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THE EFFECT OF INQUIRY-BASED VIRTUAL LABORATORY ON STUDENTS' SCIENCE PROCESS SKILLS

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Abstract

Science education at the junior high school level requires an approach that maximally develops students' science process skills (SPS). One way to achieve this is by utilizing interactive learning media, such as virtual laboratories, combined with an inquiry-based learning model. This study aims to determine the effect of implementing an inquiry-based virtual laboratory on improving students' SPS. The method used in this study is pre-experimental with a one-group pretest-posttest design. The subjects in this study were 32 students from class VIII D at SMP Negeri 4 Yogyakarta. Data collection was carried out by administering a pretest before treatment and a posttest after treatment. The data obtained were analyzed using paired t-test and N-Gain test. The paired t-test results showed a significance value (2-tailed) = (0.00) < 0.05, indicating the effect of the treatment on students' SPS. The N-Gain result was 0.73 in the high category, so it can be concluded that applying virtual laboratory media with the inquiry-based learning model in the inclined plane topic can enhance students' SPS in science subjects.

INTRODUCTION

Education is an essential element in human resource development. Education aims to create quality human resources to drive progress in various fields (Damayanti & Suniasih, 2022; Tarisna et al., 2023). Modern education today demands a balance between theory and practice to prepare outstanding human resources who are ready to face future challenges. Mastery of skills has become a key aspect in the current era, as it plays an important role in the dynamic global changes (Mahmudah et al., 2019). In the context of science learning, one of the main skills that students must master is science process skills (SPS). Integrating SPS into modern science learning not only enhances conceptual understanding but also trains students to think critically, solve problems, and conduct scientific experiments independently (Lusidawaty et al., 2020).

Science process skills are students' abilities to apply the scientific method to understand, develop, and discover knowledge. These skills are essential for every student as a foundation for using the scientific method to acquire new knowledge or expand upon existing knowledge (Gültekin & Altun, 2022; Hartati et al., 2022). SPS can be seen as one of the essential skills that students must possess today. In science learning, SPS is a crucial skill because it enables the achievement of science learning objectives through scientific inquiry activities (Angelia et al., 2022; Tan et al., 2020; Yunita & Nurita, 2021). SPS helps students connect theory with hands-on practice in the field, preparing them to face future challenges that demand proficiency in scientific thinking and the ability to adapt to technological advancements and new knowledge (Darmaji et al., 2018).

Although SPS is essential for students, the reality in the field shows that these skills are still not optimal. Based on interviews with science teachers at SMP Negeri 4 Yogyakarta, it was found that students' SPS levels remain unsatisfactory. This is because science process skills have not been fully implemented in learning activities. Typically, students' learning mainly involves listening to teacher explanations, as also highlighted in studies (Aprilia & Anggaryani, 2023; Rafiska & Susanti, 2023) which states that students' SPS are generally low because science learning tends to focus on and be dominated by knowledge-based aspects, such as memorization, and is often teacher-centered (Arumningtyas et al., 2022; Rahayu et al., 2024; Sideri & Skoumios, 2021). Students only listen to the teacher's explanation and take notes on key points without engaging in practical activities. This low level of SPS is an issue that requires specific follow-up actions. For instance, research Aprilia & Anggaryani, (2023) suggests that several SPS, such as skills in observing, classifying, creating tables, planning experiments, and drawing comprehensive conclusions, are not yet fully developed. Therefore, teachers need to foster SPS in students, as these skills play a crucial role in learning science(Nuraisyah, Harahap, and Harahap 2021).

A suitable solution is needed to address the issues at hand. Teachers should implement various alternative learning methods that support the improvement of students' SPS, such as engaging and meaningful learning that utilizes effective learning resources and media (Can et al., 2024). One learning medium that can be used is the virtual laboratory, which facilitates students in conducting practical activities, thereby enhancing their SPS. Additionally, a virtual laboratory helps students understand concepts and theories in science learning (Arumningtyas et al., 2022; Nasution et al., 2023). A virtual laboratory is a computer application that allows students to conduct experiments or practical work digitally. The virtual laboratory plays an essential role in science education as an alternative or complement to physical laboratories. This medium enables interactive experiments with realistic simulations, helping students understand abstract concepts and develop SPS. As a practical solution, virtual laboratories are easily accessible, and safe, and support innovative and technology-relevant learning in the digital era (Arumningtyas et al., 2022; Kholila & Susanti, 2023). This is supported by research by Nana, (2020) virtual laboratories provide solutions to the limitations of laboratory facilities and infrastructure for practical activities. Furthermore, Azizaturredha et al. (2019) the research suggest that there is an enhancement of SPS during science learning following the implementation of the virtual laboratory (Winangsih and Harahap 2023).

The use of virtual laboratory media will be effective in supporting students' SPS if applied with an appropriate learning model. One suitable model for this purpose is the inquiry-based learning model. Inquiry emphasizes active student participation in activities such as making observations, posing questions, designing experimental procedures, collecting and analyzing data, and concluding and communicating the results, making learning more meaningful as students directly experience the process of discovery and understanding of concepts (Arumningtyas et al., 2022; Hong et al., 2021; Safitri et al., 2024; Sulistiyono & Triyanti, 2024) This aligns with research by Arumningtyas et al., (2022) which found that implementing virtual laboratories with an inquiry-based learning model can enhance students' SPS in science learning, as evidenced by an N-Gain score of 0.8, categorized as high. Research by Aprilia & Anggaryani, (2023) also, applying the inquiry model in science learning can improve students' SPS.

Similarly, a study by Azizaturredha et al., (2019) they concluded that guided inquiry learning with a virtual laboratory can enhance students' SPS.

According to Chusna et al., (2024), the implementation of interactive learning media such as virtual laboratories for inclined plane material at the junior high school level holds significant potential to enhance students' science process skills (SPS). By optimizing the use of technology, educators can make science learning more interactive, engaging, and efficient. In this era of technological advancement, the use of learning media is crucial, especially for inclined plane material (Yunita & Nurita, 2021). The inclined plane material in junior high school science learning is part of simple machines, aimed at helping students understand the working principles of tools that simplify human tasks. An inclined plane is a slanted surface used to move objects to a certain height with less force than lifting them directly. This concept is understood through experiments involving the relationship between force, the weight of objects, the length, and the height of the inclined plane (Salafudin & Af'idah, 2022). The concept of an inclined plane is closely related to everyday life, such as its use in mountainous roads, wheelchair ramps, and goods transport boards. Through an inquiry-based approach, students are encouraged to actively explore and independently discover scientific concepts through hands-on experiments (Maulana, Harahap, and Safitri 2022).

Several relevant studies provide evidence that supports the effectiveness of virtual laboratories and inquiry-based models in enhancing students' science process skills. Kadir, (2023) research, titled "Effectiveness of Virtual Laboratory Utilization in Improving Students' Science Process Skills," demonstrates that the use of a PhET-based virtual laboratory significantly improves students' science process skills. With an N-Gain value of 0.72, classified as high, this result indicates a positive impact on students' science process skills after engaging with the virtual laboratory. Similarly, (Chairunnisa, 2024) in their study titled "The Effect of Virtual Laboratory on Science Process Skills in Metabolism Material" found that virtual laboratory media significantly influenced students' science process skills, with an N-Gain value of 0.74, also considered high. This underscores the positive effect of virtual laboratories on enhancing students' science process skills. Furthermore, Zahrotin et al., (2021) also explored the effectiveness of the "Guided Inquiry Model" in their study titled "The Effectiveness of Guided Inquiry Model in Training Students' Science Process Skills." They found that this model was highly effective in improving students' science process skills, with an N-Gain value of 0.72, which is categorized as high.

The previous studies share a common goal of improving students' SPS. The uniqueness of this research lies in developing students' SPS using both media and teaching models. One approach to achieving this is by utilizing interactive learning media, such as virtual laboratories, combined with the inquiry-based learning model. By applying both virtual laboratories and the inquiry model, students become more active in conducting scientific experiments. Virtual laboratories allow students to perform interactive experiments independently, while the inquiry model encourages question formulation and solution-seeking to develop SPS. These two approaches strengthen the understanding of scientific concepts and aspects of SPS. The difference lies in previous research, which only used virtual laboratory media without combining it with the inquiry model, whereas this study integrates both the media and the teaching model. In addition, the aspects of SPS observed in this study differ from those in previous studies, making it an innovation in the development of understanding regarding the implementation of an inquiry-based virtual laboratory in science education(Julianti, Harahap, and Safitri 2022).

This study will analyze various aspects of SPS, such as observing, predicting, applying concepts, concluding, and communicating (Chiappetta & Koballa, 2010; Kruea-In et al., 2015; Zeidan & Jayosi, 2014). This analysis is conducted to determine the extent to which the application of a virtual laboratory based on the inquiry model influences the improvement of students' SPS. Therefore, this research is focused on the implementation of an inquiry-based virtual laboratory to students' SPS.

METHOD

Type of Research

This research is a quantitative study using a descriptive method aimed at analyzing the improvement of students' SPS after utilizing virtual laboratory media within an inquiry-based learning model. The research design applied is a pre-experimental one-group pretest-posttest design (Sukarelawa et al., 2024). SPS measurement was conducted through a pretest to identify the student's initial abilities, followed by a posttest to determine the improvement after the implementation of virtual laboratory media in inquiry-based learning. The pre-experimental method was chosen for its simplicity and suitability for studies aimed at observing the effects of treatments, such as the use of virtual laboratories. This design is practical and appropriate for conditions with limited time, and resources, and without the presence of a control group. Nevertheless, this method can still provide preliminary insights into the effectiveness of the treatment. The design used in this research (Arikunto, 2006) is presented in Table 1.

Tabel 1. Experimental Design

Pretest	Experiment	Posttest
O_1	X	O_2

Explanation:

O_1 = Pretest administered before the treatment
X = Treatment using a virtual laboratory within the inquiry-based learning model
O_2 = Posttest administered after the treatment

Research Sample

This study employed purposive sampling techniques to determine the research sample. This technique was chosen as it involves deliberately selecting groups based on specific characteristics or criteria. Such considerations were made to ensure that the collected data is representative. In this context, the sample was selected from students who had used virtual laboratories in their learning process (Triedessari & Melissa, 2024). The population in this study comprised Grade VIII D students. The research sample included 32 students, consisting of 17 male students and 15 female students. The research was conducted at SMP Negeri 4 Yogyakarta during the odd semester of the 2024/2025 academic year.

Research Instrument

The instrument used in this study is a SPS test sheet, consisting of 10 multiple-choice questions covering 5 SPS indicators, each represented by 2 questions. These questions encompass basic and integrated SPS, including the ability to observe, predict, apply concepts, conclude, and communicate. The

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tested material focuses on inclined planes. Before the instrument was tested on students, the researcher conducted validity and reliability tests on the SPS instrument. The validity test aims to measure the accuracy of the prepared instrument, while the reliability test ensures that the instrument can serve as a dependable data collection tool. Four validators carried out the validity test, including a subject matter expert, a media expert, and two practitioners. The aspects of SPS used in this study were adopted from previous research by (Chiappetta & Koballa, 2010; Kruea-In et al., 2015; Zeidan & Jayosi, 2014), as presented in Table 2.

Table 2. Aspects of SPS

SPS Aspects	Question Indicators	Question Item Number	
		Pretest	Posttest
Observing	Determining the inclined plane that requires less force to move an object.	1	3
	Determining the effect of the inclination angle on the force needed to move an object.	2	4
Predicting	Predicting the difference in force required on two inclined planes with different angles of inclination.	3	7
	Predicting the effect of changing the angle of inclination on the required force.	4	8
Applying Concepts	Determining the minimum force to move a box on an inclined plane with no friction.	5	1
	Determining the force required to lift an object.	6	2
Concluding	Explaining the function of an inclined plane in reducing force.	7	9
	Concluding the relationship between the weight of an object, the angle of inclination, and the force required.	8	10
Communicating	Determining a scientific method to communicate inclined plane experiment results	9	5
	Communicating scientific findings about inclined planes	10	6

The SPS instrument presented in Table 3 has been empirically tested, validated using Aiken's V, and analyzed using the QUEST program. The results indicate that all items have an Aiken's V value of 1, reflecting a high level of validity, with INF MNSQ values ranging from 0.81 to 1.22, and a reliability score of 0.77. This demonstrates that all items align with the Rasch model and meet good criteria. INF MNSQ values within the range of 0.77 to 1.30 are considered to fit with the Rasch model, while a reliability score within the range of 0.70 to 0.90 is deemed acceptable. This SPS instrument exhibits high validity and reliability, aligns with the Rasch model, and fulfills good criteria. Therefore, this instrument is suitable for measuring students' SPS (Susdelina et al., 2018).

Data Collection Technique

Data were collected through an SPS test consisting of a pretest and posttest in the form of multiple-choice questions on the topic of inclined planes. This test aims to measure the ability in each SPS aspect, namely observing, predicting, applying concepts, concluding, and communicating.

Data Analysis Technique

The technique used is descriptive analysis to describe the results of the pretest and posttest, as well as to analyze the distribution and frequency of the data. This analysis aims to provide an overview of the improvement in students' SPS before and after the treatment. Data analysis was performed using the SPSS application with the N-Gain test to measure the improvement in students' SPS before and after the lesson, calculated using the normalized gain formula. The equation for calculating N-Gain is presented in Equation 1.

$$\text{N-Gain} = \frac{S_{post} - S_{Pre}}{S_{max} - S_{Pre}} \quad (1)$$

The obtained N-Gain values are then interpreted into various categories (Hake, 1998) as shown in Table 3.

Table 3. N-Gain Interpretation Categories

N-Gain Score	Category
g > 0,7	High
0,3 ≤ g ≤ 0,7	Medium
g < 0,7	Low

The criteria for determining the effectiveness level of virtual laboratory implementation (Hake, 1998) are shown in Table 4.

Table 4. Criteria for Determining the Level of Effectiveness

Percentage (%)	Category
> 76	Effective
56 – 75	Fairly Effective
40 – 55	Less Effective
< 40	Ineffective

The effect size is calculated to measure the extent of the impact caused by implementing the virtual laboratory with the inquiry-based learning model on students' SPS using the following effect size calculation formula.

$$d = \frac{(M_2 - M_1)}{\sqrt{\frac{SD_1^2 + SD_2^2}{2}}} \quad (2)$$

Explanation:

D	= effect size
Mean 1	= pretest mean score
Mean 2	= posttest mean score
SD 1	= pretest standard deviation
SD 2	= posttest standard deviation

The obtained effect size value is then interpreted into various categories (Cohen, 1998) listed in Table 5.

Table 5. Categories for Interpreting Effect Size

Effect Size Value	Category
d < 0,2	Low
0,2 ≤ d < 0,5	Medium
d ≥ 0,8	High

RESULT AND DISCUSSION

In the learning process, especially in science subjects, appropriate media and learning models are needed to support effective learning and enable students to discover knowledge independently. The media and learning model used in this study is the virtual laboratory with an inquiry model. The virtual laboratory was chosen because it facilitates students' conducting experiments related to the inclined plane topic. Additionally, the structured steps in the inquiry model make it more effective in developing students' SPS.

Students' SPS data were obtained through pretest and posttest scores, then analyzed using paired t-test and N-Gain analysis. The paired t-test was conducted to determine whether there was a difference in students' SPS before and after the application of the virtual laboratory by comparing pretest and posttest scores. The paired t-test results using SPSS, with a degree of freedom (df), showed a significance value (2-tailed) = 0.00. Since the significance value (2-tailed) = (0.00) < 0.05, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_a) is accepted. This indicates a significant effect of using the virtual laboratory with the inquiry learning model on students' pretest and posttest scores. In addition, calculations were performed using the effect size test formula, and the resulting value of 3.75 falls into the high category, indicating that implementing an inquiry-based virtual laboratory has a tremendous impact on students' SPS.

The results showed an average increase in students' SPS scores, recorded from a pretest score of 61.87 to a posttest score of 89. This outcome indicates an improvement in students' SPS after implementing the virtual laboratory with the inquiry model. Data regarding the improvement in students' SPS before (pretest) and after (posttest) the application of the virtual laboratory can be seen in Figure 1.

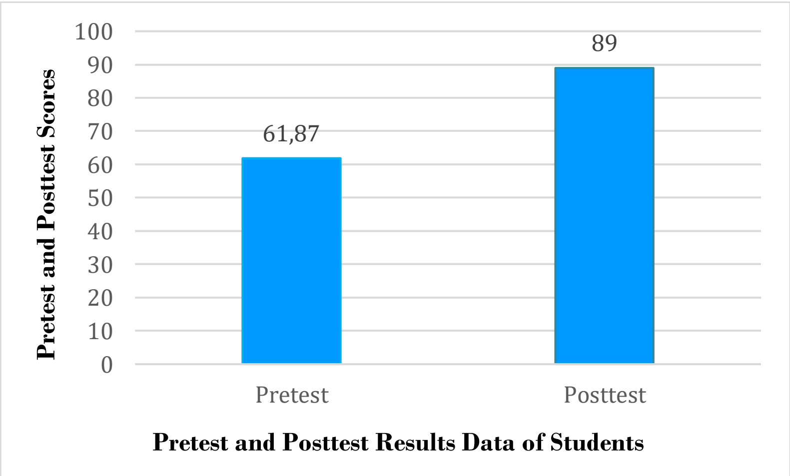

Figure 1. Pretest and Posttest Results Data of Students

Based on Figure 1, the initial test (pretest) results showed that many students scored in the low category due to a lack of understanding and low cognitive abilities, which prevented them from completing the questions. Students' mental abilities are centered on the knowledge they have acquired. Studies support this (Amanda & Darwis, 2023; Rahayu et al., 2024) which states that intellectual ability helps students achieve success in learning. Additionally, students' low initial understanding can also be influenced by the learning environment or study conditions, often referred to as social factors (Zannah & Zulfadewina, 2022). Based on initial observations with the science teacher, students usually work on tasks in groups; however, during the pretest, the seating arrangement was changed. Then, the low pretest results may be caused by the timing of the administration coinciding with the last period of the science subject that day, during which the students may have already felt tired or less focused while working on the given questions. This suggests that various factors may have contributed to the students' low initial ability to answer the questions. Meanwhile, the posttest results showed that all students achieved scores in the high category, indicating an improvement in learning outcomes, with an average posttest score of 89. Research by (Arumningtyas et al., 2022; Lailiah et al., 2021) suggest that implementing appropriate media and learning models can indeed enhance students' learning outcomes. By using a virtual laboratory, students can easily conduct experiments anywhere without the need to prepare laboratory equipment and facilities. Virtual laboratory media are usually designed with interactive elements, allowing students to actively engage in experiments and simulations, which can deepen their understanding of the concepts being studied (Indrasvari, Harahap, and Harahap 2021).

Subsequently, an N-Gain test analysis was conducted to measure the extent of improvement in students' SPS before and after the implementation of the virtual laboratory using the inquiry learning model. The analysis results showed that 19 students achieved a high category, while 13 students were in the medium category out of a total of 32 students. The N-Gain test results for the students are presented in Figure 2.

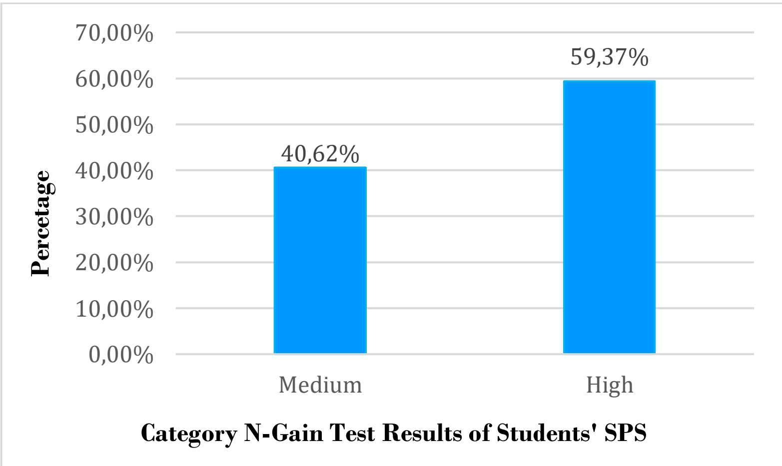

Figure 2. N-Gain Test Results of Students' SPS

Then, the N-Gain result of students' SPS, reaching 0.7 in the high category, is shown in Table 5.

Table 5. Average N-Gain Score of Students' SPS

Data	Average					
	N	Minimum	Maximum	Pretest	Posttest	N-Gain
N-gain	32	.60	1.00	61,87	89	0,73
N-Gain Percent	32	60.00	100	6.187	8.900	73.8021

Table 5 shows the average N-Gain score and percentage of students' SPS N-Gain. In the high category, the average N-Gain score of 0.73 indicates improved students' SPS before and after implementing the virtual laboratory with the inquiry model. Research by Azizaturredha et al., (2019) suggests that a virtual laboratory supported by an inquiry-based learning model can enhance students' SPS. Through a virtual laboratory, students can plan and conduct realistic experiments in a simulated environment and effectively analyze the results. This includes important SPS components such as observing, classifying, predicting, and concluding skills. The N-Gain percentage of 73.8%, categorized as moderately effective, shows that implementing the virtual laboratory with an inquiry-based model is reasonably effective in improving students' SPS.

The trial to observe the effectiveness of the virtual laboratory, conducted with 32 students of class VIII D using a one-group pretest-posttest research design, was analyzed using the N-Gain score calculation. The results of the virtual laboratory's effectiveness on each aspect of the student's science process skills are presented in Figure 3.

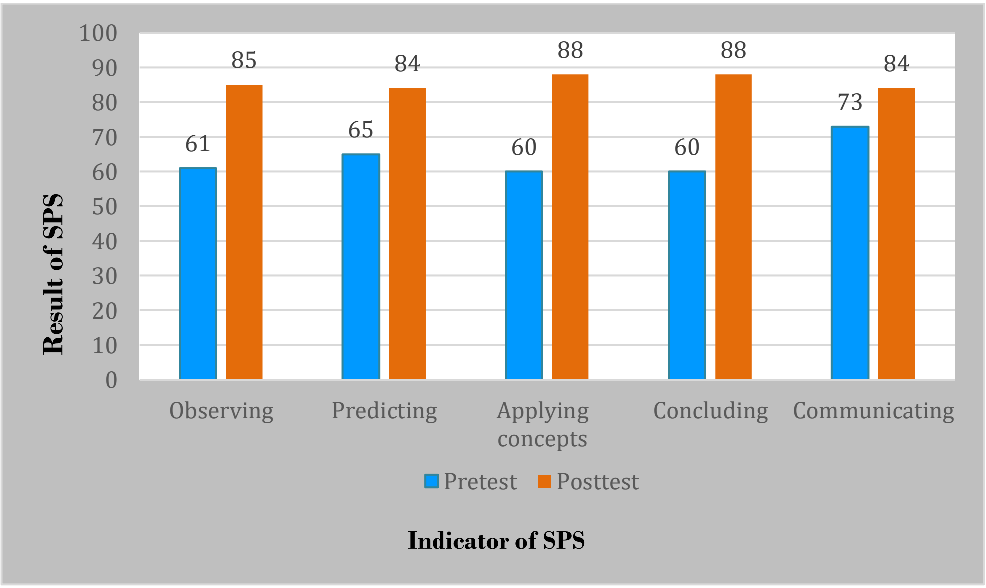

Figure 3. Pretest and Posttest Scores for Each Aspect of SPS

Figure 3 shows the comparison of SPS scores on five indicators namely observing, predicting, applying concepts, drawing conclusions, and communicating. Based on the pretest and posttest results, all aspects showed significant improvement after the implementation of the virtual laboratory with the inquiry model. The observing aspect increased from a pretest score of 61 to 85 on the posttest, the predicting aspect increased from 65 on the pretest to 84 on the posttest, and the applying concepts and drawing conclusions aspects each showed the same improvement, from 60 on the pretest to 88 on the posttest, which was the highest increase among all indicators. Finally, the communicating indicator increased from 73 on the pretest to 84 on the posttest. This improvement indicates the success of the teaching method, particularly in enhancing students' SPS.

In addition, an N-Gain analysis was conducted on each SPS aspect to determine the improvement in each aspect after implementing the virtual laboratory with the inquiry model. The results show an improvement in all observed aspects, as shown in Table 6.

Table 6. N-Gain Categories for Each Aspect of SPS

Aspect SPS	Pretest	Posttest	N-Gain Score	Category
Observing	61	85	0,73	High
Predicting	65	84	0,75	High
Applying concepts	60	88	0,73	High
Concluding	60	88	0,73	High
Communicating	73	84	0,44	Medium

Table 6 shows that two N-Gain categories were obtained out of the five observed aspects of SPS that is high and medium. All five elements of SPS that were trained showed improvement in every aspect. The aspect of communicating is the one that showed medium improvement with an N-Gain score of 0,44. According to research conducted by Yalyan et al., (2022) the student's lack of ability to communicate information is due to the need for a good understanding of scientific language to convey scientific results. Students' communication ability will be hindered if they have not mastered these terms or concepts.

Activities in the virtual laboratory play a significant role in enhancing students' SPS (Aripin & Suryaningsih, 2021; Buhera et al., 2024). For instance, during simulations of objects moving on an inclined plane, students are trained to observe parameters such as weight, mass, object height, and the length of the inclined plane, thereby improving their observation skills. Activities that involve formulating questions and hypotheses aligned with the problems presented in the worksheets related to inclined planes help develop students' prediction skills. Gathering information from books or the internet to solve problems in the virtual laboratory further enhances their ability to apply concepts. Moreover, presenting discussion results and communicating responses based on the acquired theories, both within and between groups, contributes to the improvement of communication skills. Meanwhile, the activity of concluding findings using valid sources enhances students' conclusion-drawing skills. Thus, every activity in the virtual laboratory is designed to comprehensively support the development of students' SPS.

The success of improving students' SPS through the implementation of the virtual laboratory is also supported by the use of the inquiry-based learning model. According to research by Gani et al., (2022) a well-managed class by the teacher's lesson plan can facilitate an efficient and effective learning process. The syntax of the inquiry learning model includes orientation, problem formulation, hypothesis formulation, data collection, hypothesis testing, and conclusion formulation (Gumiler et al., 2020). The inquiry model's syntax aligns with the observed aspects of SPS, making it easy to train students' SPS. This learning model requires students to be active in the learning process and directly involved in the discovery process, enabling them to understand the concepts being studied more deeply and meaningfully, rather than just passively receiving information. The use of a virtual laboratory with the inquiry learning model encourages students to independently discover knowledge, attitudes, and skills, thus demonstrating

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that the application of the virtual laboratory with the inquiry learning model can enhance students' SPS (Arumningtyas et al., 2022; Azizaturredha et al., 2019).

This study provides significant practical implications in the field of education. Inquiry-based virtual laboratories can be an innovative solution to enhance students' SPS, particularly in understanding abstract concepts such as inclined planes. This technology allows experiments to be conducted flexibly, without being limited by time, space, or the availability of physical laboratory equipment. Teachers can use it to create interactive, discovery-based learning experiences, encouraging students to be more active in exploring and analyzing. Moreover, the application of this technology can have an academic impact on future education, particularly by strengthening evidence that digital technology can improve the quality of science education, offering solutions for schools with limited physical laboratory resources, and supporting student-centered learning in line with the principles of the Merdeka Curriculum. In the future, this model has the potential to create a generation of students who are more critical, creative, and adaptive to the advancements in science and technology (Tan et al., 2020; Zannah & Zulfadewina, 2022). As explained in the study by Rizaldi et al., (2020) This indicates that the implementation of technologies such as virtual laboratories is crucial in the learning process in the digital era. Virtual laboratory simulations have proven to be effective in helping students understand abstract science concepts and can be integrated with the inquiry-based learning model to deepen understanding and SPS. Additionally, virtual laboratories are capable of presenting difficult-to-understand science concepts more visually and interactively.

The success of this study is not without the various challenges faced by the researcher, particularly regarding integrating inquiry-based virtual laboratory technology in the learning process at schools. One of the main challenges is the varying abilities of students, where some still struggle with formulating problems and understanding basic concepts like hypotheses, which are crucial components of inquiry-based learning. Additionally, teachers' adaptation to new technologies, such as virtual laboratories, often poses challenges, particularly regarding age factors. Younger teachers are generally more adept at using technology, while senior teachers may require more time to adjust. This can impact the success of the learning process, highlighting the need for consistent training and support to ensure all teachers can utilize these tools effectively (Kadir, 2023; Kholila & Susanti, 2023).

CONCLUSION

Based on the data and analysis results, it can be concluded that the implementation of virtual laboratory media with the inquiry learning model is able to enhance students' SPS in science education. This is evidenced by the N-Gain score of the pretest and posttest 0.73, indicating an improvement in the high category. Each aspect of students' SPS showed improvement, with varying categories: observing, predicting, applying concepts, and concluding, which are in the high category, while the communicating aspect falls into the moderate category.

Recommendations for readers and future researchers provided by the researcher include encouraging teachers to utilize the virtual laboratory as an innovative tool to support the learning process, which can enhance students' interest in learning, particularly their SPS. Additionally, the virtual laboratory can be used as an alternative resource to complement the limitations of physical laboratories. For future researchers, they can expand the use of virtual laboratories to cover various topics in science subjects.

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