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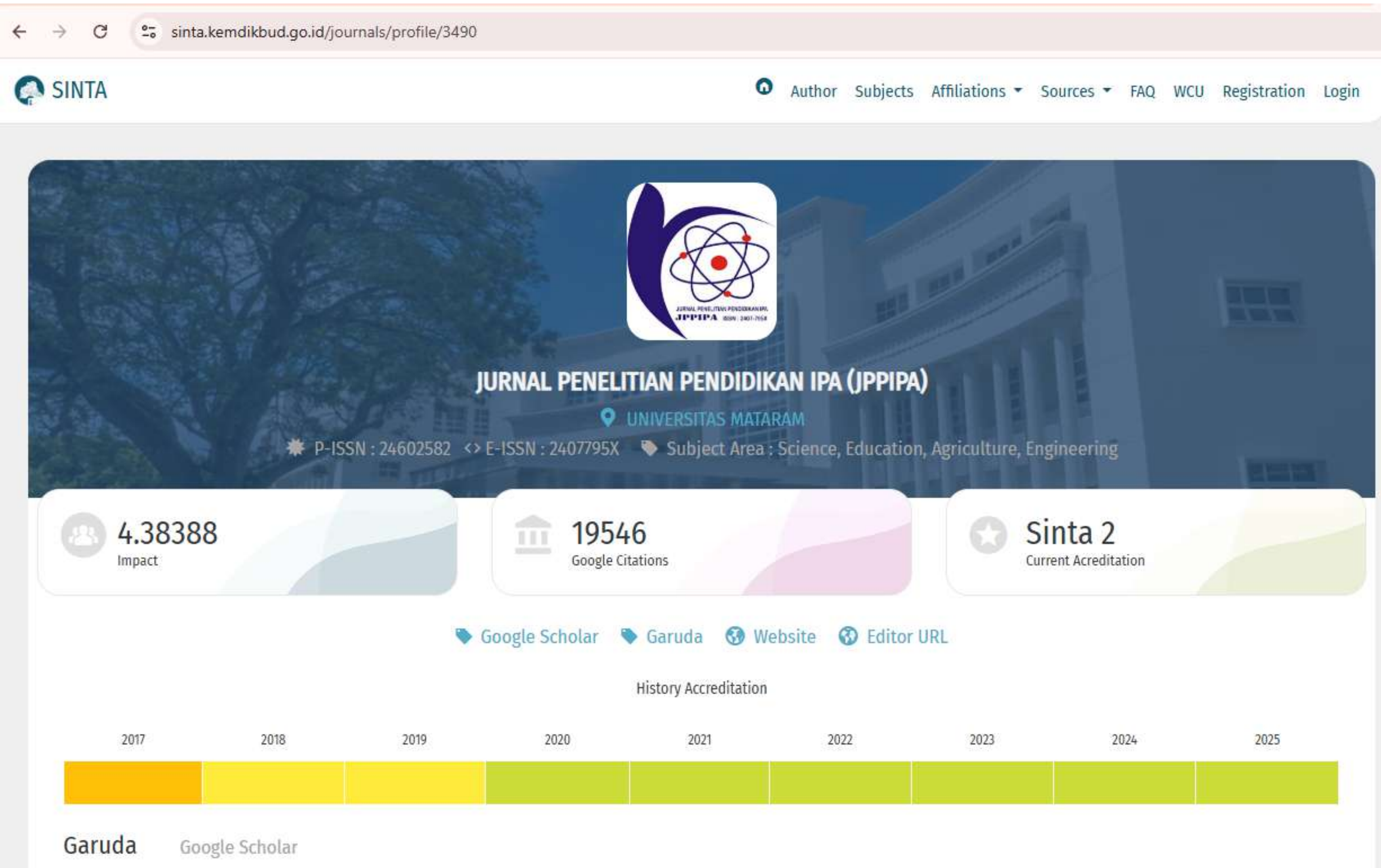

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The Utilization of Virtual Laboratories in Science Education at Junior Secondary Schools in Tangerang Regency

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Abstract: Virtual laboratories are seen as a promising solution to the shortcomings of conventional laboratories. This study aims to explore the use of virtual laboratory for science practicum in junior high schools, the supporting factors, the hindering factors, and perceptions of teachers and students regarding virtual laboratories. A survey were administered to five teachers and 122 students from public and private schools in Tangerang Regency. Additionally, semi-structured interviews were conducted with five teachers and 10 students who had prior experience using virtual laboratories in their learning. Quantitative data was analyzed using descriptive statistics, while qualitative data was examined through an interactive model approach. The findings reveal that virtual laboratories have been utilized by both teachers and students for laboratory activities, particularly in physics, although the usage remains infrequent. Factors such as device availability, internet connectivity, data limitations, and facility access were found to influence the extent of virtual laboratory adoption. Overall, both teachers and students perceived virtual laboratories as highly beneficial, especially for schools lacking sufficient conventional laboratory resources.

Keywords: Junior Secondary School; Practicum; Science Learning; Virtual Laboratory.

Introduction

The existence of science (natural sciences) and humanity cannot be separated. Through science, humans learn how to be grateful to God and to treat the universe and the surrounding environment carefully. Science is taught at all educational levels, from elementary to higher education.

Science is one of the subjects that develops an integrated concept, meaning it involves multiple disciplines, such as biology, physics, and chemistry into a complex combination. Science education allows students to study the interactions of living organisms with their environment. Discovering knowledge is carried out through scientific activities inside or outside the classroom environment. Learning science through laboratory practicums can foster and develop students' scientific processes (Ismail et al., 2016; Arnita Sari, 2019; Arumningtyas et al., 2022; Gaffar & Sugandi, 2019).

Practicum activities can train students to develop and enhance their cognitive, affective, and psychomotor skills (Amirullah et al., 2021). Activities in science laboratories can generate new knowledge for students. The laboratory experiment results serve as answers to science learning (Andris et al., 2022).

The success of students conducting experiments in the laboratory is closely tied to the role of teachers. Teachers must manage laboratory resources well to achieve learning objectives, but the current conditions could be better. This is evidenced by the fact that most teachers lack an understanding of laboratory equipment, which leads to less effective practicum activities in schools (Wardana et al., 2020; Rosidin et al., 2020). These conditions result in the equipment and materials

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becoming damaged, dusty, and poorly maintained (Wardana et al., 2020).

Moreover, time constraints are a significant factor considered by teachers (Marfuatun & Riandi, 2022; Endela & Selaras, 2019). As a result, educators tend to prioritize the verbal delivery of content, often neglecting to supplement it with hands-on activities. More than 80% of teachers deliver lessons without practicum activities (Ardius, 2020; Rahmah et al., 2021). Additionally, observational data from various schools in Tangerang Regency reveal a shift in the intended use of laboratories (Baharuddin & Wahyuni, 2008). Based on data from the Ministry of Education and Culture (2020), state junior high school science laboratories are only 11.59% in good condition, while private junior high school science laboratories are 38.19% in good condition.

Therefore, there is a need for solutions in the form of technology-based learning innovations. According to Effudoh (2016), the combination of learning and technology is considered an innovation in education. This combination will strengthen the interconnections among aspects such as physical, biological, and digital technology (Schwab, 2017). With technology, everyone can access the information they need (Pratiwi et al., 2023) efficiently, effectively, and affordably (Prajana & Astuti, 2020). One innovation is the integration of information and communication technology (ICT) in learning through the use of virtual laboratories for practicum activities. Virtual laboratories provide practicum that offers convenience for students; for example, students can adjust the magnitude of force, change the number of substances, and set the position of objects in specific experiments, all of which can be quickly accessed using devices (Bermúdez & Abrio, 2020; Owolabi et al., 2022).

Previous research findings showed that using virtual laboratories improves student learning outcomes (Susanti, 2021; Sudana et al., 2022; Hendrajanti, 2022). However, research by Ambusaidi et al. (2018) indicated that there was no difference in students' attitudes toward science after practicums with virtual laboratories. Based on a study conducted in secondary schools in the United Arab Emirates, Alneyadi (2019) showed that only eight out of 45 teachers use virtual laboratories in their teaching. The use of virtual laboratories in science education at the secondary school level is still limited, at only 13.3%, with the remainder being used in physics and chemistry at the senior high school level (Zaturrahmi et al., 2020). Other research findings indicated that teachers are not familiar with technology and virtual laboratories, thus requiring training before using virtual laboratories (Pratiwi et al., 2022; Yaman et al., 2017).

This research was conducted in junior secondary schools in Tangerang Regency to explore the use of virtual laboratories in science education, the supporting and the hindering factors for the use of virtual laboratories in science education, and the perceptions of teachers and students toward virtual laboratories.

Method

To achieve the research objectives, a mixed-methods approach with a sequential explanatory design was used. The first stage involved quantitative data collection, followed by qualitative data collection in the second stage (Creswell, 2014). The quantitative stage involved a survey to explore the use of virtual laboratories in science education, while the qualitative stage was used to confirm the responses from the respondents. The final stage involved interpreting the data and providing research recommendations.

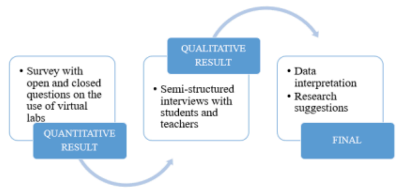

Figure 1. Research Design

The participants of this study were five teachers and 122 students from three public junior high schools and two private junior high schools in Tangerang Regency. The three public schools were coded as A1, A2, and A3, while the two private schools were coded as B1 and B2. Surveys on the use, supporting factors, hindering factors, and perceptions of virtual laboratories were administered to teachers and students in person and through Google Forms. Two teachers completed the survey via Google Forms, and three teachers completed it in person. 32 students responded to the survey via Google Forms, while 90 students responded in person. Semi-structured interviews lasting 10-15 minutes were conducted with three public school teachers coded R1, R2, and R3, and two private school teachers coded R4 and R5. Teacher informants were selected based on their willingness to be interviewed after signing an agreement to participate as research informants. Interviews to explore students' perspectives on virtual laboratories were conducted with two students from each school. Student informants were chosen based on their willingness to be interviewed. The selected students were those who had previously used virtual laboratories. Six students from public schools were coded as S1 to S6, and four students from private schools were coded as S7 to S10.

The survey instrument consisted of 19 statements covering four aspects. The first aspect, the use of virtual laboratories in science education, comprises six closed-ended statements with different answer options to explore respondents' perceptions of the need for virtual laboratories (1 item), access to the use of virtual laboratories (2 items), frequency of use (1 item), type of laboratory used (1 item), and subjects that use virtual laboratories (1 item). The second and the third aspects, supporting and hindering factors, are open-ended questions filled out by respondents. The fourth aspect, perceptions of teachers and students toward virtual laboratories, consists of 11 statements using a Likert scale with options ranging from 1 (strongly disagree), 2 (disagree), 3 (undecided), 4 (agree), to 5 (strongly agree). The Likert scale items are presented in Table 3. The interview instrument consists of 7 questions designed to delve deeper into the use of virtual laboratories. The quantitative data analysis was conducted as follows:

1. Virtual laboratory usage was expressed as a percentage, calculated by dividing the number of responses for each answer choice on each item by the total number of respondents, then multiplying by 100%.
2. Supporting and hindering factors for the use of virtual laboratories were derived from respondents' answers, which were grouped based on common themes, and then their frequencies and percentages were calculated.
3. Teacher and student perceptions regarding the use of virtual laboratories was expressed as a percentage, calculated by dividing the number of responses for each answer choice on each item by the total number of respondents, then multiplying by 100%.

Qualitative analysis of the interview results was conducted using an interactive model through three stages: data condensation, data display, and finally, conclusion drawing (Milles, Huberman, & Saldana, 2014).

Result and Discussion

The results of data analysis, conducted both quantitatively and qualitatively, were grouped into four aspects: the use of virtual laboratories, the supporting factors, the hindering factors, and teacher and student perceptions of virtual laboratories.

Use of Virtual Laboratories

The teachers and students participating in this study have used virtual laboratories in science education activities. The quantitative analysis shows that all teachers believed that virtual laboratories should be implemented in science education (Figure 1), while 99.2% of students shared the same view (Figure 2). This is because virtual laboratories are engaging learning media. According to Mauzana and Astuti (2017), a virtual laboratory is an interactive medium that provides stimuli to users, creating experiences similar to working with real tools and materials.

Virtual laboratories are generally software that can be downloaded through the App Store or a web browser and accessed via computers or smartphones. The majority of teachers, 80%, accessed virtual laboratories using laptops/computers. In contrast, 86% of students accessed virtual laboratories via smartphones. Most science teachers accessed virtual laboratories using computers or laptops because many teachers already own laptops. Additionally, the virtual laboratory interface is clearer when viewed on a laptop, which can increase students' interest in learning. These findings are consistent with research showing that the use of laptops in classrooms can enhance student engagement in learning (Deveci et al., 2018).

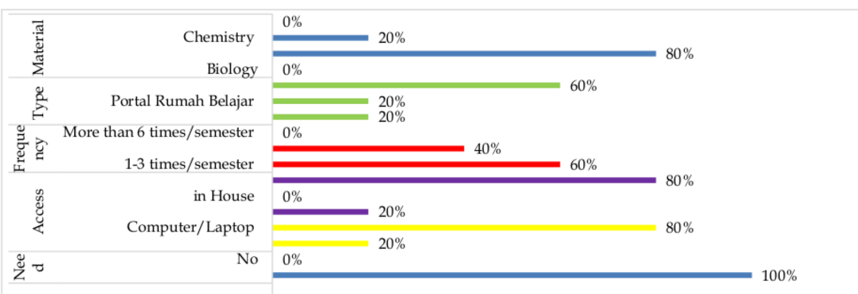

Figure 2. The Use of Virtual Laboratories by Teachers

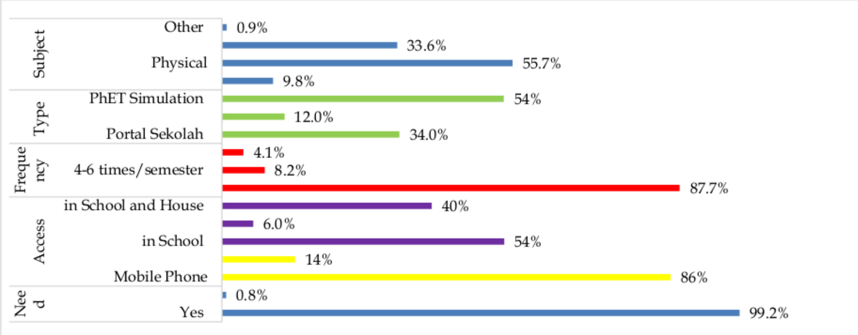

Figure 3. The Use of Virtual Laboratories by Students

For students, accessing virtual laboratories using mobile devices is considered more practical because not all students have laptops or computers to access the virtual laboratory. Moreover, many students already used Android smartphones for virtual learning. According to previous studies, in the average, students spent about 10 hours daily playing games, browsing, and using various applications, including virtual laboratories (Wulandari et al., 2019; Hardinata & Amirullah, 2017).

Most teachers (80%) reported that they accessed the laboratory both at school and at home, while the rest only accessed it at school. On the other hand, students more frequently accessed virtual laboratories at school (54%). Additionally, 40% of students accessed the virtual laboratory both at school and at home. Virtual laboratories can be accessed anywhere and anytime, making them more flexible (Warsita, 2017).

The majority of teachers and students used the virtual laboratory irregularly, only 1-3 times per semester. Both teachers and students more often used PhET simulations for practical activities compared to the Ruang Belajar portal. There are several types of virtual laboratories, but the most popular among teachers and students is the PhET simulation. This finding is also consistent with the meta-analysis conducted by Zaturrahmi et al., (2020), which showed a broader use of PhET simulations in physics compared to other subjects. PhET simulations present physics concepts in a simple and engaging way, making it easier for students to understand the concepts being studied. The PhET simulation is a virtual laboratory developed by Katherine Perkins, a scientist from the University of Colorado, United States (Rizaldi et al., 2020). Compared to the school portal, PhET simulations can be accessed for free.

The interview data were grouped into four categories: the use of virtual laboratories by teachers and students, the supporting factors, the inhibiting factors, and teacher and student perceptions of virtual laboratories.

The Use of Virtual Laboratories by Teachers and Students

A more detailed analysis of the use of virtual laboratories was divided into three subcategories: intensity of use, subject matter/lesson areas, and reasons for using virtual laboratories.

Intensity of Virtual Laboratory Use

The interview results show that all informants, both teachers and students, have used virtual laboratories for practicum activities, but their use was still infrequent. This was mentioned by teachers R1, R3, and R5. Seven out of ten students also reported infrequent use of virtual laboratories in science education. One reason for the limited use of virtual laboratories is the large amount of material that needs to be taught, as stated as follows:

"*Here, we still use the K13 curriculum, and because the K13 curriculum covers a lot of material, we don't use it frequently; only occasionally.*" (Teacher R3)

The infrequent use of virtual laboratories is due to the perception that there is still much content that must be taught in school. This contrasts with the findings of Kuehne (2020), which showed that half of the respondents in their study used virtual laboratories once a month. When calculated cumulatively, this use amounts to five to six times per semester, indicating that teachers often integrate virtual laboratories into their teaching.

Subject Matter/Subjects

In general, both teachers and students used virtual laboratories for practicum activities in physics. For example, Teachers R2, R4, and R5 used virtual laboratories specifically for static electricity material in the field of physics.

"*Virtual laboratories cover a lot of physics material, so I find them very helpful in grade 9, especially for electricity topics.*" (Teacher R4)

Reasons for Using Virtual Laboratories

One reason for using virtual laboratories mentioned by teachers is their ability to visualize abstract material, as expressed by one of the teachers:

"*One of the reasons I use virtual laboratories is to visualize abstract material, which makes it easier for students to understand.*" (Teacher R2)

The aforementioned statement highlights that the utilization of virtual laboratories inherently incorporates digital visualization into education, a practice that has become increasingly commonplace. In fact, the integration of digital technologies in educational activities signifies an acceleration in the field of education (Fathirma'ruf et al., 2021; Warsita, 2017). This digital transformation encompasses virtual laboratories, which necessitate a range of devices, including both software and hardware, for access. Consequently, this approach enhances the potential for more effective achievement of learning objectives (Yudha et al., 2023).

Another reason expressed by Teacher R1 as follows:

"*To make it easier to explain practicum materials and because it doesn't require any cost.*" (Teacher R1)

This aligns with the meta-analysis conducted by Zaturrahmi et al., (2020), which found that PhET Simulation is a type of virtual laboratory that can be accessed for free. The inadequacy of conventional laboratory equipment is also one of the reasons for using virtual laboratories, as expressed by four students. Here is a statement from one of the students:

"*Because it can be a solution for schools that lack adequate laboratory facilities.*" (Student S8)

The participants also expressed that one reason for using virtual laboratories is the transformation of conventional laboratories into classrooms and teacher offices.

The Supporting Factors for the Use of Virtual Laboratories

For most teachers (60%), the primary supporting factor for the use of virtual laboratories was equipment and signal strength, while students identified internet data quotas as the main supporting factor (41%), followed by signal strength (37.70%) and equipment (31.15%). Other supporting factors mentioned by teachers included facilities, display, and teacher understanding, whereas students also cite facilities and costs.

Soraya et al. (2022) stated that a teacher's ability to utilize and use information technology (IT) contributes to the ease of virtual laboratory use for students. Teachers who have a good understanding of IT will effectively teach students how to use virtual laboratories, so students can use them according to the learning objectives.

Table 1. Supporting Factors for the Use of Virtual Laboratories

Supporting Factrors for the Use of Virtual Laboratories	%
Teachers	
Equipment	60
Signal	60
Internet Quota	20
Facilities	20
Appearance	20
Teacher Understanding	20
Students	
Internet Quota	41
Signal	37.70
Equipment	31.15
Facilities	16.40
Cost	0.81

Interviews with teachers and students revealed the supporting factors for the use of virtual laboratories. For example, Teacher R5 mentioned the importance of devices for using virtual laboratories, such as smartphones and computers. Internet connectivity is a supporting factor for using virtual laboratories mentioned by almost all teacher informants. Here is a statement from one of the teachers:

"*Supported by internet connectivity.*" (Teacher R2)

Like the teachers, eight out of ten students also mentioned that internet connectivity is the main supporting factor.

Another supporting factor of the use of virtual laboratory is the attractive display, as explained by Student S4:

"*Virtual laboratories have a nice display.*" (Student S4)

According to Dalgarno et al. (2019), the use of virtual laboratories serves as an alternative for practical learning in educational institutions that still lack laboratory facilities and equipment. The features and visuals of virtual laboratories attract students' interest in using this medium for practical learning activities.

Hindering Factors for the Use of Virtual Laboratories

As shown in Table 2, signal strength and internet quotas are the most frequently mentioned inhibiting factors by teachers when using virtual laboratories for practical activities. Other inhibiting factors mentioned by teachers include time, equipment, and motivation. The limited use of virtual laboratories among teachers and students is also due to time constraints. The research findings indicated that the average number of teaching hours in junior high schools ranged from 28 to 32 hours per week (Elisabet, 2017). However, the teaching load for teachers should be a maximum of 24 hours per week. The underutilization of virtual laboratories in schools can be attributed to the time constraints experienced by teachers in managing administrative tasks, selecting practical materials, and coordinating schedules with computer science instructors, which often overlap.

Table 2. Hindering Factors for the Use of Virtual Laboratories

Hindering factors for the Use of Virtual Laboratories	%
Teachers	
Signal	40%
Internet Quota	40%
Time	20%
Equipment	20%
Motivation	20%
Students	
Signal	68,85%
Internet Quota	13,93%
Equipment	13,93%
Student Understanding	7,37%
Cost	4,09%
Features	1,97%
Facilities	1,97%

Students gave various answers regarding the factors inhibiting the use of virtual laboratories. Apart from signal strength, students also identified internet quota, equipment, student understanding, cost, features and facilities as factors inhibiting the use of virtual laboratories. Challenges in implementation also arise, such as internet connectivity problems. Other obstacles to using virtual laboratories are insufficient data quota, unstable network/signal, and inadequate facilities and number of devices available at the school. (Nurwahidah, 2021; Rizaldi, 2020; Winter et al., 2021).

The lack of training is an obstacle for teachers in using virtual laboratories, as mentioned by Teacher R1 and Teacher R3. This was supported by Teacher R5, who stated that no training on virtual laboratories has been organized by the Education Office or the school.

"*There has been no training from the Education Office or at the school.*" (Teacher R5)

This study also found that one of the barriers to the implementation of virtual laboratories in schools is the lack of training provided to teachers regarding virtual laboratories. This issue needs to be addressed by schools and the Ministry of Primary and Secondary Education by offering training or workshops for teachers on virtual laboratories. Before using virtual laboratories for practicum activities, teachers need to be provided with preparation and training to ensure that the practicum sessions run smoothly (Potkonjak et al., 2016; Fathirma'ruf et al., 2021). Another obstacle is the lack of adequate worksheet to assist students during practicum activities, as expressed by Teacher R3 and Teacher R5. In addition, virtual laboratories required guides and worksheets to help students follow each procedure. Teachers need to create worksheet as companions for students performing practical activities (Clarinda et al., 2021).

From the students' perspective, unstable internet connections can disrupt students during practicum sessions using virtual laboratories. Here is a statement from one of students

"*The connection is unstable.*" (Student S4)

Teacher and Student Perceptions of Virtual Laboratories

The aspect of teacher and student perceptions of virtual laboratories include eleven statement analyzed using descriptive statistics. The items are displayed in Table 3.

Table 3. Perception Statements of Teachers and Students toward Virtual Laboratories

#Item	Statement
	Virtual laboratories have an appealing appearance
	Virtual laboratories provide easier practical procedures
3.	Practicum using virtual laboratories is more effective than conventional laboratories
4.	Practical work using virtual laboratories is more efficient than conventional laboratories
5.	Virtual laboratories are an innovation in science education
6.	Virtual laboratories are safe to use for science practicum activities

#Item	Statement
7.	Practical work using virtual laboratories develops scientific skills
8.	Practicum using virtual laboratories can improve students' understanding of abstract science concepts
9.	The use of virtual laboratories for science practicum activities can improve learning outcomes
10.	Practicums with virtual laboratories can reduce students' misconceptions in science learning
11.	Virtual laboratories are easier to use than conventional laboratories

The results of the teacher perceptions of virtual laboratories are presented in Figure 4, while the student perceptions are shown in Figure 5.

The survey results show that 80% of teachers strongly agreed with the statement "*Virtual laboratories have an appealing appearance*" (Item 1). Students responses to this statement were more varied, with 34% strongly agreeing, 60% agreeing, 5% being undecided, and 1% disagreeing (Figure 5).

For Item 7, "*Practical work using virtual laboratories develops scientific skills*", 20% of teachers strongly agree and 80% agree. Among students, 30% strongly agree, 48% agree, 17% are undecided, and 5% disagree.

Another statement that received significant approval among students, is Item 5: "*Virtual laboratories are an innovation in science education*" with 11% of students strongly agreeing and 83% agreeing. The use of technology in learning is one of the practical innovations to support science learning (Asmedy et al., 2021).

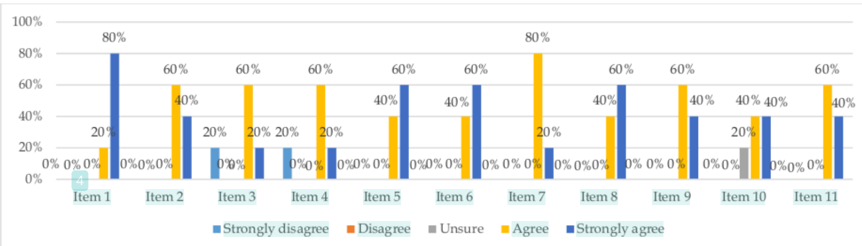

Figure 4. Teachers Perceptions of Virtual Laboratories

Regarding the comparison between virtual and conventional laboratories, teachers agreed that "*Practical work using virtual laboratories is more effective than conventional laboratories*" (item 3), "*Practical work using virtual laboratories is more efficient than conventional laboratories*" (item 4), and "*Virtual laboratories are easier to use than conventional laboratories*" (item 11). Students also tended to express similar views, although with lower percentages and more varied responses compared to teachers. All teachers perceived that the existence of virtual laboratories was very helpful for science learning in the classroom.

"*In my opinion, the use of virtual laboratories in science education is very helpful for visualization.*" (Teacher R2).

This statement was reinforced by Putri (2018) that the virtual laboratory has an attractive and interactive appearance, making students' learning more enjoyable.

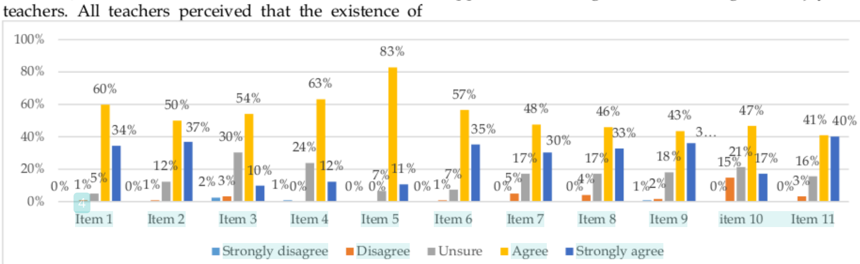

Figure 5. Students Perceptions of Virtual Laboratories

Student perceptions of virtual laboratories were more focused on the ease, efficiency, and effectiveness of use. Here are statements from students that described their perception of virtual laboratories.

"In my opinion, using virtual labs for science education is fun and easier". (Student S4)

"Especially when using virtual laboratories, learning is more effective." (Student S1)

Teachers and students in this study viewed virtual laboratories as very helpful in science education in the classroom. By using virtual laboratories, science practical activities can be visualized, and all students can view them through their individual devices. Virtual laboratories also help students learn science in an engaging and enjoyable way. Teachers also benefit by presenting material that is easy and quick for students to understand.

Conclusion

Research findings on virtual laboratories among teachers and students show that the presence of virtual laboratories is very beneficial for learning activities, especially for schools that lack adequate conventional laboratory facilities. Factors such as internet data quotas, sufficient network connectivity, access devices, and the proficiency of teachers and students need to be considered. This ensures that the use of virtual laboratories for practical activities can proceed as expected and that learning objectives can be fully achieved.

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Author Contributions
Conceptualization, G., E.D., and E.; instrument development, G., E.D., and E; data collection, G.; data analysis, G.; writing—original draft preparation, G.; writing—review, E.D. and E. writing—editing, E.D. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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