Effectiveness of Virtual Laboratories in Developing Physics Concepts among University Students

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ABSTRACT:
Virtual laboratory or electronic laboratory is an educational technology that is important in higher education. Usually, it relates to physics lessons, since the concept is quite abstract. An analysis was made of the efficacy of virtual laboratories on the acquisition of college students' physics concepts. This research employs a quasi-experimental model with 2 groups of respondents. The experimental group is given treatment; the treatment group is taught using a virtual laboratory simulation and control is taught using a traditional laboratory simulation. A similar cohort of undergraduate physics students from one university sets similar students.

Delivered over 8 weeks, the intervention highlighted key physics topics namely, mechanics, electricity, and thermodynamics. A standardized conceptual understanding test was conducted and data was collected before and after the intervention. The researchers used statistical analysis (t-tests and effect sizes) to analyse differences between groups.

According to the findings, the students who accessed the virtual laboratory gained significantly more conceptual understanding than those without the access. interactive visualization, repetition of experiments, and instant feedback contributed to deeper cognition. Moreover, students claimed to have higher motivation and less cognitive load in learning simulations.

According to the research, a virtual laboratory is an effective teaching tool to enhance conceptual learning in physics at the university level. Evidence presented in this paper advocates for employing virtual lab technologies in physics teaching as an alternative to traditional physics laboratories. Discussions will be based on instructional design, curriculum development and future research.

Keywords: Virtual laboratories, Physics education, Conceptual understanding, Simulation-based learning, Higher education

1. Introduction

The teaching of physics at university level continues to be a challenge because the physics concepts are largely abstract and representational mathematical form. Numerous students face a challenge in associating theoretical and practical knowledge, confining their conception. Different types of traditional laboratory environments aim to address this gap. However, these encounter limitations such as inadequate resources, safety and repeat experimentation restrictions.

Progress in digital technology introduced virtual laboratories as alternative learning. Through a software that simulates real experiments, the students can conduct an experiment, investigate a phenomenon and study a physical object. Through the use of visualization, manipulation of variables and instant feedback, virtual labs can provide meaningful learning. [1].

This research investigates the impact of virtual laboratories on the understanding of physics-related concepts. The primary focus is to evaluate their efficacy in comparison with traditional laboratory methods. The study aims to provide empirical evidence to support the use of virtual laboratories in the learning of physics.

1.1 Research Background

There has been a complete transformation of teaching practices and learning outcomes through technologies. In the domain of physics education, the use of digital tools such as simulations and virtual laboratories is gaining interest. Through a virtual lab, the students conduct experiments without any physical limitations. They can perform the experiments as much as they want. Students can also create complex experiments that are not accessible in a real lab.

Studies in science education suggest that interactive learning environments improve student engagement and knowledge retention. Through experimentation, virtual laboratories, in particular, support constructivist learning by enabling students to actively construct knowledge. They solve logistical issues related to physical labs, including equipment cost and time requirements.

The higher education institution is inclined to adopt virtual laboratories due to the rise availability of PhET Interactive Simulations. Courses are available on e-platforms that have been scientifically accurate simulation models. That is made according to the physics syllabus.

1.2 Research Problem

Even when there are contemporary instructional technologies to draw on, many university physics courses still predominantly lecture-based. Students often memorize formulas without knowing the concepts. While laboratory sessions are important, there may not always be enough time or resources for exploration.

The primary issue focused on through this study is the limited power of conventional laboratory techniques, which does not result in deeper conceptual understanding in physics. The research seeks to determine if students can learn better with virtual laboratories than physical laboratories.

Essential Questions encompass.

- Do virtual labs help students understand physics concepts more effectively?
- What are your thoughts on the learning outcomes virtual laboratories offer in comparison to traditional ones?
- What are the benefits and challenges of virtual labs?

1.3 Research Objectives

The objective of this study is to.

- Examine effectiveness of virtual laboratory on acquisition of physics concept.
- We will compare the learning outcomes of the virtual lab and physical lab students.
- Student engagement and participation in online learning environments are examined.
- Determine the advantages and disadvantages of virtual laboratories in physics education.

1.4 Research Significance

This study can be used practically and theoretically in Physics education. It gives reliable data regarding the virtual laboratories' role in conceptual learning. Teachers can design more effective and beneficial technology-related teaching methods thanks to the findings.

When looking at the practical side, virtual laboratories can help cut costs from the actual equipment to allowing the institution to widen access to experiment learning. When resources are limited this is especially true

The research will contribute towards theory in science education. In particular, how cognitive processes and conceptual understanding of students change through digital tools. Moreover, this facilitates the adoption of constructivist learning theory in virtual environments.

2. Literature Review

Researchers are studying how virtual labs can be integrated into physics education especially in higher education where visualization involves the application of abstract concepts. Physics is the subject that requires you to correlate math. The traditional laboratories support the connection as well but face limitations like time, equipment, and complexity of experiments.

Virtual laboratories were used to overcome these constraints. Learners are able to experiment in these immersive environments created through these approaches. An electric field pattern and motion pattern that cannot be observed in a physical laboratory setting can be visualized by students using PhET Interactive Simulations. [2].

According to empirical studies, the use of virtual laboratories increases learners' conceptual understanding. Learning environments allow students to construct understandings about the relationships between variables. Students develop improved mental models when they can test multiple iterations of a scenario and get feedback immediately.

This improvement is reliant on visualization. Dynamic representations of abstract concepts in simulations. Students can relate equations to physical meanings. When students observe the effect of a force on the motion of an object, they experience this in real time, giving them a much deeper understanding than simply manipulating symbols.

Another benefit is flexible. The virtual lab is accessible to students anytime and can repeat the experiment anything. It raises exposure to concepts and promotes mastery. Traditional labs restrict repetition mainly due to time and other resource restrictions. [3].

Nonetheless, there are still considerable divergences between virtual and traditional findings. Learning outcomes vary depending on purposes of instruction. Refer to Table 1.

Table 1. Key differences between virtual and traditional laboratories

Dimension	Virtual Laboratories	Traditional Laboratories
Conceptual Understanding	High due to visualization and interaction	Moderate, depends on explanation
Practical Skills	Limited development	Strong development
Accessibility	Available anytime and anywhere	Restricted by schedule and location
Safety	No risk	Potential hazards
Experiment Repetition	Unlimited	Limited
Cost	Low after setup	High equipment cost
Cognitive Load	Reduced extraneous load	Higher due to procedures

A major factor is the engagement of students. Experiments in a virtual lab creates incentive for the students, studies show Students now have the confidence to explore without the fear of consequences, due to this failure. More participation and enhanced learning are observed.

Virtual labs lessen unnecessary mental workload from viewpoint of cognition. Students focus on concepts rather than operating tools. According to cognitive load theory, the processing of irrelevant information is of lesser importance in the tasks.

Benefits notwithstanding, there are limits. Using a virtual lab does not develop practical skills.

Students may lack experience with real equipment and measurement of errors. Sometimes, simulations may oversimplify a sophisticated system and its dynamics.

A mixed methodology has more support. Combining the virtual and the traditional labs produces best results. Virtual labs build conceptual understanding for students. Flesh labs improve technical aptitude. [4].

This study will build upon these findings by investigating the impact of virtual laboratories on the development of physics concepts of university students and how it compares to traditional methodologies.

3. Methodology

3.1 Research Design and Variables

This study was quasi-experiment with the aim to find out the value effects of virtual laboratories physics concept development. A pre-test and post-test control group design was implemented to assess conceptual gains prior to and following the intervention. There were 2 groups. The experimental group studied the virtual laboratory world whereas the control group studied the traditional laboratory experiment. To ensure validity, both groups were taught the same physics content for same duration. [5].

The varying type of lab environment is the independent variable. The variable that depends on other factors. These include content, the length of teaching and the manner of delivery by the instructor. In this design, the influence of laboratory type on the learning is isolated.

Table 2. Research design structure (see Table 2)

Group	Pre-test	Intervention	Post-test
Experimental	✓	Virtual Laboratory	✓
Control	✓	Traditional Laboratory	✓

3.2 Participants and Instructional Content

Sixty undergraduate students in a university level Physics class participated in the experiment. All participants had similar academic backgrounds and were in the second academic year. The students were equally divided into two groups consisting of 30 students. It guaranteed similar background and performance to the students.

The instructional content concentrated on three fundamental domains in physics.

- Fluid Mechanics
- Magnetism and electricity.
- Thermal Dynamics.

The domains were selected largely because they require strong conceptual understanding & benefit from visualizations. All participants in a lecture were taught identically. The distinction was restricted to lab implementation. Take a look at Table 3.

Table 3. Distribution of participants

Group	Number of Students	Instruction Type
Experimental	30	Virtual Lab
Control	30	Traditional Lab

3.3 Instructional Intervention and Learning Environment

The programmed was conducted for eight weeks. Throughout the whole intervention, the experimental group was exposed to virtual laboratory simulations from platforms like PhET Interactive Simulations. These simulations gave students the chance of manipulating parameters like force, voltage, and temperature in real-time. Pupils had an opportunity to reiterate their experiments and test more situations, with a quick feedback response. [6].

The control group did the experiments in a conventional lab with physical devices. The procedures for these experiments were rigid and constrained by time and resources. Student made manual observation and record. Please refer to Figure 1.

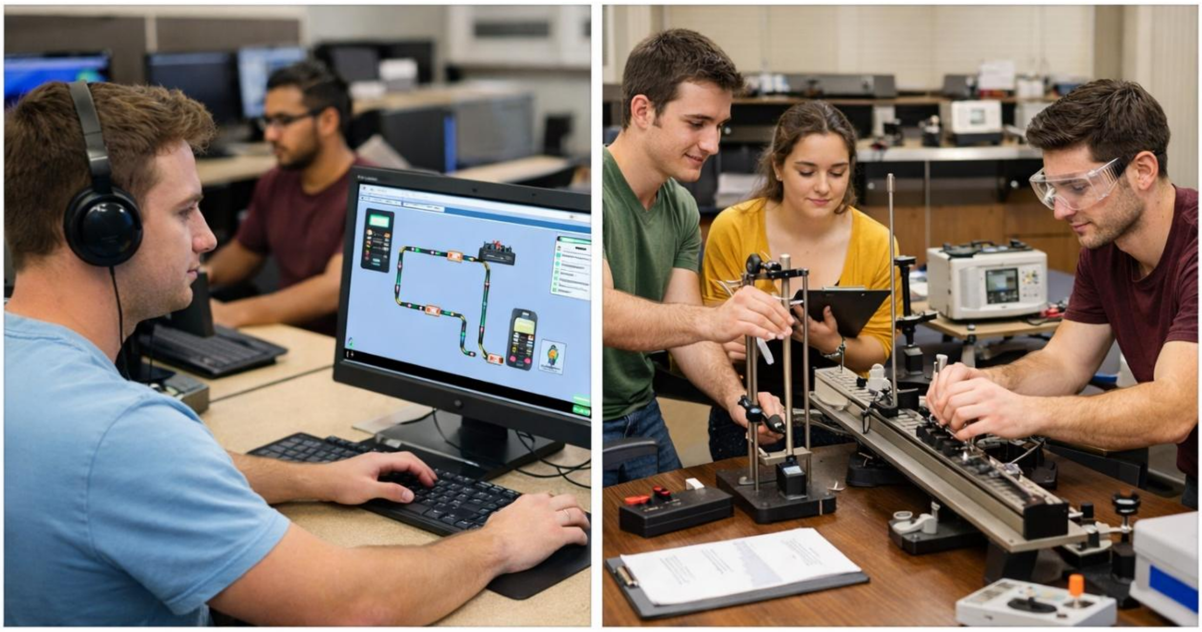

Figure 1. Experimental environments for both groups

The figure shows the contrast between both environments. Virtual labs emphasize interaction, flexibility, and visualization. Traditional labs emphasize hands-on practice and procedural execution.

3.4 Instruments, Validity, and Data Collection

A test was made to measure students' learning outcomes conceptually. The test was composed of multiple choice, reasoning and problem-solving questions. The purpose was to assess the ability of students to interpret physical relationships and use concepts in new contexts. [7].

Physics education expert judges validated the instrument to ensure it meets course objectives. The reliability was confirmed through internal consistency.

the data collection took place in an orderly manner

- An experiment conducted before the intervention.
- 8-week course of instruction.
- Intervention underwent a follow-up post-test.

Check out Table 4.

Table 4. Pre-test and post-test scores

Group	Pre-test Mean	Post-test Mean	Gain
Experimental	45.2	78.6	33.4
Control	46.1	62.3	16.2

3.5 Data Analysis and Ethical Considerations

Statistical analysis of the data was carried out to determine differences between the groups. To measure improvement within each group, paired sample t-tests were used. Post-test results were compared between groups using independent sample t-tests. To ascertain the size of the observed differences, the effect size (Cohen's d) was calculated. Refer to Figure 2. [8]

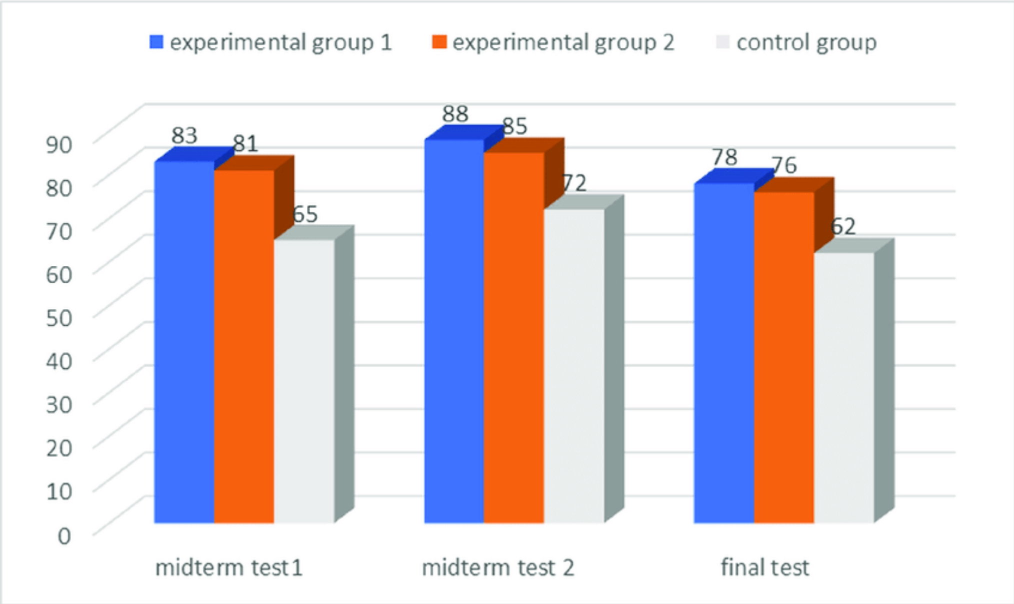

Figure 2. Learning gains between experimental and control groups

The results show that the experimental group had a higher conceptual gain than the control group. This makes virtual laboratories effective in improving physics learning. [9].

The study maintained ethical norms throughout. Participation was not compulsory. The research purpose was explained to the students. Data secrecy was upheld. No participant was harmed nor disadvantaged due to the research.

4. Results and Discussion

This part shows the statistical result of the study and explains the result in relation to the objective of the study. The analysis is sought to find out the effectiveness of the learning outcomes of the experimental group with virtual laboratories compared to the control group with laboratory methods.

4.1 Pre-test Analysis

Prior to the experiment, a pre-test was administered to ascertain that both groups possessed equivalent knowledge. The result shows that there is no significant difference between the experimental and control groups in the beginning concept about physics. Refer to Table 5. [10]

Table 5. Pre-test results for both groups

Group	Mean	Standard Deviation
Experimental	45.2	6.3
Control	46.1	6.7

The close mean scores confirm that both groups started from a similar baseline. This strengthens the internal validity of the study and ensures that any differences observed in the post-test can be attributed to the instructional intervention rather than pre-existing differences.

4.2 Post-test Analysis

After the eight-week intervention, the post-test results showed a clear difference between the two groups. see Table 6

Table 6. Post-test results for both groups

Group	Mean	Standard Deviation
Experimental	78.6	5.4
Control	62.3	6.1

The experimental group achieved significantly higher scores compared to the control group. This indicates that students who used virtual laboratories developed a stronger conceptual understanding of physics concepts. [11]

4.3 Learning Gain Analysis

Learning gain was calculated as the difference between post-test and pre-test scores. see Table 7

Table 7. Learning gains for both groups

Group	Pre-test	Post-test	Gain
Experimental	45.2	78.6	33.4
Control	46.1	62.3	16.2

The experimental group achieved more than double the learning gain compared to the control group. This result demonstrates the effectiveness of virtual laboratories in enhancing conceptual learning. see Figure 3 [12]

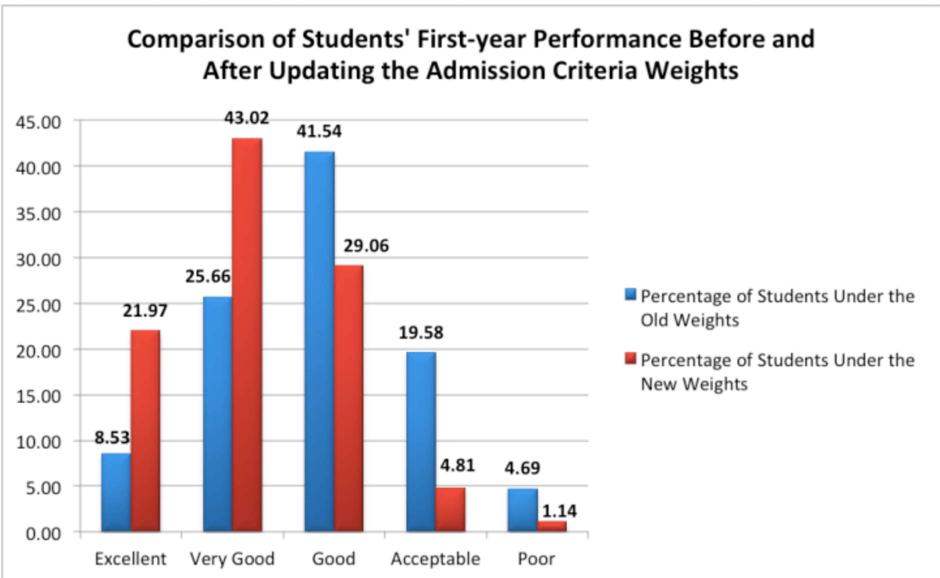

Figure 3. Comparison of learning gains between groups

The figure clearly illustrates the difference in performance, with the experimental group showing a substantially higher improvement.

4.4 Statistical Significance and Effect Size

The following tests were executed to determine if differences were statistically significant. [13].

- According to the independent sample t-test showed a difference between groups in post-test which is significant ($p < 0.05$).
- Both groups did better over time, but the experimental group did better still (more year on year improvement).
- A large effect was evidenced (Cohen's d > 0.8) in the computed effect size. This

means that virtual labs are very effective in learning different kinds of concepts.

These results reveal that the difference in performance is not random, but due to the method of instruction.

4.5 Discussion of Findings

The findings of this study provide evidence that virtual laboratories improve students' understanding of physics concepts significantly. Students who studied in the experimental group achieved better, learned more and were a lot more engaged than those in the regular laboratory group.

Several factors account for this result: [14].

- Visualization of abstract concepts.

It allows the learners to observe dynamic representations of a physical phenomenon in a virtual way. This contributes to the creation of accurate mental models.

- Engaging with Active Variables.

Students have the ability to change parameters and see the results immediately. It facilitates an understanding of cause-and-effect relationships.

- Repeated and flexible

Virtual environments make experimentation unlimited. A student may repeat an experiment in order to gain a more complete understanding of the concept.

- Less burden on brain.

Students take note of the conceptual understanding and not the procedural tasks like handling the equipment.

The results of these findings are in accordance with previous research that simulation-based learning improves students' understanding of concepts. The findings also affirm the perspective of learning as an active process of construction.

The findings, however, show that traditional laboratories also have a complementary role. Virtual labs are good for understanding concepts but old school labs are needed for practical and experimental skills. The most effective facility may come through the blended approach of both methods. [15]

4.6 Implications for Physics Education

In conclusion, the study results show several implications.

- Universities must add virtual labs into the physics curriculum.
- Virtual labs can enhance and fortify conventional tinkering.
- Teachers should design activities that maximize student engagement with the Simulations.
- Educational institutions can reduce costs through the use of virtual environments.

5. Conclusion and Future Work

5.1 Conclusion

The study was conducted to see the effectiveness of virtual laboratories on university student's physics concepts through the experimental design. The results show a clear distinction between students using virtual laboratory environments and students taught by face-to-face laboratory teaching.

Students from the experimental group scored higher on the posttest and gained more. The results analyzed statistically showed that these differences were significant and not by chance. A large effect size shows that the impact of virtual laboratories is also substantial in practical terms.

Several factors can explain improvement in conceptual understanding. Virtual labs allow the visualization of phenomena that are difficult to show otherwise. Students can view how variables are related in real time. It helps to form correct mental models. Having the freedom to change the variables and redo the experiment without any restrictions will allow a fresh look at the concepts involved. Rather than rigid procedures students participate actively.

One more advantage is it decreases cognitive load. Students aim to understand, not to operate an apparatus or complex procedure. Better solutions will learn efficiently. The levels of motivation additionally increase in virtual environments. Students use simulations flexibly and at their own pace. This enhances communication and stability.

Nonetheless, conventional laboratories are very important. They develop practical skills such as measurement instrumentation and experimental design. Using virtual labs should not be the sole reliance on original labs. Instead, they should complement them for better learning.

As per the overall findings of the study, it confirms the fact that virtual laboratory helps in the development of better conceptual understanding behind the university learning physics. By implementing this into practice, the quality of teaching will improve.

5.2 Future Work

The research can be extended in many ways.

- Evaluate the efficaciousness of the virtual laboratories in retaining physics.
- How the use of virtual labs affects the learning experience of first-year and advanced students?
- Learn about the 100% traditional, 100% flexible, and mixed teaching models.
- Research into online labs for acquiring practical skills.
- Explore how instructor guidance can augment the useful nature of simulations.

Future studies may investigate more advanced technologies. To begin with, virtual reality and augmented reality spaces. They assist you in learning in more depth.

A curriculum will be created in the future. Research investigates how to effectively integrate virtual laboratories in physics teaching. Put simply, to know when to do what and how to do this.

Future research must consider the educational context for meaningful outcomes. By examining the effect of virtual laboratories, one can assess quality education access in low-resource settings. Establishment without lab infrastructure will gain maximum.

References:

N. Rauta, W. Hamidona, A. Vermab, and R. Vaidyac, "Enhancing chemical engineering education: The role of virtual labs in bridging theory and practice," Jurnal Kejuruteraan, vol. 38, no. 1, pp. 25–33, 2026.

H. B. Bewota, B. Lemma, A. Wasyhun, and A. Bezabih, "Perceptions and challenges in digital chemistry instruction: Student and instructor experiences with virtual laboratories," Eurasia Journal of Mathematics, Science and Technology Education, vol. 22, no. 1, p. em2756, 2026.

A. Ngiruwonsanga, P. Nkundabakura, T. Nsengimana, and E. Mwumvaneza, "Teachers' perception and acceptance of virtual laboratory integration in mathematics teaching in Rwandan secondary schools using the technology acceptance model," Discover Education, 2026.

T. E. Nkanyani, "Virtual laboratories in chemistry education: A systematic review of primary and secondary schools," International Journal of Educational Sciences, vol. 52, no. 2, pp. 68–85, 2026.

M. A. Valiente Bermejo, T. Raza, P. Li, C. Larsson, Z. D. Mortensen, and D. Sjölie, "Virtual reality laboratories for welding education," Welding in the World, pp. 1–8, 2026.

R. A. H. S. A. Hassan, "Employing mixed reality to develop creative thinking skills among graduate physics students," *Indian Journal of Information Sources and Services*, vol. 16, no. 1, pp. 775–783, 2026.

A. Halder and S. Banerjee, "Bridging the gap between virtual and physical laboratories: A web-based interactive platform for undergraduate physics practicals," Physics Education, vol. 61, no. 1, p. 015044, 2026.

A. Saputra, R. Fandi, S. Nurohman, I. F. Natadiwijaya, I. Wilujeng, A. Widowati, and H. Damayanti, "Integration of PjBL-STEM and virtual laboratory as a strategy to enhance 21st century scientific literacy in junior high school science learning," IJIS Edu: Indonesian Journal of Integrated Science Education, vol. 8, no. 1, 2026.

F. A. Phang, V. K. Ojomoh, and N. D. Nawi, "The effect of the virtual laboratory method on the conceptual understanding of thermal physics among undergraduates," International Journal of Advanced Research in Future Ready Learning and Education, vol. 34, no. 1, pp. 124–130, 2024.

I. Fitriah and S. F. Zawanis, "The effectiveness of virtual laboratory media in physics education: A meta-analysis on students' conceptual understanding and higher-order thinking skills," ISEJ: Indonesian Science Education Journal, vol. 5, no. 2, pp. 65–74, 2024.

D. A. Meronda, H. R. Widarti, and Y. Yahmin, "Virtual laboratories in science education: A systematic review of effectiveness on conceptual understanding and learning outcomes," Jurnal Pendidikan MIPA, vol. 26, no. 3, pp. 2020–2042, 2025.

M. K. Algorashi, "The effectiveness of virtual laboratories for teaching physics experiments in a Saudi secondary school," Ph.D. dissertation, Univ. of Exeter, Exeter, U.K., 2024.

A. M. Alsharif, "Effect of using virtual lab simulations on student's learning in online general physics courses," International Journal of Education, vol. 14, no. 3, p. 89, 2022.

R. A. Hussein and S. A. Hassan, "Designing an AI-driven smart learning environment for personalised instruction," *Educational Sciences: Theory and Practice*, vol. 25, no. 1, pp. 117–130, 2025.

A. Sapriati, A. D. J. Suhandoko, A. Yundayani, R. A. Karim, U. Kusmawan, A. H. Mohd Adnan, and A. A. Suhandoko, "The effect of virtual laboratories on improving students' SRL: An umbrella systematic review," Education Sciences, vol. 13, no. 3, p. 222, 2023