Analysis of the integration of the hot-lab method in resistor practical work using incandescent lamps on the topic of conductor resistance with PhET virtual lab

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Abstract
In the digital era, students still face difficulties in understanding abstract physics concepts such as Ohm's Law and resistance, primarily due to conventional, teacher-centered instructional methods. This study aims to investigate the integration of the Higher-Order Thinking Laboratory (HOT-Lab) method with PhET virtual simulations to improve students' higher-order thinking skills (HOTS) in learning about conductor resistance. Using an experimental method, students conducted virtual practicum activities via the PhET Interactive Simulations platform, specifically utilizing the "DC Circuit Construction Kit." The learning process followed structured HOT-Lab phases: identifying problems, hypothesis formulation, experimentation, data analysis, and result communication. Results showed a strong linear correlation (R^2 = 0.9999) between voltage and electric current, indicating that incandescent lamps can function as resistors under certain conditions, consistent with Ohm's Law. Regression analysis further validated this with a model $I = 0.0554V + 0.0021$, and students demonstrated improved conceptual understanding and analytical reasoning. The integration of HOT-Lab with virtual labs is applicable in remote or resource-limited learning environments, promoting active, reflective, and student-centered learning aligned with 21st-century skills.

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1. Introduction

In the current digital era, technology has become an integral part of our daily lives (Egard & Hansson, 2023). From the use of smartphones to household appliances, all leverage the principles of electronics, including the concept of resistance(Prabhu & Urban, 2020). Resistance plays a crucial role in designing more efficient energy solutions, such as in the development of electric cars, which rely on this technology to enhance efficiency and reduce carbon emissions(Yadlapalli et al., 2022).

In physics, resistance refers to the degree of difficulty for electric current to flow through a circuit. This concept is based on Ohm's Law, formulated by the German physicist Georg Simon Ohm in 1827. Ohm's Law states that the electric current (I) flowing through a conductor is directly proportional to the voltage (V) applied across it, and inversely proportional to the resistance (R) of the conductor. Mathematically, it is expressed as:

In physics, resistance refers to the extent to which a material opposes the flow of electric current in a circuit. This concept is based on Ohm's Law, formulated by the German physicist Georg Simon Ohm in 1827. Understanding Ohm's Law provides the crucial theoretical foundation for explaining how electric current depends on the type of conductive material and the applied voltage (Ahmad et al., 2021). This knowledge is also essential for improving public technological literacy (Wetzel et al., 2019), as it enables individuals to make better decisions regarding the efficiency and safety of electronic device usage (Kemp et al., 2019). In the context of engineering, the concept of resistance is fundamental in designing and optimizing electronic systems, from simple devices to complex industrial infrastructures (Nabizadeh Rafsanjani & Nabizadeh, 2023).

Several studies on physics learning, particularly in electricity topics such as Ohm's Law, show that instruction still often relies on conventional methods that do not adequately incorporate higher-order thinking skills (HOTS) (Yusuf & Widyaningsih, 2022). HOTS are crucial in supporting students' academic and professional success, especially in the era of technological and informational disruption (Anwar et al., 2024). According to research by Alanazi et al. (2024), learning in the face of such disruption must be student-centered, active,

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reflective, and problem-based. Moreover, the teacher's role should be emphasized as that of a facilitator who provides guidance and gradual support, rather than merely a transmitter of information. This approach aims to cultivate students who can think critically, work independently, and compete in the 21st century.

However, a recurring issue is that many students struggle to apply the concepts of Ohm's Law and to solve problems requiring analytical and logical reasoning, mainly because instruction is often delivered conventionally through lectures and formula memorization (Kim & Ha, 2024). Therefore, it is necessary to design learning strategies that activate students' roles as problem-solvers and small-scale researchers, rather than merely passive recipients of information.

Previous research has proposed solutions such as using active and meaningful learning approaches like guided inquiry. This approach is suitable for students unfamiliar with scientific methods because it provides direct, exploratory experiences of Ohm's Law and electrical circuits (Molla, 2022). For students already accustomed to scientific methods, inquiry-based approaches supported by scaffolding, reflection, and contextual learning resources help them understand, connect, and apply Ohm's Law accurately in solving complex problems (Riantoni et al., 2024). Similarly, the Discovery Learning approach has been recognized as effective in improving conceptual understanding of Ohm's Law by assigning students an active role in discovering concepts through critical thinking and independent exploration (Taurusi et al., 2024).

Many students, however, struggle to understand abstract topics like Ohm's Law, making it necessary to use visual aids that explain the relationships among voltage, current, and resistance (Buhera et al., 2025). In addition to using instructional methods, practicum activities are an effective way to strengthen students' understanding of concepts (Shana & Abulibdeh, 2020). Through practicum activities, students can directly test the concepts they have studied (Hartikainen et al., 2019). Practicum work is essential for building both conceptual understanding and student experience (Al-Masarweh, 2021).

Given the urgency of 21st-century skills, education must transform from rote memorization approaches into those focused on conceptual understanding. In physics learning, conceptual understanding is especially important because it enables learners to apply physical principles to solve real-life problems (Wahyuni et al., 2024). Compared to guided inquiry, discovery learning, or flipped classroom approaches, the HOT-Lab (Higher Order Thinking Laboratory) method is specifically designed to train students through structured problem-solving stages, from identifying problems to communicating results, making it highly suitable for enhancing HOTS. The HOT-Lab method offers a relevant solution because it emphasizes applying concepts through higher-order thinking skills (Ubaidillah et al., 2022).

The HOT-Lab approach has been shown to improve students' critical thinking, creativity, and communication skills (Malik et al., 2019). Both physical and virtual laboratories play crucial roles in science education by allowing students to interact directly with the objects they are studying (Shambare & Jita, 2025). The success of learning also depends on teachers' abilities to continually learn and adapt to technological developments (Jena & Barad, 2024). Information and Communication Technology (ICT) offers various innovations that can transform educational systems (Ambarwati et al., 2022).

According to Malik & Setiawan (2015), there are eight stages in HOT-Lab: identifying opportunities, gathering information, formulating problems, generating ideas, developing solutions, testing hypotheses, conducting laboratory activities, and evaluating and communicating results.

However, practicum activities are often constrained by limited laboratory equipment. Therefore, teachers need to develop skills in designing virtual laboratory-based learning. Digital laboratories enable students to understand concepts through digital experiments and develop scientific process skills and higher-order thinking (Udie et al., 2023). These laboratories are more accessible and require less preparation compared to physical practicums (Kapici et al., 2020; Reyes et al., 2024), although they still have limitations in developing students' psychomotor skills (Udin et al., 2020).

One widely used virtual laboratory is PhET Interactive Simulations from the University of Colorado, which allows dynamic and interactive simulations of physics concepts (Behcet Celik, 2022). PhET provides a solution to the lack of practicum equipment by offering safe and engaging virtual exploration, helping students build mental models of physics concepts (Saudelli et al., 2021). Nonetheless, (Ipsita et al., 2025) notes that virtual laboratories have weaknesses, such as limited psychomotor aspects, reliance on student autonomy, available infrastructure, and the risk of confusion if students do not understand how to use them.

For example, Sengul (2023) successfully applied the 5E instructional model with PhET simulations; however, the primary focus was on inquiry-based learning rather than systematically enhancing higher-order thinking skills as emphasized in the HOT-Lab method. Shedrack et al. (2024) merely compared the effectiveness of virtual laboratories with conventional hands-on labs in the context of Ohm's Law, without examining the structured learning stages aimed at developing a complete scientific process. Similarly, Canet et al. (2024) tilized a flipped classroom approach to address misconceptions, yet did not adapt the HOT-Lab experimental framework into the digital simulation environment. Similarly, Daniel & Juma (2023) and Daniel et al. (2024) explored students' perceptions of simulations, but did not address the instructional design aspects of experimental learning based on the structured stages of the HOT-Lab model.

The HOT-Lab method is fundamentally designed to enhance experiment-based learning through three systematic stages: Pre-Lab (concept exploration and prediction), Lab (observation and data collection), and Post-Lab (result analysis and concept reflection). However, this structured approach has not yet been widely adopted in virtual learning environments, despite the fact that simulations such as PhET offer considerable potential to support the full implementation of the HOT-Lab process in a digital context. While numerous studies have examined the use of PhET simulations in teaching Ohm's Law, few have specifically investigated the integration of the HOT-Lab model into virtual environments particularly in addressing the concept of conductor resistance. Therefore, this study seeks to analyze how the HOT-Lab method can be effectively integrated into virtual practicum activities using PhET on the topic of conductor resistance, with the aim of enhancing students' higher-order thinking skills.

2. Method

The research method used is an experimental approach with the HOT-Lab model. Figure 1 shows the flow of the HOT-Lab method consisting of three systematic sessions.

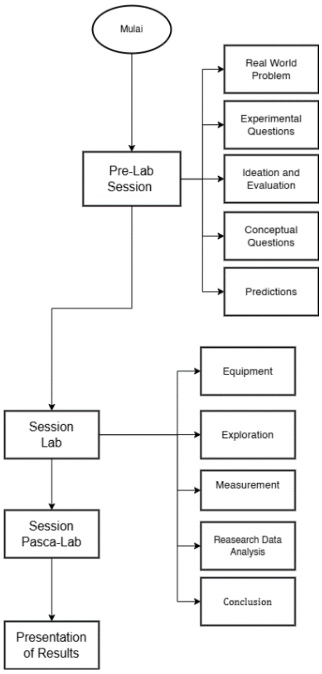

Figure 1. Research Flowchart HOT-Lab Method

Data collection was conducted virtually through practical activities in a virtual laboratory, using the Construction DC Kit simulation on PhET Interactive Simulation. The differences in functionality between resistors and incandescent lamps in a series circuit were examined by varying the voltage in each experiment. Here, DC voltage serves as the independent variable, total resistance serves as the control variable, and electric current serves as the dependent variable.

The equipment used includes Virtual Lab PHET and a Laptop. Following the HOT-Lab systematic approach, this research involves the following steps:

2.1. Pre-Lab Session

Real World Problem: When the switch is turned on, the incandescent light bulb in the house lights up too brightly and dazzles. Unfortunately, there are no tools or electronic components such as a dimmer or variable resistor available to adjust the light intensity. This has become a problem for the residents who want a softer lighting, especially at night.

Experimental Questions: a. How can an incandescent lamp function as a substitute for a resistor?, b. What factors influence the effectiveness of an incandescent lamp as a resistor substitute?

Ideation and Evaluation: Examining the basic theory of electrical resistance in resistors and incandescent lamps. Making initial predictions about how an incandescent lamp can function as a resistor.

Conceptual Questions: Understanding the concept of electrical resistance and comparing the resistive properties of incandescent lamps with resistors.

Predictions: Predicting that an incandescent lamp can replace a resistor under certain conditions but may not be stable for long-term use due to temperature effects.

2.2. Session Lab

Equipment: Using the PHET Virtual Lab. Figure 2 shows the electrical simulation circuit with resistors and Figure 3 shows the circuit where the resistor is replaced with a light bulb.

Exploration: Comparing the use of two resistors with one resistor and one incandescent lamp in a series circuit. Voltage variations include 9V, 12V, 15V, 18V, 21V, 24V, 28V, and 30V to determine if an incandescent lamp can replace a resistor in an electrical circuit.

Measurement: After assembling the series circuit, measurements are taken for each voltage variation to analyze the electric current produced by both circuits.

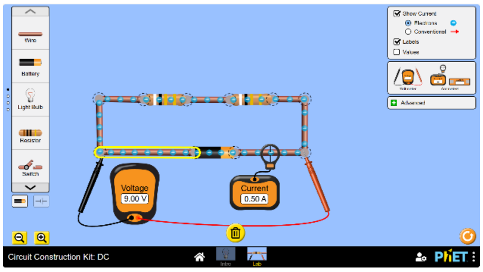

Figure 2. Experimental Circuit Design 1

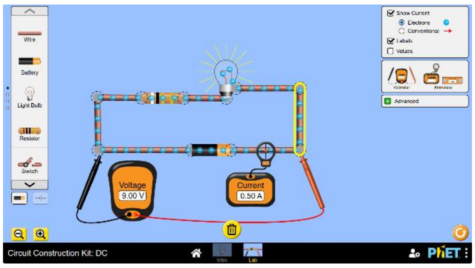

Figure 3. Experimental Circuit Design 2

The research data is analyzed using regression and correlation tests. According to Sugiyono (2017:260), regression analysis is used to determine whether changes in the dependent variable can be explained by changes in the independent variable. The main objective of regression analysis is to determine the relationship between the independent and dependent variables, and how this relationship leads to increases or decreases. In other words, regression analysis allows us to examine whether changes in electric current strength are influenced by voltage magnitude (Indrawan & Kaniawati Dewi, 2020). From this analysis, we can determine whether an incandescent lamp can replace a resistor in a series circuit based on the electric current generated.

Conclusion: Based on the analysis results, conclusions are drawn regarding whether an incandescent lamp can be used as a substitute for a resistor and the factors influencing its long-term use.

2.3. Session Pasca-Lab

After conducting the experiment, proceed with creating a scientific journal containing the research findings. The journal will document all stages of the research from Pre-Lab, Lab, to Post-Lab.

3. Results and Discussion

This research conducted two sets of experiments using two resistors and a combination of one resistor and one incandescent lamp, each with a resistance of 9 Ω in a series circuit. The measurements of Total Resistance (Rt), Voltage (V), and Electric Current (I) are summarized in the following Table 1 and Table 2.

Table 1. Results from 2 Resistors

No	Rt (Ω)	Voltage (V)	Strong Current (A)
1		$(90.000 \pm 50.000) \times 10^{-4}$	$(5.00 \pm 0.50) \times 10^{1}$
2		$(12.000 \pm 5.0000) \times 10^{-3}$	$(6.700 \pm 0.050) \times 10^{4}$
3	$(18.00 \pm 0.100) \times 10^{-2}$	$(15.000 \pm 5.0000) \times 10^{-3}$	$(8.300 \pm 0.050) \times 10^{4}$
4		$(18.000 \pm 5.0000) \times 10^{-3}$	$(10.00 \pm 0.050) \times 10^{1}$
5		$(2.1000 \pm 0.5000) \times 10^{-2}$	$(11.70 \pm 0.050) \times 10^{1}$
6		$(2.4000 \pm 0.5000) \times 10^{-2}$	$(13.30 \pm 0.050) \times 10^{1}$

Table 2. Results from 1 Resistors and 1 Incandescent Lamp

No	Rt (Ω)	Voltage (V)	Strong Current (A)
1		$(90.000 \pm 50.000) \times 10^{-4}$	$(5.00 \pm 0.50) \times 10^{1}$
2		$(12.000 \pm 5.0000) \times 10^{-3}$	$(6.700 \pm 0.050) \times 10^{4}$
3		$(15.000 \pm 5.0000) \times 10^{-3}$	$(8.300 \pm 0.050) \times 10^{4}$
4	$(18.00 \pm 0.100) \times 10^{-2}$	$(18.000 \pm 5.0000) \times 10^{-3}$	$(10.00 \pm 0.050) \times 10^{1}$
5		$(2.1000 \pm 0.5000) \times 10^{-2}$	$(11.70 \pm 0.050) \times 10^{1}$
6		$(2.4000 \pm 0.5000) \times 10^{-2}$	$(13.30 \pm 0.050) \times 10^{1}$

In the first experiment with two resistors totaling $(18.00 \pm 0.100) \times 10^{-2}\ \Omega$ in a series circuit, varying the voltage resulted in different current values. By reviewing the first six sets of data shown in Table 1, when the voltage was $(90.000 \pm 50.000) \times 10^{-4}\ V$, the measured current was $(5.00 \pm 0.50) \times 10^{1}\ A$. In the second experiment, when the voltage was increased to $(12.000 \pm 5.0000) \times 10^{-3}\ V$, the current also increased to $(6.700 \pm 0.050) \times 10^{4}\ A$.

In the second experiment, where one resistor was replaced by an incandescent lamp, the data from the research can be seen in Table 2. In this second experiment, the resistance of the incandescent lamp itself had the same value as the resistor used in the first experiment, which was 9 Ω. Therefore, the resistance values between the resistor and the incandescent lamp are equal. This substitution and the assignment of the same value is intended to review whether the incandescent lamp can function as a substitute for the resistor in an electrical circuit for practical and other purposes. The results from the second experiment yielded the same values as the first experiment, where a voltage of $(90.000 \pm 50.000) \times 10^{-4}\ V$ resulted in a current of $(5.00 \pm 0.50) \times 10^{1}\ A$. As the voltage was increased incrementally up to the sixth experiment with a voltage of $(2.4000 \pm 0.5000) \times 10^{-2}\ V$, the recorded current was $(13.30 \pm 0.050) \times 10^{1}\ A$. These experimental findings indicate that increasing the applied voltage influences the current, causing it to increase proportionally. Reviewing Table 1 and Table 2 shows a consistent relationship between the applied voltage and the resulting current, consistent with Ohm's Law stating that voltage (V) is directly proportional to electric current. The graph of voltage relationship to electric current is shown in Figure 4.

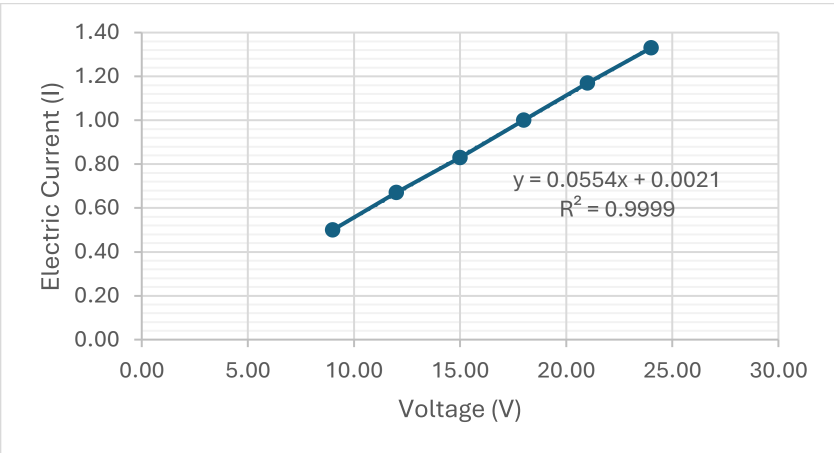

Figure 4. Graph of Voltage Relationship to Electric Current

In Figure 4, which shows the graph of the relationship between voltage and electric current, it explains that as the voltage increases, the electric current produced also increases. In the first experiment, a voltage of $(90.000 \pm 50.000) \times 10^{-4}\ V$ produced a current of $(5.00 \pm 0.50) \times 10^{1}\ A$. In the second experiment, when the voltage was increased to $(12.000 \pm 5.0000) \times 10^{-3}\ V$, the current rose to $(6.700 \pm 0.050) \times 10^{4}\ A$. This trend continued up to the sixth experiment, where at a voltage of $(2.4000 \pm 0.5000) \times 10^{-2}\ V$, the current measured $(13.30 \pm 0.050) \times 10^{1}\ A$. Therefore, increasing the voltage applied to a circuit leads to a corresponding increase in electric current flowing through it.

The correlation analysis yielded an R^2 value of 0.9999, indicating an extremely strong positive linear relationship between voltage and electric current. This suggests that changes in voltage directly lead to changes in electric current with a very strong correlation.

The regression analysis resulted in the equation of the line $y = 0.0554x + 0.0021$, where y represents electric current (I) and x represents voltage (V). The slope of the regression line is 0.0554 A/V, indicating that for every 1V increase in voltage, the electric current increases by approximately 0.0554 A, aligning well with Ohm's Law. The intercept of 0.0021 A represents the residual current when the voltage is 0 V, which is minimal and likely due to experimental error.

The high coefficient of determination (R^2) indicates that the regression model effectively explains the variability of electric current based on voltage. These findings support the validity of the results obtained and are consistent with Ohm's Law.

In this study, we explore the integration of the HOT-Lab method with the PhET virtual laboratory to understand how resistance in conductors can be taught using incandescent lamps as a substitute for resistors and the potential of integrating the HOT-Lab method in virtual labs. The experimental results show that incandescent lamps can indeed replace resistors under certain conditions, although there are significant differences that need to be considered.

3.1. Comparison of Research Results with Ohm's Law Theory

The experimental results are consistent with the fundamental principle of Ohm's Law, where voltage (V) is directly proportional to electric current (I) flowing through a conductor, with resistance (R) determining the magnitude of the current (Popat, 2021). In both sets of experiments conducted—using two resistors in the first set and a combination of one resistor with one incandescent lamp in the second set—the data obtained from the virtual lab experiment indicate a strong linear relationship between voltage and electric current. This is reflected in the high coefficient of determination ($R^2 = 0.9999$), demonstrating that the regression model effectively explains the variability of electric current based on voltage.

During data collection and processing, it was observed that the results obtained from the 12 data points remained consistent and exhibited no variation. This consistency can be attributed to the fixed and controlled operational procedures of the PhET virtual lab, which eliminates most experimental errors typically present in real laboratory settings (Daniel & Juma, 2023). This idealized condition offers an opportunity to shift students' focus from routine procedural tasks to deeper conceptual analysis and critical reasoning. Therefore, integrating the HOT-Lab (Higher-Order Thinking Laboratory) method into virtual practicum activities using PhET, particularly on the topic of conductor resistance, holds the potential to enhance students' higher-order thinking skills by engaging them in tasks that require analysis, evaluation, and synthesis rather than mere data collection (Alatas et al., 2023).

3.2. Similarity with Previous Research

The findings of this study are in line with previous studies, which show that virtual simulation and practical learning can significantly improve students' understanding of physics concepts. For example, Yuliati et al. (2018) showed that the application of a scientific approach using PhET simulations can improve students' problem-solving skills. Likewise, Banda & Nzabahimana (2023) found that PhET simulations increased students' motivation and academic achievement in learning physics concepts. Furthermore, Taibu et al. (2021) reported that PhET simulations effectively improved laboratory skills and resulted in very positive student experiences, with 88% of students expressing satisfaction. Then according to Anisa & Astriani (2022) learning with PhET makes it easier for students to understand the concept of resistance in open and closed electrical circuits and helps students distinguish between series and parallel circuits and understand the direction of electric current and electron movement.

3.3. Differences with Previous Research

However, this study also identified some significant differences in using incandescent lamps compared to fixed resistors. Incandescent lamps have variable resistance depending on temperature, whereas fixed resistors have a constant resistance value. Although the study did not find differing data between the first and second experiments, factors influencing resistance, such as temperature, should be considered. Another factor affecting resistance in metals is temperature. When the temperature of the metal increases, the metal atoms vibrate more vigorously, and the transmission electrons collide more intensely with them, resulting in increased metal resistance (Sari & Kirindi, 2019).

Therefore, the use of incandescent lamps might be unstable for long-term use under varying operating conditions. The resistance of incandescent lamps changes with temperature. When the lamp is cold, its resistance value is low, and when the lamp is hot, its resistance increases. This variation requires students to have an additional understanding of how temperature affects resistance and how this can impact experimental results.

3.4. The Role of the HOT-Lab Method in Enhancing Learning

The integration of the Higher-Order Thinking Laboratory (HOT-Lab) method into virtual practicum activities using PhET simulations on the topic of Ohm's Law has strong potential to enhance students' Higher-Order Thinking Skills (HOTS). This aligns with the demands of 21st-century education, which emphasizes the mastery of essential skills such as critical thinking, creativity, communication, and collaboration core competencies required in today's and future workplaces (Parmini et al., 2023; Rodríguez-Nieto et al., 2024)

A review of the HOT-Lab method and its outcomes suggests that it fosters reflective and logical thinking through systematic phases including observation, problem formulation, hypothesis development, data collection, analysis, and conclusion. These structured stages not only support the development of scientific process skills but also reinforce students' conceptual understanding of physical phenomena, such as Ohm's Law and the relationships among resistance, electric current, and voltage in a conductor (Indrasari et al., 2022).

Moreover, the HOT-Lab method can be effectively integrated with various active learning approaches, including challenge-based learning, problem-based learning, experiential learning, and gamification (Almazroui, 2023). This integration enhances the virtual learning experience by offering authentic challenges, contextual case studies, and formative feedback, all of which encourage active student participation (Santosa, 2024). Such elements are crucial in digital or remote learning environments that require instructional designs to be not only informative but also transformative.

Therefore, the HOT-Lab method, when embedded within virtual practicum platforms such as PhET, offers a promising instructional strategy for developing higher-order thinking. It not only addresses pedagogical challenges in remote education but also serves as a transformative learning model that equips students with critical, conceptual, and innovative thinking abilities aligned with 21st-century educational goals.

3.5. Benefits and Challenges in Implementing the HOT-Lab Method in Virtual Laboratories

The primary advantage of integrating the HOT-Lab method with the PhET virtual laboratory is the ease of access and reduced preparation compared to physical laboratories (Deriba et al., 2024). Moreover, using the PhET virtual lab facilitates the learning process by providing easily accessible and efficient tools for conducting experiments (Habibi et al., 2020). This allows students to perform experiments safely and efficiently without the risk of accidents. The PhET simulation media emphasizes the relationship between real-life phenomena and the underlying science, supports an interactive and constructivist approach, provides feedback, and offers a creative workspace (Haryadi & Pujiastuti, 2020).

By using the PhET virtual lab, students can develop their critical thinking skills and build deep learning experiences (Reeves & Crippen, 2021). PhET allows students to explore and manipulate all relevant variables without the fear of damaging laboratory facilities (Verawati et al., 2024). Thus, students can formulate initial hypotheses based on the practical results they conduct.

The development of virtual laboratories is important as their use has been proven to enhance students' understanding (White et al., 2019), improve their thinking abilities (Hess, 2014; Widowati et al., 2017), increase scientific literacy (Putri et al., 2021), and enhance students' thinking skills, scientific skills, attitudes (Damayanti et al., 2025) and critical thinking (Achuthan et al., 2020). Additionally, the use of virtual labs can enhance students' research and analytical skills due to the meaningful learning processes that occur in a virtual learning environment (Chen & Hsu, 2020). This statement is consistent with research conducted by Wästberg et al. (2019) on pre-service teachers in a virtual biology laboratory.

4. Conclusion

Our research demonstrates the effectiveness of the HOT-Lab model, which comprises Pre-Lab, Lab, and Post-Lab sessions, in enhancing students' understanding of resistance and the practical application of Ohm's Law. The use of PhET simulations provides an interactive and engaging platform for students to explore theoretical concepts through virtual experiments.

The advantages of our approach include a systematic and structured learning process facilitated by the HOT-Lab model, which encourages active learning and critical thinking. PhET simulations offer a cost-effective and accessible way for students to visualize and interact with physical phenomena, making complex concepts more comprehensible. Additionally, combining traditional laboratory equipment with virtual simulations bridges the gap between theoretical knowledge and practical application.

However, there are also some drawbacks to our method. The reliance on technology and virtual simulations may pose challenges for institutions with limited access to computers or the internet. Furthermore, the accuracy of virtual simulations may not always fully replicate real-world conditions, potentially leading to discrepancies in experimental results.

Future plans include expanding the scope of our research to integrate more complex electrical circuits and components, as well as exploring the integration of other interactive simulation tools. Further studies could also focus on assessing the long-term impact of the HOT-Lab model on students' understanding and retention of physics concepts. We aim to refine and enhance our approach to provide a more comprehensive and effective learning experience for students in the field of physics.

Author Contributions

Diah Mulhayatiah contributed to conceptualization, investigation, supervision, validation, and writing – review & editing. Muhammad Ziddan Rachman was responsible for data curation, formal analysis, writing – original draft, investigation, and visualization. Adam Malik contributed to methodology and supervision. Rena Denya Agustina provided resources, project administration, and assisted in writing – review & editing. Muhammad Minan Chusni contributed to software development, validation, and visualization. Endah Kurnia Yuningsih was involved in investigation and data curation. All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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