates the need for a comparative study that does not merely replicate prior findings in a different location, but scientifically examines how differences in learning environments, virtual and real, interact with guided inquiry processes to influence students' higher-order thinking development.

From a theoretical perspective, this study also contributes to the understanding of how guided inquiry learning theory operates across different experimental modalities. Specifically, this research extends the theoretical discourse on inquiry-based learning by examining whether the mode of laboratory experience (virtual versus real) produces different patterns of critical thinking skill development. Thus, this study contributes not only empirical evidence but also theoretical insight into the role of learning media as a moderating factor in inquiry-based physics instruction.

The uniqueness of this research lies in its direct comparative design between PhET-assisted virtual lab SW and real lab SW under the same guided inquiry learning model and within the same physics learning context. Unlike previous studies that generally examined only one laboratory type separately, this study specifically compares both approaches under equivalent learning objectives and instructional procedures. This novelty is expected to provide more comprehensive empirical and theoretical insights into which approach is more effective in improving students' critical thinking skills. Therefore, due to the differences in the use of virtual lab SW and real lab SW, this study was conducted to compare the effectiveness of virtual lab SW and real lab SW using the guided inquiry learning model in physics education to improve students' critical thinking skills.

## RESEARCH METHOD

Research Design

This study employed a quasi-experimental method with a non-equivalent pretest-posttest design, aiming to compare the effectiveness of the guided inquiry learning model assisted by Virtual Lab (PhET) and Real Lab worksheets (SW) in enhancing students' critical thinking skills. Two experimental classes were involved without random grouping. Both classes were given a pre-test before the treatment and a post-test afterward to determine skill improvement (Figure 1).

$$O_1 \longrightarrow X_1 \longrightarrow O_2$$
$$O_1 \longrightarrow X_2 \longrightarrow O_2$$

**Figure 1.** Research design.

in figure $O_1$: pre-test (before treatment), $X_1$: Treatment (learning using Virtual Lab worksheets), $X_2$: Treatment (learning using Real Lab worksheets), $O_2$: Post-test (after treatment).

**Sample**

This study was conducted at a public senior high school in Surabaya during the even semester of the 2024/2025 academic year. The population consisted of all 11th-grade science students (XI MIPA). A saturated sampling technique was employed, in which the entire population was included as the research sample (Sugiyono, 2014). Two classes were assigned as experimental groups, with each class receiving different treatments based on the type of SW implemented.

**Instrument and Procedures**

The main instrument used in this study was a critical thinking skills test presented in the form of essay questions. These questions were developed based on the critical thinking skill indicators proposed by Facione, in which this study used 5 out of the 6 indicators: interpretation, analysis, evaluation, inference, and explanation (Facione, 2015). Each test item was designed to assess students' ability to understand, examine, and draw conclusions based on the context of the given physics problems. This instrument was validated by expert lecturers and physics teachers using a validation sheet with a 4-point Likert scale and tested for reliability through Cronbach's Alpha calculation with the help of SPSS.

In addition to the test instrument, the learning tools used in this study included teaching modules, handouts, and Student Worksheets (SW), which were developed in two versions: Virtual Lab SW based on PhET simulations and Real Lab SW based on hands-on experiments. These learning tools were designed according to the syntax of the guided inquiry learning model, which consists of six stages: orientation, formulating problems, formulating hypotheses, collecting data, testing hypotheses, and drawing conclusions.

The research procedure began with administering a pre-test to students in each experimental class to measure their initial critical thinking skills. Next, students received treatment according to their group: physics learning using the guided inquiry model with Virtual Lab SW in Experimental Class 1, and with Real Lab SW in Experimental Class 2. After the entire learning process was completed, students were given a post-test using the same instrument to assess the improvement in their critical thinking skills after the treatment. The pre-test and post-test data were then analyzed to determine the effectiveness of each type of SW in enhancing students' critical thinking skills.

**Data Analysis**

Data analysis in this study was conducted quantitatively to evaluate the improvement and comparison of students' critical thinking skills after receiving learning treatments using Virtual Lab SW and Real Lab SW. This analysis included instrument validity and reliability testing, calculation of learning improvement through N-gain, and statistical tests including normality test, homogeneity test, paired t-test, independent t-test, and effect size analysis.

**(1) Instrument Validity and Reliability Testing**

The validation of instruments and learning tools in this study was carried out by two expert lecturers, and one physics teacher as validators. The assessment was conducted using a 4-point Likert scale with score ranges from 1 to 4. Each score corresponds to specific criteria: a score of 4 indicates "Very Good," 3 indicates "Good," 2 indicates "Fair," and 1 indicates "Poor." (Asbanu & Laos, 2023). The validation scores from each validator were calculated using the following formula:

$$P = \frac{f}{N} x100\% \qquad \ldots(1)$$

Description:
$P$ = Validity percentage results
$f$ = The scores obtained
$N$ = The total frequency or maximum score

The calculated validity percentage results were then interpreted into categories as shown in Table 1.

**Table 1.** Validity score categories (Azahra & Wasis, 2023).

| Percentage | Criteria |
|---|---|
| 81% - 100% | Very Valid |
| 61% - 80% | Valid |
| 41% - 60% | Quite Valid |
| 21% - 40% | Less Valid |
| 0% - 20% | Very Invalid |

Next, the reliability of the instruments and learning tools was tested to determine the stability and consistency of respondents' answers. This test was conducted using Cronbach's Alpha formula with the assistance of SPSS software. An instrument or tool is considered reliable if the α value is greater than 0.6, and unreliable if the α value is less than 0.6. The interpretation of Cronbach's Alpha values is presented in Table 2.

**Table 2.** Reliability criteria intervals (Azahra & Wasis, 2023).

| *Cronbach's Alpha* Value | Criteria |
|---|---|
| $\alpha < 0,6$ | Poor |
| $0,6 \leq \alpha < 0,7$ | Fair |
| $0,7 \leq \alpha < 0,8$ | Good |
| $0,8 \leq \alpha < 0,9$ | Very Good |
| $\alpha \geq 0,9$ | Excellent |

**(2) N-gain Analysis**

To measure the improvement in students' critical thinking skills, an N-gain analysis was conducted based on the pre-test and post-test results using the following formula:

$$N - gain\ (g) = \frac{x_2 - x_1}{x_{maks} - x_1} \quad \ldots(2)$$

Description:

$x_1$ = *pre-test* score

$x_2$ = *post-test* score

$x_{maks}$ = maximum score

Next, the categorization of N-gain scores used to measure the improvement in students' critical thinking skills after the implementation of learning with Virtual Lab (PhET) SW and Real Lab SW can be seen in Table 3.

**Table 3.** N-gain score categories (Febrinita, 2022).

| N-gain score | Categories |
|---|---|
| $g > 0,7$ | High |
| $0,3 \leq g \leq 0,7$ | Medium |
| $g < 0,3$ | Low |

**(3) Normality and Homogeneity Tests**

Before conducting parametric statistical tests, prerequisite tests in the form of normality and homogeneity tests were carried out with the help of SPSS software. The normality test aims to determine whether the pretest and posttest data are normally distributed.

The Shapiro-Wilk test was used, which is suitable for small to medium sample sizes. The decision-making criteria are as follows:

- If the significance value (p-value) > 0.05, the data are normally distributed.
- If the significance value (p-value) ≤ 0.05, the data are considered not normally distributed.

Next, to determine whether the variances between groups are homogeneous, a homogeneity test was conducted using Levene's Test. The decision-making criteria are as follows:

- If the significance value (p-value) > 0.05, the data have homogeneous variances.
- If the significance value (p-value) ≤ 0.05, the data have non-homogeneous variances. If the test results show that the data are normally distributed and homogeneous, then the analysis can proceed using parametric testing, specifically the t-test.

**(4) Paired Sample t-Test**

The paired sample t-test was conducted to determine whether there was an improvement in critical thinking skills within each experimental class after the treatment. This analysis was carried out using SPSS by comparing the pretest and posttest scores within the same group.

The hypotheses used are as follows:

- $H_0$: There is no significant difference between the pretest and posttest scores (no improvement occurred).
- $H_1$: There is a significant difference between the pretest and posttest scores (an improvement occurred).

Decision making criteria:

- If the p-value > 0.05, then $H_0$ is accepted, meaning there is no significant improvement.
- If the p-value ≤ 0.05, then $H_0$ is rejected and $H_1$ is accepted, meaning there is a significant improvement.

**(5) Independent Sample t-Test**

The independent t-test was used to compare the mean N-gain scores between the two experimental classes: the class using Virtual Lab SW and the class using Real Lab SW. This test aimed to determine whether there was a difference in the improvement of critical thinking skills between the two treatment groups. The analysis was conducted using SPSS.

The hypotheses used are as follows:

- $H_0$: There is no significant difference in the improvement of critical thinking skills between the two experimental classes.
- $H_1$: There is a significant difference in the improvement of critical thinking skills between the two experimental classes.

Decision making criteria:

- If the p-value > 0.05, then $H_0$ is accepted, meaning there is no significant difference.
- If the p-value ≤ 0.05, then $H_0$ is rejected and $H_1$ is accepted, meaning there is a significant difference between the two groups.

**(6) Effect Size (Cohen's d)**

To determine the magnitude of the effect of the given treatment, an Effect Size analysis was conducted using Cohen's d formula. This calculation was also carried out with the help of SPSS and was intended to complement the results of the t-test by measuring the strength of the observed differences. The interpretation of Cohen's d values is presented in Table 4 (Becker, 1999) in this study (Umam & Jiddiyyah, 2020)

**Table 4.** Cohen's d effect size category intervals

| Interval | Criteria |
|---|---|
| $d \geq 2{,}1$ | Very High |
| $0{,}8 \leq d \leq 2{,}0$ | High |
| $0{,}5 \leq d \leq 0{,}79$ | Medium |
| $0{,}2 \leq d \leq 0{,}49$ | Low |
| $0{,}0 \leq d \leq 0{,}19$ | Very Low |

## RESULTS AND DISCUSSION

### Results

Before the learning process was implemented, all tools and instruments used in the study underwent a validation process by two expert lecturers and one physics teacher. The validation was carried out using a 4-point Likert scale, which was then converted into percentages. The results showed that all components of the tools and instruments received scores above 90%. As shown in Table 5, the validation scores were as follows: teaching module 91.67%, SW 90.91%, handout 94.64%, test instrument 93.52%, lesson implementation observation sheet 96.30%, and student response questionnaire 94.44%. Based on the score interpretation, all components fall into the "very valid" category and are therefore deemed suitable for use in the research process.

Reliability testing of the tools and instruments was conducted using Cronbach's Alpha with the assistance of SPSS. As shown in Table 5, all components obtained α values ≥ 0.6, indicating that all instruments are considered reliable. The teaching module received the highest score of 0.916, which falls into the "excellent" category, while the SW and the questionnaire were categorized as "fair." These results indicate that the instruments have good internal consistency.

**Table 5.** Results of validity and reliability of instruments and learning tools.

| No | Instruments and Learning Tools | Validity Percentage (%) | Category | Cronbach's Alpha Value | Category |
|---|---|---|---|---|---|
| 1 | Teaching Module | 91,67 | Very Valid | 0,916 | Excellent |
| 2 | SW | 90,91 | Very Valid | 0,629 | Fair |
| 3 | Handout | 94,64 | Very Valid | 0,718 | Good |
| 4 | Test Instrument | 93,52 | Very Valid | 0,844 | Very Good |

After the instruments were declared valid and reliable, a pre-test and post-test were administered in each experimental class. Based on Table 6, in the experimental class 1 (Virtual Lab SW), the average pre-test score was 46.69 and increased to 89.49 in the post-test. The calculated N-gain was 0.79, which falls into the high category. Meanwhile, in the experimental class 2 (Real Lab SW), the average pre-test score of 46.29 increased to 88.11 in the post-test, with an N-gain of 0.78, also classified as high. This indicates that both treatments were equally effective in improving students' critical thinking skills.

**Table 6.** Results of N-gain analysis for each class

| Class | Average Pre-test | Average Post-test | *N-Gain* | Category |
|---|---|---|---|---|
| Experiment 1 | 46,69 | 89,49 | 0,79 | High |
| Experiment 2 | 46,29 | 88,11 | 0,78 | High |

Normality testing was conducted to ensure that the distribution of pre-test and post-test data followed a normal distribution. As presented in Table 7, the significance value for experimental class 1 was 0.252 and for experimental class 2 was 0.131. Since both values are greater than 0.05, the data are normally distributed.

**Table 7.** Normality test results

| Class | *Shapiro-Wilk* | | |
|---|---|---|---|
| | Statistics | Df | Sig. |
| Experiment 1 | 0,961 | 35 | 0,252 |
| Experiment 2 | 0,952 | 35 | 0,131 |

The homogeneity test was conducted to determine whether the variances between the two experimental classes were homogeneous. Table 8 shows a significance value of 0.075 (> 0.05), thus it can be concluded that the data have homogeneous variances.

**Table 8.** Homogeneity test results

| Class | Test of Homogeneity of Variance | | | |
|---|---|---|---|---|
| | Levene's Statistic | df1 | df2 | Sig. |
| Based on Mean | 2.654 | 2 | 103 | 0,075 |

The paired sample t-test was conducted to determine whether there was a significant improvement within each class after the treatment. The results are presented in Table 9. The significance values for both classes were 0.000 (< 0.05), indicating a significant difference between the pre-test and post-test. The mean differences were also substantial: -42.800 for the experimental class 1 and -41.829 for the experimental class 2.

**Table 9.** Paired sample t-test results

| *Paired Differences* | | | | | |
|---|---|---|---|---|---|
| Class | N | Correlation | Mean | t | Sig2-tailed) |
| Experiment 1 | 35 | 0,139 | -42,800 | -16,639 | 0,000 |
| Experiment 2 | 35 | 0,224 | -41,829 | -22,875 | 0,000 |

To determine whether there was a difference in effectiveness between the two treatments, an independent t-test was conducted on the N-gain values. Table 10 shows that the significance value was 0.644 (> 0.05), indicating that there was no significant difference between the two experimental classes. To determine the strength of the treatment effect, an effect size calculation was carried out using Cohen's d. The results are presented in Table 11. The value of d = 0.111 indicates that the effect of the difference between the two experimental classes is categorized as very small.

**Table 10.** Independent t-test results

| *Independent Sample Test* | | | |
|---|---|---|---|
| **Class** | **Mean Difference** | **t** | **Sig2-tailed)** |
| Experiment 1 & Experiment 2 | 0,015 | 0,465 | 0,644 |

**Table 11.** Effect size test results (Cohen's d)

| *Effect Size (Cohen's d)* | | |
|---|---|---|
| **Class** | **Point Estimate *Cohen's d*** | **Criteria** |
| Experiment 1 | 2,813 | Very High |
| Experiment 2 | 3,867 | Very High |
| Experiment 1 & Experiment 2 | 0,111 | Very Low |

**Discussion**

The validation results of the learning devices and instruments showed that all components, including the teaching module, student worksheets (SW), handouts, and test instruments, were categorized as very valid. The validation was conducted by two physics lecturers and one physics teacher using a 4-point Likert scale. The assessments, obtained from percentage analysis, all exceeded 90%, indicating that all learning devices were aligned with the learning objectives and the critical thinking indicators to be measured (Saputri et al., 2023). In addition to being valid, the learning devices and instruments were also tested for reliability using Cronbach's Alpha formula with the help of SPSS. The results showed that all instruments had α values above 0.6, with some even falling into the categories of very good to excellent (Azahra & Wasis, 2023). This reliability indicates that the instruments are consistent and stable in measuring students' critical thinking skills, making the measurement results trustworthy (Anggriani & Jumrah, 2022).

The improvement of students' critical thinking skills after the learning process can be seen from the comparison of pre-test and post-test scores, which showed a significant increase. In the experimental class 1 that used SW Virtual Lab, the average score increased from 46.69 to 89.49, with an N-gain of 0.79, while in experimental class 2 with SW Real Lab, the score increased from 46.29 to 88.11 with an N-gain of 0.78. Both fall into the high improvement category. These results are consistent with the study by Wahid et al., (2024), which showed that learning with laboratory-based SW effectively improves critical thinking skills. The PhET simulation used in the SW Virtual Lab helped students visualize concepts, formulate hypotheses, and test them through digital interactions that resemble real experiments (Koilmo et al., 2025). Meanwhile, the use of the Real Lab provided students with hands-on experience in conducting physics experiments, manually processing data, and drawing conclusions based on observations, which indirectly trained critical thinking skills in a contextual manner (Rahma & Arista, 2022).

The guided inquiry learning model used in both experimental classes consisted of six phases: orientation, problem formulation, hypothesis formulation, data collection, hypothesis testing, and drawing conclusions. Each phase of this model directly trains the critical thinking indicators proposed by Facione, such as interpretation, analysis, inference, evaluation, and explanation (Sadidah & Irvani, 2021). This is in line with Vinsensius Polli et al. (2022), who stated that the implementation of guided inquiry syntax trains students to process information logically, construct arguments, and evaluate information based on the data obtained. Through exploration activities in both virtual and real laboratories, students actively engage in the learning process, build conceptual understanding, and enhance the critical thinking skills required for 21st-century learning (Marina et al., 2024). Although there was a difference in the average learning outcomes between Experimental Class 1 and Experimental Class 2, the results of the independent sample t-test showed that the difference was not statistically significant ($p = 0.644$). This finding is supported by the effect size calculation using Cohen's d, which yielded a value of 0.111, categorized as a very small effect. This means that both types of SW, whether based on Virtual Lab or Real Lab, have comparable effectiveness in improving critical thinking skills.

The absence of a statistically significant difference indicates that the learning model and instructional design may play a more dominant role in improving students' critical thinking skills than the type of laboratory medium itself. In this study, both experimental classes were taught using the same guided inquiry learning model, which emphasizes active investigation, problem identification, hypothesis formulation, data collection, and conclusion drawing. These inquiry stages provide similar opportunities for students to engage in higher-order thinking processes, regardless of whether the experiments are conducted virtually or in a real laboratory setting. As a result, the comparable effectiveness observed between the two classes may be attributed to the consistency of the pedagogical approach rather than the difference in media format. These results are consistent with the study by Rararati et al., (2025), which stated that laboratory-based approaches, whether digital or conventional, can equally enhance learning outcomes and critical thinking skills when implemented with appropriate pedagogical strategies.

Furthermore, this finding suggests that the essential factor in fostering critical thinking lies in how students are guided through the inquiry process. Both Virtual Lab and Real Lab environments allow students to observe phenomena, analyze variables, interpret evidence, and evaluate results. The Virtual Lab provides advantages in terms of visualization, repeated simulations, and accessibility, while the Real Lab offers direct hands-on experience and authentic manipulation of equipment. Despite these differences, both environments appear to facilitate similar cognitive processes required for the development of critical thinking skills.

These findings have important practical implications for physics education. Teachers can adjust the use of SW types according to the availability of school facilities and infrastructure. In schools with limited laboratory equipment, PhET-based virtual laboratories can serve as an effective alternative, while real laboratory activities remain valuable for providing direct empirical experience when facilities are available. Importantly, both approaches can be equally effective in developing students' critical thinking skills when they are systematically designed and implemented through active learning strategies. Thus, the selection between Virtual Lab and Real Lab should be aligned with instructional objectives, resource availability, and the specific learning context rather than being viewed as the sole determinant of learning effectiveness.

## CONCLUSION

**Fundamental Finding:** this study found that guided inquiry learning using both Virtual Lab (PhET) SW and Real Lab SW is equally effective in improving students' critical thinking skills, with no significant difference between the two. **Implication:** these results indicate that both types of SW can be applied flexibly according to school facilities to support the development of higher-order thinking skills. **Limitation:** this research was limited to one school, two classes, and measured only short-term impacts through written tests. **Future Research:** future studies are recommended to involve larger samples, adopt qualitative approaches, and explore hybrid laboratory models as well as the long-term impacts on the development of students' critical thinking skills.

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