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Student Activities and Perceptions of Web-Based Virtual Laboratory: Insight From Physics Learning

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ABSTRACT

Purpose-The implementation of web-based virtual laboratories in physics education has significant potential to enhance students' scientific process skills and conceptual understanding of physics. The objectives of this study are: (1) to analyze the impact of implementing an interactive web-based virtual laboratory in activitiy physics learning, and (2) to describe students' perceptions of the use of this virtual laboratory.

Methodology-The research design follows a pre-experimental method with a one-shot case study approach. The population consisted of all twelfth-grade students, distributed across four classes with consisting of 24 students for the samples. Observations of students' scientific process skills were conducted to assess the intervention's impact. A questionnaire was administered after the learning session to measure students' SPS activities before and after the intervention.

Findings—The results of the observational data analysis on scientific process skills revealed an average activity percentage of 90.3%, indicating that the interactive web-based virtual laboratory is highly effective in supporting virtual practical-based learning. Additionally, the analysis of students' perceptions showed an average perception score of 86.42%, categorized as "very good."

Significance– These findings suggest that virtual laboratories can serve as an innovative solution in physics education. However, improvements in operational aspects are still necessary to overcome existing challenges.

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INTRODUCTION

The development of information and communication technology has significantly impacted various aspects of human life, including education. In Indonesia, integrating technology into education remains a major focus, particularly in efforts to enhance the quality of learning and address existing challenges. One notable initiative is the implementation of the Merdeka Curriculum, which emphasizes student-centered learning, the development of critical thinking skills, and the application of problem-solving strategies relevant to real-world contexts(Kemdikbud), 2022). This curriculum offers educators substantial opportunities to innovate teaching methods, especially in science subjects such as physics.

Physics is a branch of science that presents unique challenges in its teaching. Ideally, physics education requires practical approaches through experiments and laboratory practices to enable students to comprehend concepts effectively and thoroughly (Setiawan et al., 2023). Laboratories are essential learning facilities that enhance the educational process by developing students' skills. However, in practice, many schools both public and private face significant limitations in laboratory facilities (Manikowati & Iskandar, 2018). These limitations often compel teachers to rely on theoretical teaching methods, which are less effective in developing students' scientific process skills.

Observations conducted in high schools in Lhokseumawe revealed that several schools face challenges related to limited physics laboratory facilities. This situation affects the quality of education, often resulting in monotonous learning processes that focus solely on theory without adequate experimental support. Consequently, the development of scientific process skills (SPS) critical for fostering students' critical thinking, problem-solving abilities, and understanding of natural phenomena through scientific approaches is hindered (Kusumayuni et al., 2023). In addition to limited facilities, another challenge is students' low motivation to learn physics, as many perceive it as a difficult subject with little relevance to everyday life.

Scientific process skills involve a series of cognitive and procedural abilities that help students understand physics concepts. These skills not only enable students to gain a deeper understanding of physics but also prepare them to face real-world challenges requiring scientific thinking abilities (Yusuf & Widyaningsih, 2018). However, implementing SPS in schools is often obstructed by theoretical teaching approaches and the lack of experimental practice due to inadequate laboratory facilities.

The lack of physics laboratory facilities further contributes to students' inability to comprehend scientific concepts holistically. Scientific process skills including observation, hypothesis formulation, experimentation, data analysis, and conclusion drawing are difficult to develop without adequate support from laboratory facilities (Bybee & Ed., 2002). Additionally, monotonous teaching methods that fail to engage students in the learning process can reduce their interest in physics, ultimately affecting their academic performance (Yulianti et al., 2012).

Virtual laboratories have emerged as an innovative solution to address the limitations of traditional laboratory facilities in schools. These platforms simulate real-world experiments in a digital environment, allowing students to interact with variables, observe outcomes, and engage in inquiry-based learning. Virtual laboratories provide broader access to experimental resources without requiring expensive or complex physical facilities. Moreover, they can enhance students' motivation, deepen conceptual understanding, and develop their scientific process skills through interactive and flexible learning experiences (Rina Mirdayanti & Murni, 2017).

Virtual laboratories enable students to conduct experiments in a controlled, digital environment. This technology offers opportunities for students to explore physics concepts interactively and to develop scientific process skills without the need for costly physical equipment or limited access. Using virtual laboratories, students can manipulate variables, observe results, and repeat experiments as needed to achieve a better understanding of the material (Jong et al., 2013).

Several studies indicate that using virtual laboratories can improve students' understanding of physics concepts, as well as their motivation and engagement in learning. Research by (Zacharia & Olympiou, 2011) found that students using virtual laboratories demonstrated better conceptual understanding compared to those in traditional laboratory settings. Studies by (Swandi & Amin, 2016); (Abdjul et al., 2019) reported that virtual laboratories enhance students' motivation, observational skills, hypothesis formulation, and data analysis abilities. A comprehensive review by (Potkonjak et al., 2016) highlights the significant potential of virtual laboratories to bridge resource gaps in schools with limited facilities. Additionally, (Gunawan et al., 2015) described the integration of virtual laboratories in physics education as a transformational approach, offering accessible, interactive, and resource-efficient solutions. Virtual laboratories hold substantial promise and contribute significantly to physics education by improving students' process skills and engagement in learning activities.

While the concept of virtual laboratories is not new, their application in physics education represents an innovative approach that has not been widely explored. Further research is needed to focus on the implementation of web-based virtual laboratories, exploring their impact on physics learning and addressing the limitations of traditional laboratory facilities. This research also aims to holistically analyze the effectiveness of virtual laboratories in enhancing students' activity levels and scientific process skills, as well as examine students' perceptions of the technology.

Web-based virtual laboratories are expected to address existing challenges by providing easy access anytime and anywhere. Exploring this technology is anticipated to make a significant contribution to the body of knowledge on digital innovation in education, offering practical recommendations for educators, policymakers, and researchers. This highlights the importance of leveraging technology to bridge educational gaps and empower students with the skills needed for the future.

METHODOLOGY

Research Design

This study employs a Pre-Experimental Design with a mixed-methods approach. The Pre-Experimental Design is utilized to assess the effectiveness of an intervention in the experimental class, providing an initial understanding of its impact. The mixed-methods approach combines quantitative and qualitative methods to offer a more comprehensive understanding of the effects of web-based virtual laboratories in physics learning. Quantitative analysis is used to measure the effectiveness of the intervention, while qualitative analysis examines the broader impacts of the treatment. The One-Shot Case Study design was applied, in which one group undergoes an intervention involving the implementation of an interactive web-based virtual laboratory.

Data Collection Techniques

Observations of students' scientific process skills (SPS) were conducted by observers during the learning process to assess the intervention's impact. A questionnaire was administered after the learning session to measure students' SPS activities before and after the intervention (Zulimah et al., 2018). Additionally, interviews with students and teachers were conducted to complement the observational and questionnaire data. The dependent variables in this study are students' scientific process skills and perceptions during the learning process, while the independent variable is the implementation of the interactive web-based virtual laboratory.

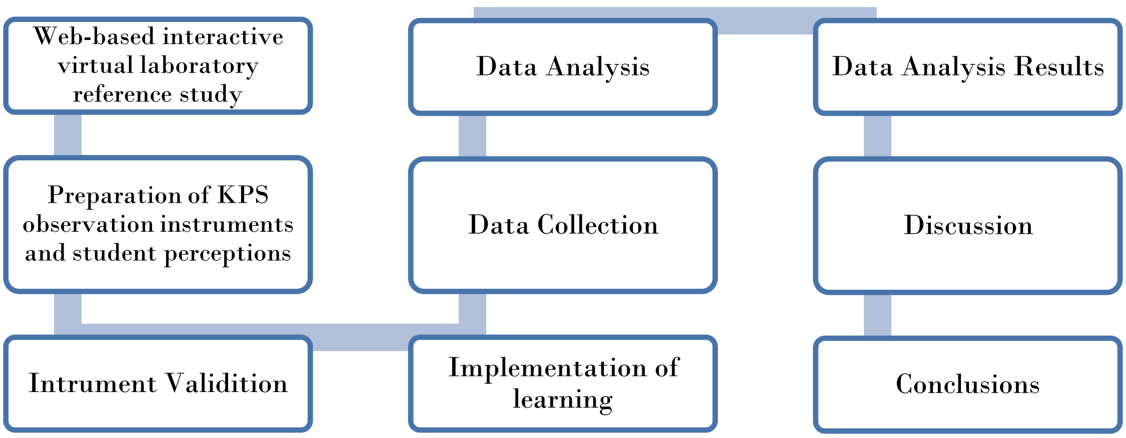

Figure 1. Research flowchart

The research was conducted at SMA Negeri 5 Lhokseumawe, Lhokseumawe City, in May 2024. The population consisted of all twelfth-grade students, distributed across four classes: XII.1, XII.2, XII.3, and XII.4. The sample was selected using a cluster random sampling technique, which involved randomizing class groups to ensure the sample represents the population. Class XII.2, consisting of 24 students, was chosen as the research sample (Sugiyono, 2016).

The parameters measured to evaluate the implementation of the interactive web-based virtual laboratory in physics learning include the mean score of SPS observations, interviews, field notes, and the average score of students’ perception questionnaires. SPS observations were conducted during the learning process to document students’ learning activities, interactions with the virtual laboratory, and their use of SPS to complete experimental tasks. The perception questionnaire included questions about students’ interest, satisfaction, and intrinsic motivation regarding the use of the web-based virtual laboratory during the learning process.

The research instruments included an SPS observation sheet used during the learning process and a student perception questionnaire administered at the end of the learning session. These instruments underwent expert validation, with the results analyzed for validity using Aiken's V equation and reliability using Cronbach’s Alpha equation. The implementation of the instruments involved scoring responses based on the following criteria:

Table 1. Observation and Questionnaire Scoring Criteria

Category	Positive Statement Score	Negative Statement Score
Strongly Agree	4	1
Agree	3	2
Disagree	2	3
Strongly Disagree	1	4

Source: Riduwan in (Yusuf & Widyaningsih, 2018)

To determine the extent to which the implementation of the interactive web-based virtual laboratory influences students' interaction and SPS activities, as well as to analyze their perceptions of its use in physics learning, data analysis techniques were employed using the implementation level equation, which calculates the percentage values of the research instrument results. Additionally, data reduction was performed by summarizing relevant interview findings and field notes to support the observation data. Percentage values were interpreted descriptively based on the following category scoring guidelines:

Table 2. Scoring Interpretation Guidelines

Percentage (%)	Category
< 54	Very Poor
55 – 69	Poor
70 – 84	Good
85 – 100	Very Good

Source: Riduwan in (Yusuf & Widyaningsih, 2018)

FINDINGS

Observation of Science Process Skills (SPS)

Data on science process skills (SPS) observations were collected by observers during the teaching and learning process. The observation aimed to assess the extent to which the interactive web-based virtual laboratory influenced students' activities and interactions during the learning process. The maximum score for each observation statement was 96, referred to as the expected score. The minimum score for each observation statement was 24, placing the assessment range between 24 and 96. The following table presents the results of the SPS observations:

Table 3. Analysis of SPS Observation Results

No	Statement	Observation Score	Expected Score	Percentage
1	Students follow all instructions carefully and in detail	91	96	94.8%
2	Students answer the teacher’s questions accurately	84	96	87.5%
3	Students actively ask relevant questions	80	96	83.3%

4	Students provide relevant opinions during discussions	85	96	88.5%
5	Students listen attentively to others' opinions	92	96	95.8%
6	Students formulate hypotheses aligned with the experiment goals	82	96	85.4%
7	Students perform measurements and calculations accurately	91	96	94.8%
8	Students observe changes in measuring instruments carefully	89	96	92.7%
9	Students systematically organize observation tables	87	96	90.6%
10	Students collaborate effectively during experiments	93	96	96.9%
11	Students document relationships between voltage, current, and resistance	90	96	93.8%
12	Students draw conclusions based on observations	89	96	92.7%
13	Students present experimental data clearly	86	96	89.6%
14	Students ask relevant questions to peers	78	96	81.2%
15	Students answer peer questions accurately	83	96	86.4%
	Average	86.7	96	90.3%

The table above indicates that the highest scores were achieved in the indicators of collaboration during experiments (96.9%), performing measurements and calculations (94.8%), and listening to peers' opinions during discussions (95.8%). However, the lowest scores were observed in asking relevant questions to peers (81.2%) and actively asking questions to the teacher (83.3%). To facilitate understanding, the results of the SPS observation are presented in the following graph.

The analysis of the collected data demonstrates at Figure 2 that students' science process skills are generally good, with students showing competency in most observed indicators. For the observation aspect, students achieved a high average percentage of 94.4% (categorized as excellent). This is evident from statements such as following instructions carefully (94.8%), listening attentively to peers' opinions (95.8%), and carefully observing changes in measuring instruments (92.7%). These results reflect students' attentiveness to important details during the learning process.

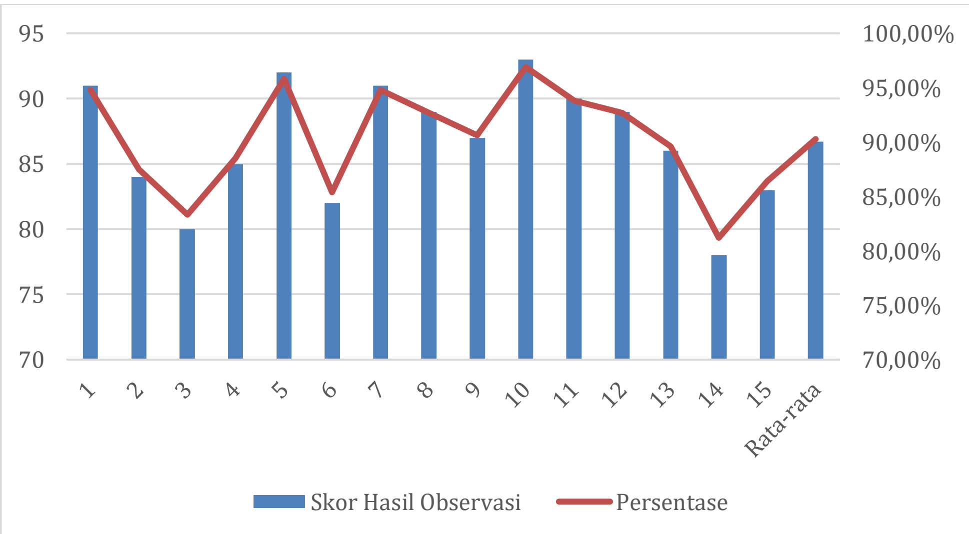

Figure 2. SPS Observation Results Diagram

In terms of hypothesis formulation, students achieved 85.4% (categorized as excellent). Despite this, reinforcement is needed to ensure students consistently formulate hypotheses that are precise and relevant to experimental goals. For the aspect of conducting experiments, students performed excellently, with an average percentage of 95.9%. This is evident in statements about performing measurements and calculations accurately (94.8%) and collaborating effectively during experiments (96.9%). These results indicate that students have developed both meticulous experimental skills and collaborative abilities.

For data collection, students demonstrated very good performance, as shown by statements about systematically organizing observation tables (90.6%) and documenting relationships between voltage, current, and resistance (93.8%), with an average percentage of 92.2%. This reflects their understanding of organizing and recording observational data. Meanwhile, in the aspect of data analysis and conclusion drawing, high percentages were seen in indicators like drawing conclusions based on observations (92.7%) and presenting experimental data clearly (89.6%). This illustrates students' abilities to interpret experimental data, summarize findings, and effectively present their results during class discussions. However, class discussions showed the lowest interaction levels, particularly in indicators like actively asking questions (83.3%) and asking relevant questions to peers (81.2%). Although categorized as excellent, these aspects require improvement to enhance students' interaction and curiosity during class discussions.

Overall, the average percentage of SPS results was 90.3%, indicating that the implementation of the interactive web-based virtual laboratory effectively enhances students' science process skills and engagement in the learning process. These results align with previous studies (Zulimah et al., 2018); (Abdjul et al., 2019); (Swandi & Amin, 2016) that demonstrate the effectiveness of virtual laboratories in promoting student interaction and activity in science learning. However, the observation results highlight the need for further efforts to enhance student interaction with teachers and peers, particularly in asking questions and fostering curiosity during class discussions.

Student Perception Survey

Data on students' perceptions of the implementation of the interactive web-based virtual laboratory were collected using a questionnaire containing 40 items divided into five aspects. The questionnaire was administered after the completion of the learning process to assess students' perceptions of the virtual laboratory's effectiveness in teaching physics. The responses were measured using a Likert scale, with a maximum score of 4 and a minimum score of 1. The following table presents the analysis of the survey results:

Table 4. Analysis of Student Perception of Virtual Laboratory Usage

No	Aspect	Number of Items	Average Percentage (%)	Category
1	Usage of the Virtual Laboratory	21	91.85%	Very Good
2	Ease of Using the Virtual Laboratory	10	92.08%	Very Good
3	Difficulty Using the Virtual Laboratory	4	76.40%	Good
4	Anxiety Using the Virtual Laboratory	3	82.64%	Good
5	Confidence in Using the Virtual Laboratory	2	91.15%	Very Good

Based on the average percentage of each aspect, the use of the virtual laboratory in physics learning showed very positive results. The "Usage of the Virtual Laboratory" aspect scored 91.85%, indicating that students found the medium highly beneficial in understanding Ohm’s Law and electrical circuits. This suggests that the virtual laboratory served as an effective and interactive alternative to physical labs, providing relevant practical experiences. The "Ease of Use" aspect scored 92.08%, demonstrating that the platform was not only accessible but also supportive of students during the entire practical process, from preparation to data analysis. This ease of use enhanced the efficiency of the learning process, reducing operational time and providing a more comfortable learning experience.

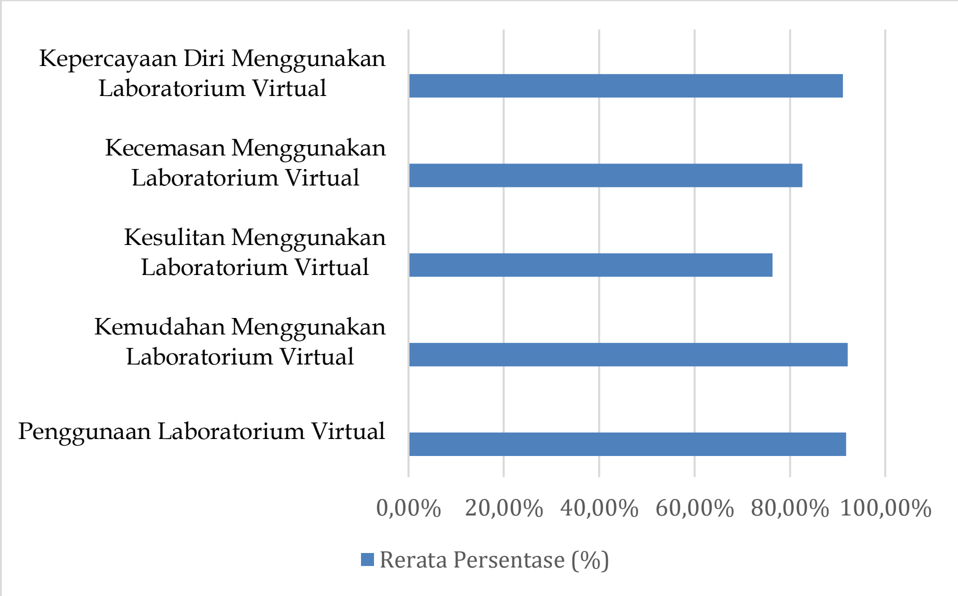

Figure 3. Student Perception Survey Results Diagram

However, the Difficulty Using the Virtual Laboratory aspect received a lower score of 76.40%, indicating some challenges, particularly in identifying and operating virtual laboratory tools. Interviews with students revealed that most difficulties arose due to their lack of prior experience with similar digital media and limited step-by-step guidance. Addressing these challenges through the development of interactive guides or additional training for students could significantly improve usability. The Anxiety aspect scored 82.64%, indicating that the virtual laboratory successfully reduced students' stress during learning. This can be attributed to the safe learning environment with minimal risks compared to physical laboratories. Nonetheless, some students felt tense when using the virtual lab, primarily due to fears of making technical errors. These findings align with academic anxiety theories (Cassady & Johnson, 2002). which state that technological uncertainty can impact learning experiences. Strategies such as providing interactive guides or preliminary orientation sessions could help mitigate anxiety.

The Confidence aspect scored 91.15%, showing that students felt confident in completing practical tasks successfully. The strong correlation between ease of use and confidence highlights the importance of user-friendly designs in ensuring a positive learning experience. Each aspect provides critical insights into the implementation of the virtual laboratory. The high usage score emphasizes the medium's effectiveness as a relevant practical learning alternative. However, the lower score on usability difficulties indicates the need for interface improvements, video tutorials, and increased self-practice opportunities. The correlation between ease of use and confidence underscores the importance of intuitive design for a positive user experience. Anxiety factors were influenced by students' perceptions of safety and flexibility in the virtual environment. Although virtual settings reduce physical risks, the lack of direct control can increase stress for some students. Providing introductory simulations or simple orientations before the main practical sessions could be an effective solution.

The use of virtual laboratories in physics learning yielded positive results, with an overall average percentage of 91.47% for general usage. These findings support constructivist learning theories (Piaget, 1970). which emphasize the importance of interactive and experiential learning environments to reinforce conceptual understanding. Compared to previous studies (Rina Mirdayanti & Murni, 2017), these results align with findings that virtual laboratories enhance students' understanding of physics concepts. Virtual labs not only improve technical skills but also strengthen students' confidence in their abilities. This highlights the potential of virtual laboratories as innovative solutions in physics education.

The primary recommendations include developing a more intuitive interface for the virtual laboratory and providing additional training for students. Interactive guides and video tutorials can help students overcome operational challenges. Furthermore, conducting orientation sessions before practical activities can build students' confidence. Strategies such as gamification or offering small incentives for successful practical completion could also enhance student motivation. Virtual laboratories hold significant potential for further development, such as integration with virtual reality (VR) for a more immersive experience and incorporating automatic assessment features to provide instant feedback to students.

DISCUSSION

This study analyzed data from SPS observations and student perception surveys to evaluate the effectiveness of interactive web-based virtual laboratories in physics learning. The findings indicate that the implementation of virtual laboratories positively impacted students' SPS and perceptions, despite some challenges requiring future improvements.

The virtual laboratory effectively enhanced students' SPS, particularly in observing, conducting experiments, and drawing conclusions. The average SPS score of 90.3% suggests that this medium serves as an effective alternative to physical laboratories, consistent with prior research (Abdjul et al., 2019) demonstrating virtual labs' efficacy in enhancing scientific skills. While overall SPS results were excellent, active student participation in asking questions and discussions needs improvement. This factor may be linked to students' anxiety when using new media, as revealed by the perception survey. Therefore, additional approaches, such as interactive guides or training, are necessary to boost student confidence during discussions.

Students' perceptions of the virtual laboratory were overwhelmingly positive, with high scores in ease of use and confidence. These results align with constructivist theories (Piaget, 1970), which highlight the role of interactive learning environments in fostering conceptual understanding. Enhancing student interaction through additional strategies, such as preliminary orientations, step-by-step guides, or self-practice exercises, could address challenges in active participation during class discussions. Further development of the medium, such as integrating virtual reality (VR) or gamification, could increase student engagement and motivation.

These findings are consistent with previous studies (Rina Mirdayanti & Murni, 2017); (Swandi & Amin, 2016), which demonstrate that virtual laboratories improve physics concept comprehension and technical skills. However, challenges in student interaction during class discussions provide critical insights into the use of virtual laboratories. This study shows that while technology can enhance scientific skills, interpersonal communication remains an area for development. This contrasts with findings by (Zulimah et al., 2018) which suggest that virtual learning environments foster more active student interactions.

CONCLUSION

Data analysis was conducted to evaluate students' activities through SPS observation sheets, improvements in SPS through pretest-posttest results, and students' perceptions via survey questionnaires. The SPS observation results showed an average activity percentage of 90.3%, indicating that the interactive web-based virtual laboratory effectively supports virtual practical-based learning. The perception survey results showed an average percentage of 86.42%, categorized as excellent, indicating that virtual laboratories can be innovative solutions in physics education. However, operational aspects need improvement to address existing challenges.

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