

## Utilization of Virtual Labs in Science Learning: An Alternative Solution for Student Practicals in Secondary Schools

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### ABSTRACT

This study aims to describe the use of virtual labs in Natural Science (IPA) learning as an alternative solution to the limitations of practical implementation in secondary schools. The method used is a descriptive qualitative approach with data collection techniques through in-depth interviews, observation, and documentation. Research informants consisted of teachers and students in secondary schools that have implemented virtual lab-based learning. The results of the study indicate that virtual labs are able to improve conceptual understanding, learning interest, and provide easy access to practical activities. However, there are still obstacles such as limited devices, internet networks, and digital readiness of teachers and students. This study confirms that virtual labs are a potential learning medium to support innovation in science learning, especially amidst the limitations of conventional laboratory facilities.

**Keywords:** Virtual lab, science learning, practicals, high school

### INTRODUCTION

Learning Natural Sciences (IPA) essentially demands active and direct involvement from students in the process of exploring and discovering scientific concepts through practical activities. The need for practical work in science learning is crucial because this approach not only helps students understand theory more concretely but also enables them to develop various science process skills, such as observing, classifying, measuring, interpreting data, and drawing conclusions (Setyawati, 2025). In addition, practicums also play an important role in developing students' critical and analytical thinking skills, as they are exposed to a scientific inquiry process that demands problem-solving, decision-making, and reflection on the experimental results obtained. Thus, the integration of practicums in science learning is not merely a complement, but an essential element in achieving complete learning objectives, both from the cognitive, affective, and psychomotor aspects (Restudila et al., 2025).

Although lab work plays a crucial role in science learning, its implementation in many secondary schools often faces various limitations, particularly related to conventional laboratory facilities. Many schools lack laboratory facilities and infrastructure, including adequate laboratory space, the availability of lab equipment and materials, and other technical support (Lestari et al., 2025). These limitations directly impact the frequency and quality of classroom practicums. Furthermore, other



constraints include time constraints within the learning schedule, limited school budgets for expensive practicum tools and materials, and safety issues related to the use of chemicals or sharp instruments, which require strict supervision. These factors make it difficult to implement conventional practicums optimally and evenly across all educational units, necessitating innovative alternatives that can bridge this gap (Arvianti et al., 2024).

Rapid technological advancements have brought about significant transformations in education, including in the way science is taught. One prominent innovation is the emergence of virtual labs, which enable digital, interactive, and computer-simulated practical work. Virtual labs are designed to mimic the real-world experience, allowing students to conduct observations, experiments, and analyze data visually and conceptually, even without a physical presence in the laboratory (Jaya et al., 2024).

The main advantage of a virtual lab lies in the flexibility of access, where students can use it anytime and anywhere as long as a device and internet connection are available (Kurniawan et al., 2024). Furthermore, using virtual labs is much more cost-effective because it eliminates the need for expensive physical equipment and materials and does not generate waste or the risk of accidents, such as injuries or exposure to hazardous chemicals. Thus, virtual labs are an innovative and relevant alternative solution to address the various limitations of conventional practicums, while also supporting more adaptive, technology-based learning. The COVID-19 pandemic has been a catalyst driving the accelerated adoption of digital-based learning at various levels of education (Saleh et al., 2024).

This emergency situation has forced educational institutions to quickly adapt to distance learning models, making the use of information and communication technology (ICT) an unavoidable necessity. In this context, the presence of virtual labs has become highly relevant as an alternative solution to support interactive science learning, even when conducted online. Kusuma & Muharom, 2024). In line with this, the Merdeka Curriculum, which is now being implemented in various schools, along with the 21st-century learning orientation, emphasizes the importance of using ICT as a tool in creating contextual, creative, and student-centered learning. This curriculum encourages teachers to provide meaningful, collaborative, and exploration-based learning experiences, for which virtual labs are highly suitable. Therefore, the integration of virtual labs is not only relevant in online learning situations but also a crucial part of transforming education toward something more flexible, innovative, and in line with the needs of the times (Proboatmojo et al., 2025).

While virtual labs offer numerous advantages as a technology-based science learning solution, their implementation in the field is not without significant challenges. One major challenge is the lingering skepticism among some educators about the effectiveness of virtual labs in developing hands-on practical skills and in-depth conceptual understanding. Conventional labs are considered capable of providing real-world experiences interacting directly with tools and materials, something that digital simulations have not yet fully replaced (Yusiani et al., 2025). In addition, digital competency constraints are also a barrier in themselves, considering that not all teachers and students have sufficient technological literacy to operate virtual lab software optimally (Akhyar et al., 2025). Differences in technology proficiency can create gaps in the learning process and reduce the effectiveness of virtual labs. Therefore, ongoing training, technical support, and planned integration into the curriculum are needed to maximize the use of virtual labs and provide tangible benefits to science learning.

The existing research gap indicates that most previous studies have focused more on the effectiveness of virtual labs from a cognitive perspective using a quantitative approach, such as improving student learning outcomes. However, there is still little research that has in-depth examined how the process of implementing virtual labs occurs in the context of secondary schools in Indonesia, especially from a qualitative perspective. Aspects such as teachers' and students' subjective perceptions of the use of virtual labs, including their attitudes, experiences, and levels of acceptance, have not been widely addressed as a primary focus. Furthermore, various practical obstacles faced in using virtual labs in real-life learning environments, such as limited infrastructure, digital competency, and technical support, have also rarely been the object of comprehensive study. Therefore, research that explores these aspects is needed to provide a more comprehensive and contextual understanding of the use of virtual labs in science learning at the secondary school level.

This study presents a novelty by offering a qualitative-descriptive approach that focuses on exploring the real and in-depth experiences of teachers and students in using virtual labs in science learning. Different from previous research that tends to be quantitative and oriented towards learning outcomes, this study highlights the social and pedagogical dimensions of technology utilization in the context of secondary education in Indonesia. Another novelty lies in highlighting the reality on the ground regarding how technology is accepted, interpreted, and integrated by educational actors at the school level. The findings of this study are expected to provide contextual and applicable input for the development of education policies, particularly in designing teacher training and strategies for integrating virtual labs into the science curriculum more effectively and sustainably.

The purpose of this study is to describe and analyze in depth how virtual labs are utilized in Natural Science (IPA) learning in secondary schools as an alternative solution to the limitations of conventional laboratories which are often inadequate in terms of facilities, costs, and security. This study also aims to comprehensively explore the perceptions, attitudes, and subjective experiences of teachers and students in using virtual labs, both in terms of ease of access, interactivity, and effectiveness in supporting the understanding of concepts and science process skills. Using a qualitative approach, this study seeks to present a real picture of technology-based learning practices in the field, as well as identify the challenges and potentials that accompany the implementation of virtual labs as part of learning innovations that are in line with curriculum developments and the demands of 21st-century education.

## **METHOD**

This study uses a qualitative descriptive approach which aims to describe in depth how virtual labs are utilized in science learning and the perceptions of teachers and students regarding the effectiveness of their use (Sanimah et al., 2024). The research subjects consisted of science teachers and junior high or high school students who had used virtual labs in their learning. The research location was several high schools that had implemented virtual lab-based science learning as case studies. Informants were selected using purposive sampling, namely those who were relevant and had direct experience using virtual labs, such as experienced science teachers and students who actively participated in virtual-based practicums (Rusdi, 2024).

Data collection techniques included in-depth interviews with teachers and students, observations of virtual lab activities in the classroom or computer laboratory, and documentation in the form of lesson plans, virtual lab usage logs, or student work results. Instruments used included semi-structured interview guides, observation

sheets for learning activities, and cameras or field notes for documentation. Data were analyzed using thematic analysis techniques with the steps of data reduction, data presentation, and drawing conclusions or verification as proposed by Miles and Huberman. Data validity was maintained through triangulation of sources and techniques, member checks to validate interview results with informants, and an audit trail to record the research process in detail. Ethical aspects of the research were maintained by providing clear information regarding the research objectives to informants, obtaining informed consent from all participants, and maintaining the confidentiality of informants' identities.

## **RESULTS AND DISCUSSION**

The results of the study indicate that the use of virtual labs provides easy access for students in conducting practicums, where experiments can be done anytime and anywhere through devices such as laptops or mobile phones, so they are no longer limited to certain class hours or the availability of physical equipment in the laboratory. The findings also revealed that interactive visualizations and experimental simulations provided by virtual labs can increase students' interest, enthusiasm, and active participation in science learning. Both teachers and students stated that the use of virtual labs helps in understanding scientific concepts that are abstract or risky if carried out directly, such as chemical reactions, body organ systems, and the laws of physics.

However, the implementation of virtual labs still faces several technical challenges, such as unstable internet connections and limited student devices. From the teacher perspective, virtual labs are generally perceived as a complement to conventional lab work, not a complete replacement, and many teachers expressed the need for further training to optimally utilize virtual lab features. Furthermore, support from the curriculum and school management plays a crucial role in successful implementation. Schools that are proactive in integrating technology and implementing flexible curricula like the Independent Curriculum (Kurikulum Merdeka) tend to show more positive outcomes in the use of virtual labs.

### **Virtual Lab as an Alternative Solution**

Virtual labs offer a realistic and relevant alternative solution for schools facing limitations in providing adequate physical laboratory facilities. In the context of limited space, equipment, materials, and budget, virtual labs enable practical activities to be carried out effectively through digital simulations. Their advantages lie not only in cost efficiency and flexibility of use, but also in their ability to serve as an information and communication technology (ICT)-based learning medium that supports modern learning approaches. Virtual labs have been proven to improve the quality of learning by providing interactive, visual, and widely accessible experimental experiences (Sabila et al., 2024). Thus, virtual labs are not only a temporary substitute in emergency situations, but also a long-term strategy for transforming science learning to be more inclusive, innovative, and adaptive to technological developments.

### **Active and Meaningful Learning**

The use of virtual labs in science learning significantly supports the creation of active and meaningful learning, in line with the constructivist approach that emphasizes students' active role in constructing their own understanding. Through digital simulations and experiments, students are not only recipients of information but also directly involved in the process of exploration, observation, analysis, and drawing conclusions, all of which contribute to strengthening a deeper understanding of

concepts. Putra & Efriyanti, 2023). Virtual labs provide a space for students to try, repeat, and modify experiments as needed, fostering curiosity and critical thinking skills. The visual and dynamic interactions in the digital environment also strengthen students' emotional engagement, making the learning experience more contextual and relevant to the real world. Thus, learning becomes not only cognitively and psychomotorically active but also meaningful because students are able to connect the knowledge learned to their own exploratory experiences through technology (Atmojo & Wardana, 2025).

### **Comparison with Conventional Practicum**

Compared to conventional labs, virtual labs offer a number of significant advantages, particularly in terms of time efficiency, visualization quality, and security. With virtual labs, students can conduct experiments instantly without having to physically prepare tools and materials, resulting in more effective learning time (Asikin, 2024). Visualization of complex scientific concepts, such as molecular structure, body organ systems, or motion dynamics, can be presented in an animated and interactive way, allowing students to understand the material more intuitively (Febriana et al., 2024). In addition, virtual labs eliminate the risk of accidents that often arise in conventional labs, such as exposure to hazardous chemicals or injuries from sharp instruments (Muawanah & Harjani, 2024). However, virtual labs cannot completely replace hands-on practical experience, especially in developing psychomotor skills, such as using laboratory equipment, mixing solutions, or manually measuring. These aspects still require real-world experience for students to fully master laboratory procedures. Therefore, virtual labs are ideally positioned as a complement and support for practical learning, not a total replacement, to create a holistic and balanced learning experience between mastery of concepts and skills (Zahro et al., 2023).

### **Implications for the Role of Teachers**

The implementation of virtual labs in science learning has important implications for transforming the role of teachers in the digital age. Teachers are no longer merely conveyors of information, but must also adapt to become technology facilitators, assisting students in accessing, exploring, and utilizing digital media effectively (Laila et al., 2025). In this context, teachers are required to possess adequate digital competencies, both in the technical aspects of operating virtual labs and in designing integrative, ICT-based learning strategies. Strengthening digital competencies is crucial so that teachers can creatively manage the learning process, guide students in using virtual labs according to learning objectives, and optimally integrate technological features into learning activities. Furthermore, teachers also need reflective and adaptive skills to evaluate the effectiveness of virtual lab use and adapt it to student needs and characteristics. Therefore, support in the form of ongoing training, professional mentoring, and progressive school policies is essential to strengthen teachers' capacity to optimally fulfill this new role.

### **Implementation Constraints and Challenges**

The implementation of virtual labs in science learning is not without various obstacles and challenges that require serious consideration. One of the main obstacles is the issue of access to technology, which includes the availability of devices such as laptops or smartphones, the quality of internet connections, and other supporting infrastructure, which is not evenly distributed across all schools, especially in remote areas or those with limited resources. This inequality in access directly impacts equal learning opportunities and the effectiveness of virtual lab utilization. Furthermore,

another equally important challenge is the process of adapting to a digital learning culture, both from the perspective of students and teachers (Agista & Hendrawati, 2025).

Not all students are ready to learn independently and are disciplined in using technology productively, while some teachers still struggle to shift from conventional teaching patterns to technology-based approaches. This shift requires a change in mindset, digital literacy skills, and effective virtual classroom management. Therefore, the success of virtual lab implementation depends not only on the provision of technology but also on systemic support in the form of training, mentoring, and educational policies that encourage a comprehensive transformation of learning culture (Hadiono, 2021).

### **Contribution to Science Learning in Secondary Schools**

The use of virtual labs significantly contributes to strengthening science learning at the secondary school level by providing alternative learning methods that are innovative, contextual, and adaptive to current developments. Through a digital simulation-based approach, students can explore scientific concepts in a more engaging, interactive, and understandable way, while simultaneously overcoming various limitations often encountered in conventional laboratory practices. Virtual labs also enable more flexible, personalized, and integrated learning that addresses the characteristics of learners in the digital age.

On the other hand, the existence of virtual labs encourages innovation in curriculum development that is more open to the use of technology, including in the development of lesson plans, project-based assessments, and differentiated learning. Furthermore, empirical experience from the use of virtual labs can also serve as a basis for policymakers in formulating more inclusive, evidence-based educational strategies that align with the needs of 21st-century learning (Widiyan et al., 2025). Thus, virtual labs are not only a learning tool, but also part of a more visionary and sustainable transformation of the science education system (Juneda et al., 2025).

### **CONCLUSION**

Based on the research findings, it can be concluded that virtual labs are an effective alternative solution to support the implementation of science practicums in secondary schools, especially for schools with limited physical laboratory facilities. The use of virtual labs has been proven to improve students' understanding of complex and abstract science concepts through interactive visualizations, as well as fostering interest, enthusiasm, and active engagement in the learning process. Teacher and student responses generally showed a positive attitude towards the use of virtual labs, with the note that this technology is more appropriate as a complement to conventional practicums, not as a complete replacement, especially in terms of developing psychomotor skills. The main obstacles in its implementation include limited technological infrastructure, internet network access, and the digital skills of teachers and students, which still need to be continuously improved. The successful use of virtual labs is greatly influenced by the support of school policies, teacher readiness to integrate technology into learning, and curriculum flexibility that allows adaptation to digital learning innovations. Overall, virtual labs have great potential to support science learning that is more flexible, safe, and relevant to the needs of the 21st century, and open up opportunities for wider implementation in the secondary education system in Indonesia.

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