

Analysis of Students' Activities and Perceptions Toward Web-Based Virtual Laboratories in Science Learning

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<https://doi.org/10.17977/um065.v6.i10.2026.8>

Article history

Submitted: 3 June 2026

Revised: 23 June 2026

Accepted: 25 June 2026

Published: 27 June 2026

Keywords

Perception

Physics learning

Student activities

Virtual laboratory

Website

Abstract

The use of web-based virtual laboratories in physics learning is considered capable of supporting the improvement of students' science process skills and conceptual understanding. This study aims to: (1) examine the effect of implementing an interactive web-based virtual laboratory on physics learning activities, and (2) describe students' perceptions of the use of the virtual laboratory. The study employed a pre-experimental method with a one-shot case study design. The research population consisted of all twelfth-grade students divided into four classes, with a sample of 24 students. Data collection was carried out through observations of science process skills to determine the impact of the intervention, as well as questionnaires distributed after the learning process to measure students' perceptions regarding their Science Process Skills (SPS) activities during the implementation. The results of the observational analysis showed an average percentage of science process skills activities of 89.9%, indicating that the interactive web-based virtual laboratory effectively supports virtual practical learning. Meanwhile, the analysis of students' perceptions obtained an average score of 93.6%, categorized as very good. These findings indicate that virtual laboratories have the potential to become an effective innovation in physics learning. Nevertheless, further development in operational aspects is still needed to address various existing challenges.

1. Introduction

The rapid advancement of information and communication technology has brought about profound changes across many dimensions of human life, with education being no exception. In the context of Indonesia, the incorporation of technology into educational systems continues to be a primary concern, particularly as a means of improving learning outcomes and overcoming persistent challenges in the field. A prominent example of this effort is the adoption of the Merdeka Curriculum, which places strong emphasis on learner-centered approaches, the cultivation of critical thinking abilities, and the use of problem-solving strategies grounded in real-life situations (Kemdikbud, 2022). This curriculum opens up considerable room for teachers to explore and apply innovative instructional methods, especially within science disciplines such as physics.

Natural science is among the academic disciplines that present unique difficulties in the teaching and learning process. In an ideal setting, physics education calls for a hands-on approach through experimentation and laboratory activities, enabling students to grasp concepts more effectively and thoroughly (Setiawan et al., 2023). The laboratory serves as a vital educational facility that supports the learning process by fostering the development of students' practical skills. In reality, however, many schools both public and private continue to struggle with inadequate laboratory infrastructure (Manikowati & Iskandar, 2018). These limitations frequently lead teachers to rely more heavily on theoretical instructional methods, which tend to be less effective in nurturing students' scientific process skills.

Observations conducted at junior high schools in Pidie revealed that a number of schools face constraints related to the insufficiency of science laboratory facilities. This condition has a direct bearing on the quality of education and frequently causes the learning process to become monotonous, as instruction tends to revolve around theoretical content without being adequately supported by experimental activities. As a consequence, the development of science process skills (SPS) which are essential for cultivating critical thinking, problem-solving abilities, and students' understanding of natural phenomena through a scientific approach becomes significantly hindered (Kusumayuni et al., 2023). Beyond the issue of limited facilities, another considerable challenge is the low level of student motivation in studying science, as many students perceive the subject as difficult and disconnected from their everyday lives.

Science process skills encompass a range of cognitive and procedural competencies that assist students in comprehending core concepts in science. These skills not only enable students to attain a deeper understanding of science subjects but also equip them to face real-world challenges that demand scientific thinking abilities (Yusuf & Widyaningsih, 2018). However, the application of science process skills in schools is frequently impeded by predominantly theoretical instructional approaches, as well as the scarcity of hands-on experimental practice resulting from insufficient laboratory facilities.

The limited availability of science laboratory facilities is one of the factors contributing to students' low ability to comprehensively understand scientific concepts. Science process skills, such as observing, formulating hypotheses, conducting experiments, processing data, and drawing conclusions, are difficult to develop optimally without adequate laboratory support facilities (Bybee & Ed., 2002). In addition, the use of less varied teaching methods and the lack of active student involvement in learning activities can reduce students' interest in science learning, which ultimately affects their learning outcomes and academic achievement (Yulianti et al., 2012).

Virtual laboratories have become one of the modern learning alternatives that can be used to overcome the limitations of conventional laboratory facilities in schools. Through digital technology, virtual laboratories are able to present scientific experiment simulations that resemble real conditions, allowing students to conduct observations, test various variables, and participate more actively in inquiry-based learning processes. The presence of virtual laboratories also facilitates students' access to practical activities without depending on physical laboratory facilities that require high costs and complex equipment. In addition to increasing students' learning interest, the use of virtual laboratories can strengthen students' understanding of science concepts and improve science process skills through more interactive and adaptive learning experiences (Mirdayanti & Murni, 2017).

The use of virtual laboratories provides students with opportunities to conduct experiments in a safe and controlled digital environment. This technology supports students in learning science concepts more deeply through exploratory and interactive experimental activities. By using virtual laboratories, students can modify experimental variables, observe changes in results, and repeat experiments at any time according to learning needs. These conditions help students achieve a more optimal understanding of the material without being constrained by limitations in laboratory tools and materials (Jong et al., 2013).

Various recent studies have shown that the implementation of virtual laboratories can help demonstrated very good science process skills (SPS) activity while also enhancing their motivation and engagement in the learning process. Research conducted by Mahendra and Killis (2025) revealed that microlearning-based virtual laboratories have a positive impact on students' learning motivation, participation, and academic achievement in online learning. In addition, a study by Tsirulnikov et al. (2023) demonstrated that virtual laboratory simulations developed using an immersive learning approach are able to significantly improve students' motivation and learning outcomes.

The meta-analysis conducted by Li and Liang (2024) also indicated that virtual laboratories make a substantial contribution to increasing students' learning motivation and engagement, while serving as an effective alternative to overcome the limitations of conventional laboratory facilities. Meanwhile, the literature review by Nurroniah and Farizi (2024) explained that the application of virtual laboratory technology and immersive technology in science education can improve learning interaction, conceptual understanding, and learning effectiveness in the digital era. Therefore, virtual laboratories have great potential to support science learning through strengthening science process skills, enhancing learning motivation, and encouraging students' active participation in learning activities.

Although virtual laboratories have long been recognized in the field of education, their implementation in science learning remains an innovation that has not been widely explored in depth. Therefore, further research is needed to focus on the use of web-based virtual laboratories in examining their impact on the science learning process, while also serving as an alternative solution to overcome the limitations of conventional laboratories. This study is also aimed at evaluating the effectiveness of virtual laboratories in improving students' learning activities and science process skills, as well as identifying students' perceptions toward the use of this technology in learning.

The presence of web-based virtual laboratories is expected to provide solutions to various learning challenges through easy access that can be utilized anytime and anywhere. Studies on this technology are believed to contribute significantly to the development of digital innovation in education, while also offering practical recommendations for teachers, researchers, and policymakers. Therefore, the integration of technology in education becomes an important step in reducing educational gaps and preparing students to meet the skill demands of the future.

2. Method

2.1. Research Design

This study applied a Pre-Experimental Design using a mixed-methods approach. The Pre-Experimental Design was employed to determine the effectiveness of the treatment given to the experimental class, thereby providing an initial overview of the impact of the intervention. The mixed-methods approach combined quantitative and qualitative analyses to obtain a deeper understanding of the implementation of web-based virtual laboratories in science learning. Quantitative analysis was used to measure the effectiveness of the treatment, while qualitative analysis aimed to examine the impact of the virtual laboratory implementation more comprehensively. This study employed a One-Shot Case Study design, in which a single group was given treatment through the use of an interactive web-based virtual laboratory. The overall stages of the research procedure are presented in Figure 1.

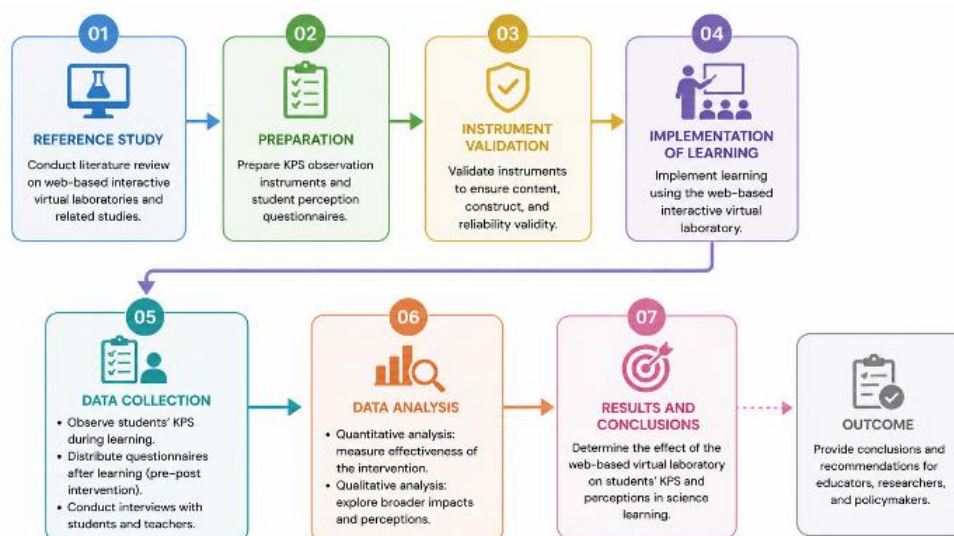


Figure 1. Research Flowchart

2.2. Data Collection Techniques

Observations of students' science process skills (SPS) were carried out by observers during the learning activities to determine the effect of the treatment provided. Data collection through questionnaires was conducted after the learning process to examine students' SPS activities before and after the implementation of the intervention (Zulimah et al., 2018). In addition, interviews with teachers and students were also conducted as supporting data to strengthen the results of the observations and questionnaires. In this study, the dependent variables included students' science process skills and perceptions in science learning, while the independent variable was the use of an interactive web-based virtual laboratory.

This research was conducted at one of the junior high schools in Pidie, Indonesia. The research population consisted of all seventh-grade students divided into classes VII A and VII B. The research sample was selected using the cluster random sampling technique, which is a sampling method carried out by randomly selecting class groups so that the samples obtained could represent the entire research population (Sugiyono, 2016).

The indicators used to evaluate the implementation of the interactive web-based virtual laboratory in physics learning included the average scores of SPS (Science Process Skills) observations, interviews, field notes, and students' perception questionnaires. SPS observations were conducted during the learning process to record students' learning activities, their interactions with the virtual laboratory, and the application of SPS in completing experimental tasks. Meanwhile, the perception questionnaire contained questions related to students' interest, level of satisfaction, and intrinsic motivation toward the use of the web-based virtual laboratory during the learning process.

The research instruments consisted of an SPS (Science Process Skills) observation sheet employed during the learning activities and a student perception questionnaire administered at the end of the learning session. These instruments were validated by experts, with the validity results analyzed using the Aiken's V formula and the reliability measured using Cronbach's Alpha formula. The implementation of the instruments was carried out by assigning scores to the responses based on the criteria presented on Table 1.

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, 2018)

To examine the extent to which the implementation of the interactive web-based virtual laboratory affects students' interactions and Science Process Skills (SPS) activities, as well as to analyze students' perceptions of its application in physics learning, data analysis techniques were applied using the implementation level formula to calculate the percentage scores obtained from the research instruments. In addition, data reduction was carried out by summarizing relevant interview results and field notes to strengthen the observation data. The percentage scores were then interpreted descriptively according to the following assessment category guidelines presented in Table 2.

Table 2. Scoring Interpretation Guidelines

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

Source: Yusuf & Widyaningsih (2018)

3. Results and Discussion

3.1. Observation of Science Process Skills (SPS)

Science Process Skills (SPS) data were obtained through observations conducted by observers during the learning process. The observations aimed to describe students' science process skills during the implementation. The highest score for each observation indicator was set at 100 as the ideal score, while the lowest score was 25. Therefore, the observation assessment range was between 25 and 100. The results of the SPS observations are presented in the Table 3

Table 3. Analysis of SPS Observation Results

No	Statement	Observation Score	Ideal Score	Percentage
1	Students follow all instructions carefully and thoroughly	95	100	95%
2	Students answer the teacher's questions correctly	88	100	88%
3	Students actively ask relevant questions	84	100	84%
4	Students provide relevant opinions during discussions	89	100	89%
5	Students listen attentively to others' opinions	96	100	96%
6	Students formulate hypotheses aligned with the experiment objectives	86	100	86%
7	Students perform measurements and calculations accurately	94	100	94%
8	Students carefully observe changes in measuring instruments	92	100	92%
9	Students systematically organize observation tables	90	100	90%
10	Students collaborate effectively during experiments	97	100	97%
11	Students document relationships between voltage, current, and resistance	93	100	93%
12	Students draw conclusions based on observations	91	100	91%
13	Students present experimental data clearly	87	100	87%
14	Students ask relevant questions to peers	82	100	82%
15	Students answer peer questions accurately	85	100	85%
	Average	89.9	100	89.9%

Based on the Table 3, the highest percentages were obtained in the indicators of students' collaboration during experiments (97%), attentiveness to peers' opinions during discussions (96%), and accuracy in performing measurements and calculations (94%). In contrast, the lowest percentages were found in the indicators related to students asking relevant questions to peers (82%) and actively asking relevant questions during the learning process (84%). To provide a clearer overview, the SPS observation results are illustrated in the Figure 2.

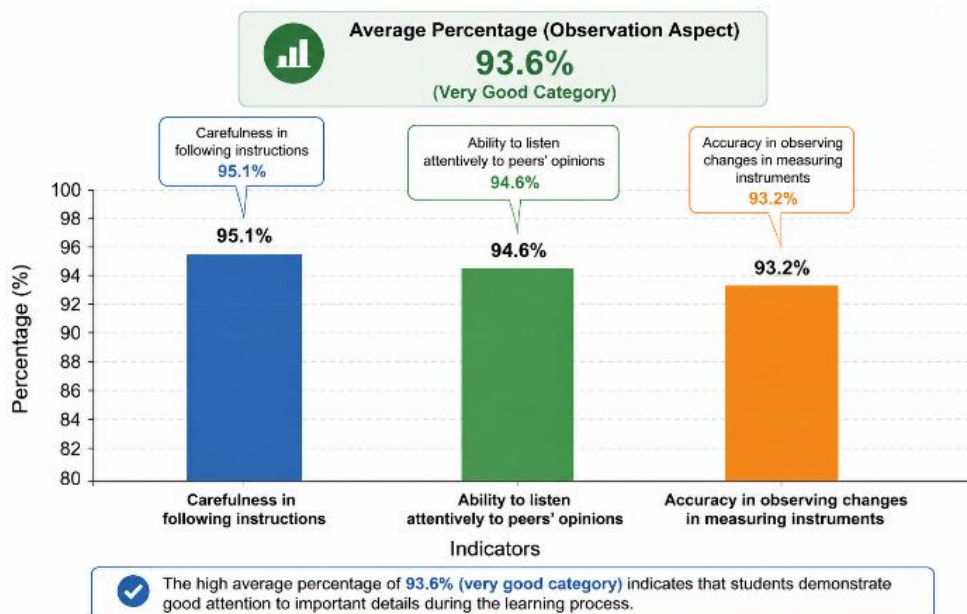


Figure 2. SPS Observation Results Diagram

Based on the diagram in Figure 2, the observation aspect of students' science process skills achieved an average percentage of 93.6%, which is categorized as very good. These results indicate that students demonstrated strong observation skills during the learning process. The high percentage confirms that students were able to pay attention to important details and participate optimally in learning activities.

The indicator of carefulness in following instructions obtained a percentage of 95.1%, indicating that most students were able to understand and carry out learning instructions properly. This ability is very important in supporting the success of practical activities and scientific observations. In addition, the indicator of the ability to listen attentively to peers' opinions achieved a percentage of 94.6%. This result shows that students demonstrated good cooperation and communication skills during the learning process.

Meanwhile, the indicator of accuracy in observing changes in measuring instruments obtained a percentage of 93.2%. Although this score still falls within the very good category, it was the lowest among the observed indicators. This finding suggests that some students still experienced difficulties in carefully observing changes in measuring instruments. Based on the observations, these difficulties may have been influenced by students' limited experience in using measuring instruments or their lack of understanding of proper observation procedures. Therefore, more intensive guidance, additional practical exercises, and clearer instructional guidelines are needed to further improve students' observation skills.

Overall, the results of each indicator demonstrate that students possessed very good observation skills. The high level of students' observation abilities confirms that the learning process was able to help students understand scientific concepts more deeply. Furthermore, strong observation skills also play an important role in improving accuracy, scientific thinking skills, and students' success in conducting practical activities and simple research.

The use of virtual laboratories in physics learning has shown highly positive impacts, with the average percentage of general usage reaching 89.9%. These results are in line with the constructivist learning theory proposed by Piaget (1970), which emphasizes that interactive and experience-based learning environments can help students understand concepts more deeply. This finding is also consistent with the study conducted by Rina Mirdayanti & Murni (2017), which stated that virtual laboratories are effective in improving students' understanding of physics concepts. In addition to enhancing technical skills, the use of virtual laboratories also helps increase students' confidence in carrying out practical activities. Therefore, virtual laboratories can become an effective innovation in supporting modern physics learning.

Several recommendations can be proposed, including developing a more user-friendly virtual laboratory interface and providing additional training for students. Interactive guides and video tutorials can assist students in overcoming operational difficulties when using virtual laboratories. Furthermore, providing orientation sessions before practical activities begin can also help improve students' self-confidence. The implementation of strategies such as gamification or providing simple rewards for successfully completing practical tasks is also expected to enhance students' learning motivation.

In the future, virtual laboratories have significant potential for further development, such as through the integration of virtual reality (VR) technology to create a more realistic and engaging learning experience. In addition, the inclusion of automatic evaluation features can provide direct feedback, helping students understand their learning outcomes more quickly and effectively.

3.2. Implications

The findings indicate that the use of a web-based virtual laboratory was accompanied by very good science process skills (SPS) activity and highly positive student perceptions. These results suggest that virtual laboratories may serve as a valuable learning resource for supporting science learning, particularly in contexts where access to physical laboratory facilities is limited. In addition, the integration of virtual laboratory activities can provide students with opportunities to engage in observation, experimentation, data interpretation, and scientific reasoning in a flexible learning environment. Therefore, web-based virtual laboratories have the potential to complement conventional laboratory activities and enrich students' learning experiences.

3.3. Limitations

Several limitations should be considered when interpreting the findings of this study. First, the study employed a descriptive research design without a comparison group or pretest–posttest measurements. Consequently, the results cannot be used to establish causal relationships or determine the effectiveness of the intervention in improving students' science process skills. Second, the study relied primarily on observations of SPS activities and students' perceptions during the implementation of the virtual laboratory. Third, the study was conducted within a specific educational context and involved a limited number of participants, which may restrict the generalizability of the findings. Future studies are encouraged to employ experimental or quasi-experimental designs with larger and more diverse samples to provide stronger evidence regarding the impact of web-based virtual laboratories on science learning outcomes.

4. Conclusion

Data analysis was conducted to assess students' activities based on SPS observation sheets, improvements in SPS skills through pretest and posttest results, and students' responses obtained from survey questionnaires. The SPS observation results showed an average activity percentage of 89.9%, indicating that the interactive web-based virtual laboratory effectively supports virtual practical learning. In addition, the perception survey results obtained an average percentage of 93.6%, categorized as excellent, suggesting that virtual laboratories have the potential to become an effective innovation in physics learning. Nevertheless, operational aspects still require further development to address various existing challenges.

Author Contributions

All authors contributed equally to this paper. All authors have read and approved the final manuscript.

Funding

No funding support was received.

Declaration of Conflicting Interests

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

Data Availability

The datasets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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