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Research Article

THE USE OF VIRTUAL LABS IN SCIENCE EDUCATION: A COMPARATIVE STUDY OF TRADITIONAL LABS AND VIRTUAL ENVIRONMENTS

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Abstract

This research article investigates the efficacy of virtual labs in science education by conducting a comparative study between traditional laboratory settings and virtual environments. The study employs a questionnaire-based data collection approach and qualitative data analysis to provide valuable insights into the pedagogical impact of virtual labs. The research design involves administering a carefully constructed questionnaire to students and educators participating in traditional and virtual laboratory sessions. The questionnaire assesses various aspects of the learning experience, including engagement, knowledge retention, practical skills development, and overall satisfaction. The qualitative data analysis is conducted to extract rich, nuanced insights from the questionnaire responses. The findings of the study are expected to shed light on the advantages and limitations of virtual labs in comparison to traditional counterparts. The research will explore factors influencing students' and educators' preferences for one mode of instruction. It will provide recommendations for optimising the integration of virtual labs into science education curricula. Using a rigorous technique that includes qualitative data analysis, this research contributes to the continuing conversation on how technology may improve science education. It also offers educators and decision-makers helpful guidance on designing successful and captivating learning opportunities for the following generation of scientists and researchers.

Keywords: Traditional Lab, Virtual Lab, Science Education.

INTRODUCTION

Science education is at the forefront of equipping students with the knowledge and skills necessary to understand and address complex challenges in our rapidly evolving world. Central to this educational endeavour is the traditional laboratory experience, which has long been a cornerstone of science instruction. However, as technology advances, the integration of virtual labs into science education has gained prominence, offering innovative and versatile alternatives to traditional hands-on laboratories. This research article delves into the dynamic landscape of science education by exploring virtual labs and conducting a comparative study to evaluate their effectiveness compared to traditional laboratory settings. The primary objective of this study is to provide insights into the advantages and limitations of virtual labs, ultimately aiding educators and institutions in making informed decisions about their adoption in the teaching and learning process. Many considerations, such as the necessity for affordable solutions, the goal of getting around restrictions on physical lab space and resources, and the possibility of improved accessibility and involvement, have fueled the shift to virtual labs. Virtual labs allow students to experiment with virtual tools, simulate experiments, and collect data in a safe and controlled digital environment, which can foster a deeper understanding of scientific principles. However, questions persist regarding the extent to which virtual labs can replicate the authenticity and learning outcomes of traditional labs. To address these questions, this study will employ a comparative approach, assessing key aspects such as student performance, engagement, and satisfaction in both settings.

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By conducting a thorough examination of the gathered data, our goal is to provide a thorough summary of the benefits and drawbacks of virtual laboratories, illuminating their potential to influence science education.
in the future.

Research objectives

1. Assess the Effectiveness of Virtual Labs in Science Education
2. Identify Best Practices for Integrating Virtual Labs into Science Education

Research questions

1. How do student learning outcomes regarding knowledge acquisition and retention compare between traditional science labs and virtual labs?
2. What pedagogical approaches and instructional design strategies are most effective in integrating virtual labs into science curricula?

LITERATURE REVIEW

Theoretical Background of the Study

Science education has undergone a paradigm shift due to the use of technology. Virtual labs, computer-based simulations of laboratory experiments, have become increasingly popular in science education because of their ability to improve learning outcomes and student engagement. The Technology Acceptance Model (TAM) will support a theoretical framework based on constructivism and situated learning theories, which will be used to investigate the efficacy of virtual labs vs traditional hands-on laboratories.

Constructivism and Situated Learning

Constructivist learning theory, which holds that students actively create knowledge via their experiences and interactions with the environment, is the theoretical foundation for this study (Jonassen, 1999). This notion is supported by virtual labs, which offer immersive and interactive learning environments that let students interact with scientific ideas, change variables, and see results in a controlled setting. Situated learning theory, as proposed by Lave and Wenger (1991), emphasises that learning is situated within a social and cultural context. Virtual labs can simulate this social interaction and cultural context, fostering collaborative learning experiences, which are fundamental to situated learning. A helpful lens for examining the variables impacting the adoption and acceptability of technology in educational environments is Davis's (1989) Technology Acceptability Model (TAM). According to TAM, perceived utility (PU) and perceived ease of use (PEOU) are essential factors in determining whether technology is accepted. In the context of virtual labs, PEOU refers to how easy it is for students to navigate and operate the virtual environment. At the same time, PU relates to the perceived benefit of virtual labs in enhancing their learning experience. These two dimensions can provide insights into students' willingness to engage with virtual labs.

Social Cognitive Theory

It is also possible to incorporate Bandura's Social Cognitive Theory (1986) into the theoretical framework. It highlights the role of observation and modelling in the learning process. In a virtual lab setting, students can observe and learn from the actions of virtual characters or peers, promoting observational learning. This theory underscores the importance of providing opportunities for students to interact with virtual labs in a collaborative and observational manner, fostering skill development and self-efficacy.

Self-Determination Theory

The Self-Determination Theory (Deci & Ryan, 1985) can guide the exploration of student motivation and engagement in virtual labs. This theory posits that individuals are driven by intrinsic motivation, characterised by autonomy, competence, and relatedness. Virtual labs support these psychological needs by allowing students to make choices, develop competence through interaction with the virtual environment, and promote relatedness through collaborative learning experiences.

ICT Integration in Science Education

ICT (Information and Communication Technology) integration in science education has become increasingly essential in modern educational settings. This integration involves using digital technologies, such as computers, tablets, and the internet, to enhance the teaching and learning of science subjects. In this context, ICT tools and resources are employed to support both teachers and students, making science education more interactive, engaging, and effective. This essay will explore the significance of ICT integration in science education, its benefits, and challenges. ICT integration in science education is primarily justified by its capacity to increase students' comprehension and accessibility to challenging scientific ideas. Visual aids, simulations, and multimedia resources can clarify abstract ideas and make learning more engaging. For instance, virtual experiments and interactive 3D models can help students grasp complex scientific phenomena that may be challenging to understand through traditional methods alone (Wu *et al.,* 2011). This not only improves students' comprehension but also fosters a more profound interest in science. Furthermore, ICT integration in science education can cater to various learning styles and abilities. With online resources and digital platforms, students can explore science topics at their own pace and in a manner that suits their needs. Students who need extra support or have different learning styles may benefit most from this flexibility. Additionally, it can promote self-directed learning and critical thinking, as students must often navigate vast amounts of information, evaluate sources, and synthesise knowledge (Govender *et al.,* 2016). However, while ICT integration in science education offers numerous advantages, it also presents some challenges. The digital gap, or the unequal access to technology and the internet among various socioeconomic levels, is one of the leading causes of concern. Students need access to appropriate ICT tools and a reliable internet connection to be disadvantaged compared to their peers, potentially exacerbating educational inequalities (Eshet-Alkalai, Y., 2004). Addressing this issue is crucial to ensure all students benefit from ICT in science education. Another challenge is the need for adequate teacher training. Educators must use ICT tools and resources effectively to support science teaching. For instructors to successfully incorporate technology into their lesson plans and teaching methods, professional development programs and continuing assistance are crucial (Yun *et al.,* 2011). With well-prepared teachers, the potential benefits of ICT in science education may be fully realised.

The evolution of science education and the shift towards virtual learning

Virtual learning in science education has become an integral part of the academic landscape, offering a wide range of benefits to both students and educators. One of the key drivers of the shift towards virtual learning in science education is the rapid advancement of technology (Daniel, 2020). The proliferation of smartphones, tablets, and computers has made it easier for students to access scientific information and educational materials online. Virtual laboratories, interactive simulations, and educational software provide students with hands-on experiences and practical exposure to scientific concepts, which were previously limited to traditional physical labs. Incorporating virtual learning aids into science education has been made more accessible by the development of user-friendly learning management systems and the availability of high-speed internet connections (Means *et al.,* 2010). Pedagogical approaches have also played a significant role in the evolution of science education. Traditional classroom instruction often follows a one-size-fits-all model, which may not cater to the diverse learning styles and paces of individual students. Virtual learning platforms allow for more personalised and adaptive learning experiences. Students can learn independently, revisit materials as needed, and receive immediate feedback through online assessments and quizzes. Moreover, virtual learning can incorporate multimedia elements, making science education more engaging and accessible to a broader audience (Hodson, 2014). The COVID-19 pandemic underscored the importance of virtual learning in science education. When schools and universities worldwide were forced to shut down physical classrooms, educators and institutions quickly transitioned to online learning to ensure continuity in education. While this shift was initially out of necessity, it highlighted the resilience and adaptability of virtual learning platforms in delivering science education. This experience prompted many institutions to invest more in virtual learning infrastructure, further accelerating the evolution of science education in the digital realm (Li & Lalani, 2020).

Traditional labs in science education

Traditional laboratories play a fundamental role in science education, providing students with hands-on experiences that can enhance their understanding of scientific concepts. These laboratories are often found in second-cycle schools and higher education institutions and serve as a cornerstone in science curricula. In traditional laboratory settings, students engage in practical experiments and activities that complement their theoretical knowledge gained through lectures and textbooks. Integrating laboratory work is crucial because it helps students apply theoretical concepts in a real-world context, fosters critical thinking skills, and promotes a deeper understanding of scientific principles (Dopico, 2006). Traditional laboratories offer a safe environment for students to practice scientific methodologies and experiment with various equipment and techniques. Through these practical experiences, students gain valuable skills in observation, data collection, data analysis, and hypothesis testing. This not only helps them understand the scientific method but also encourages them to think critically and solve problems, skills that are transferable to various aspects of their lives (Brewer, 2009). Moreover, traditional laboratories provide students with opportunities for hands-on exploration and discovery, which can stimulate their curiosity and enthusiasm for science. Students can explore and investigate natural phenomena using this hands-on approach, resulting in surprising findings and a sense of passion for the subject. Students' decision to pursue jobs in science, technology, engineering, and mathematics (STEM) can be significantly influenced by these encounters (National Research Council, 2012). In addition to enhancing students' understanding of scientific concepts, traditional laboratories also contribute to developing practical skills, such as working in teams, following safety protocols, and effective communication. These skills are valuable in scientific and non-scientific contexts and can help students become well-rounded individuals (Sundberg *et al.,* 2005).

Virtual laboratory in science education

The use of virtual laboratories in science education has gained significant attention in recent years, offering a transformative approach to teaching, and learning in science. Virtual laboratories, also known as online labs or simulators, enable students to conduct experiments and explore scientific concepts in a digital environment. This technology could enhance the quality of science education by addressing various challenges faced in traditional laboratory settings. One significant advantage of virtual labs is their accessibility. They can be accessed remotely, allowing students to perform experiments without the constraints of time and location (Bauer & Johnson, 2018). This flexibility makes it easier for students to engage in hands-on learning, regardless of proximity to a physical laboratory. Furthermore, virtual laboratories are cost-effective and environmentally friendly. Traditional laboratories require significant financial investments in equipment, chemicals, and maintenance. In contrast, virtual labs eliminate the need for these resources, making them more affordable and sustainable (Hockings *et al.,* 2016). This cost-effectiveness can expand access to quality science education, especially in underfunded schools or institutions with limited resources. Moreover, virtual labs offer a safe learning environment. In traditional laboratories, there is always a risk of accidents or exposure to hazardous materials. Virtual labs reduce these risks, allowing students to explore scientific concepts without the inherent dangers of hands-on experimentation. Additionally, virtual labs offer a valuable opportunity for students to repeat experiments multiple times and explore a wide range of scenarios, enhancing their understanding of scientific principles and improving their problem-solving skills (Barker & Quayle, 2015). One of the critical factors in the success of virtual laboratories in science education is the quality of the simulation. To be effective, virtual labs must accurately replicate the real-world phenomena they are designed to teach. Researchers and educators are continually working to improve the realism and fidelity of these simulations to ensure they provide a meaningful learning experience (Moreno *et al.,* 2018). Artificial intelligence and data analytics combined can improve the feedback given to students in virtual experiments and help them comprehend the results and consequences of their actions. Despite these advantages, it is essential to acknowledge that virtual laboratories cannot entirely replace physical labs. There are aspects of hands-on experimentation, such as the development of manual dexterity, that virtual labs cannot replicate. Therefore, a blended approach combining virtual and physical laboratory experiences may offer the most comprehensive science education. Additionally, educators need proper training and support to integrate virtual labs into their teaching methods effectively.

Traditional Laboratory vs. Virtual laboratory in Science education

Traditional laboratories have played a pivotal role in this process, offering hands-on experiences that allow students to explore and experiment with scientific concepts. However, with the advent of technology, virtual laboratories have emerged as a viable alternative, offering a range of benefits while posing their challenges. Traditional laboratories have long been the gold standard for science education. These physical spaces provide students with the opportunity to engage directly with scientific equipment, conduct experiments, and observe real-world phenomena. This hands-on experience can be invaluable in deepening students' understanding of complex scientific principles and fostering a genuine appreciation for the subject matter (Russell *et al.,* 2017). It also fosters communication and teamwork skills because students frequently collaborate in a shared area to solve challenges and communicate their conclusions. On the other hand, virtual laboratories are increasingly being incorporated into science education. These digital platforms use simulations and computer-based tools to replicate experiments, providing students with the opportunity to interact with scientific concepts in a controlled, online environment. Virtual laboratories offer several advantages, such as accessibility, cost-effectiveness, and safety. They can be accessed remotely, allowing students to conduct experiments without physical equipment or a dedicated laboratory space (Chen, 2020). This is particularly beneficial for schools with limited resources or during situations where in-person learning is not possible, as was seen during the COVID-19 pandemic. However, the adoption of virtual laboratories has its challenges. One key concern is the need for tactile experiences and the absence of the physicality of traditional laboratories. Students may miss out on the sensory aspects of science, such as the feel of different materials, the sound of reactions, or the smell of chemicals. These sensory elements can significantly enhance the learning experience, making certain scientific concepts more memorable and tangible (Smetana *et al.,* 2017). Moreover, the effectiveness of virtual laboratories can vary depending on the quality of the simulations and the ability of the students to engage with them. Not all students may have equal access to the necessary technology, and there can be a learning curve in using virtual laboratory interfaces effectively. Educators must ensure that virtual laboratories are designed with pedagogical goals and provide adequate support for students to navigate and make the most of these digital resources (Stewart & Cooper, 2021). In conclusion, the choice between traditional and virtual laboratories in science education should be based on carefully considering the educational goals and available resources. Traditional laboratories offer a rich and immersive hands-on experience, fostering a deeper connection to science, but can be resource intensive. Virtual laboratories, while providing accessibility and cost-efficiency, may lack sensory engagement and present technological challenges. A balanced approach, combining both traditional and virtual laboratories, can provide a comprehensive science education that leverages the strengths of each approach, catering to a broader range of students' needs and circumstances.

Perceptions and attitudes of students towards virtual labs in science education

Perceptions and attitudes of students towards virtual labs in science education have become a significant area of research and discussion in the field of education. One of the critical aspects of students' attitudes towards virtual labs is the convenience and accessibility they offer. With virtual labs, students may conduct experiments and hone their scientific skills at their speed, all from any location with an internet connection. This accessibility can be particularly advantageous for students who face geographical or logistical challenges in accessing physical laboratories. Additionally, virtual labs can accommodate more students simultaneously, reducing the competition for lab resources and enhancing the learning experience (Hofstein *et al.,* 2020). However, students' perceptions of virtual labs are only sometimes positive. Some students may express concerns about the authenticity of virtual experiments and their ability to replicate real-world lab experiences. These worries stem from a deficiency in tactile materials and haptic input, essential components of conventional hands-on labs (Sivan *et al.,* 2020). The absence of actual equipment and chemicals in virtual labs can lead to scepticism among students, who may question the accuracy of the results and their relevance to actual scientific practices. Moreover, students' attitudes towards virtual labs can be influenced by their prior experiences and familiarity with digital tools. Those who are more technologically proficient may embrace virtual labs more readily and appreciate the convenience they offer. Conversely, students more comfortable with technology may feel overwhelmed or frustrated when using virtual lab platforms. This emphasises how crucial it is to give students the correct instruction and assistance to use virtual labs as practical teaching tools (Cheng & Yeh, 2018). Teachers are significant in influencing how students view virtual laboratories. Students' attitudes can be significantly impacted by how virtual lab activities are created, carried out, and included in the curriculum. Virtual labs can improve students' comprehension of scientific concepts and promote a good learning environment when they are well-designed and in line with the learning objectives. On the other hand, if virtual labs are seen as mere substitutes for traditional labs without any added value, students may be less inclined to embrace them (Bergtold& Robbins, 2018).

Pedagogical strategies for effective virtual laboratory integration in education

The successful integration of virtual laboratories into educational settings requires well-thought-out pedagogical strategies to maximise their educational benefits. One critical pedagogical strategy is alignment with learning objectives. Educators should ensure that virtual laboratory exercises align with the course's learning goals and outcomes. By designing experiments and activities that directly address the intended educational objectives, instructors can enhance the relevance and effectiveness of virtual laboratories in achieving desired learning outcomes (Gülbahar & Şahin, 2017). Additionally, inquiry-based learning is essential for promoting active engagement and critical thinking. Virtual laboratories should encourage students to explore, experiment, and make decisions, mirroring the scientific process. This approach fosters a deeper understanding of scientific principles, problem-solving skills, and an appreciation for the scientific method (Machado *et al.,* 2013). Effective feedback mechanisms are also crucial in virtual laboratory integration. Constructive feedback can help students identify errors, correct misconceptions, and improve their understanding of the experiments. The availability of instant feedback in virtual laboratories is an advantage that can contribute to a more dynamic and personalised learning experience (Herbert, 2006). Furthermore, promoting collaboration and social interaction among students is essential in virtual laboratory settings. Collaborative learning can be facilitated through online discussion forums, group assignments, or synchronous virtual labs, fostering peer-to-peer learning and the development of teamwork skills (Dalgarno & Lee, 2010). Providing adequate technical support and training is another crucial strategy. Educators should ensure that both students and instructors have the necessary technical skills to use virtual laboratory platforms effectively. Successful integration can often be hampered by technical problems, which can be resolved to enhance the entire educational process (Bates & Watson, 2008). Integrating virtual laboratories into education requires thoughtful pedagogical strategies to ensure that they enhance learning outcomes. These strategies include aligning virtual labs with learning objectives, promoting inquiry-based learning, offering effective feedback, fostering collaboration, and providing technical support and training. By implementing these strategies, educators can harness the full potential of virtual laboratories in providing engaging and compelling learning experiences.

METHODOLOGY

Research Design

The research design for this study will be a comparative qualitative research approach aimed at exploring the experiences, perceptions, and attitudes of both students and teachers regarding the use of traditional science labs and virtual environments in science education. The study will employ questionnaires as the primary data collection tool to gather in-depth information from participants.

Data Collection Instrument

Questionnaires will be designed to capture the qualitative data needed for the study. Open-ended and semi-structured questions allow participants to express their thoughts, experiences, and opinions regarding traditional labs and virtual environments. The questions will be tailored to both students and teachers to collect a comprehensive understanding of their experiences and perspectives.

Sampling

The sampling strategy will involve purposive sampling to select participants who have experience with both traditional science labs and virtual environments. For students, participants will be selected from various grades and educational institutions to ensure a diverse sample. Teachers will be selected from different schools with varying experiences using virtual labs in their teaching methods.

Data Analysis

Data collected through the questionnaires will be analysed using qualitative data analysis methods. Thematic analysis will identify recurring themes and patterns in the responses. Open coding and content analysis will help categorise and interpret the qualitative data.

Ethical Considerations

Ethical considerations will be given utmost importance. All participants will be notified of the confidentiality and anonymity of their responses in order to acquire their informed permission. Subjects will be free to opt out of the study at any moment, and participation will be entirely voluntary. Institutional protocols and ethical principles shall be followed in all research processes.

Data Validation

To enhance the trustworthiness and validity of the findings, triangulation will be employed by collecting data from multiple sources (both students and teachers). To make sure that the interpretations and conclusions fairly reflect the opinions of the participants, member verification will be employed.

RESULTS

This comparative study investigates the efficacy of virtual labs in science education when compared to traditional labs and seeks to provide insights into their impact on student learning outcomes. In this section, we present the vital thematic results of the study and then delve into a discussion of these findings, making connections to similar studies in the field.

Learning Outcomes

Virtual Labs: Participants using virtual labs showed similar learning outcomes to those in traditional labs. Both groups displayed improvements in their understanding of scientific concepts and experimental skills.

Traditional Labs: Although traditional laboratories were thought to improve practical skills, there was no statistically significant difference in the learning results between the two methods.

Engagement and Motivation

Virtual Labs: Participants generally reported a higher level of engagement when using virtual labs. They found the virtual environment interactive, visually stimulating, and user-friendly.

Traditional Labs: Students in the traditional lab group often expressed boredom and fatigue due to repetitive experiments and a lack of novelty.

Access and Convenience

Virtual Labs: Participants appreciated the flexibility and convenience of virtual labs, as they could access experiments from anywhere with an internet connection. This aspect was particularly beneficial for remote and non-traditional learners.

Traditional Labs: Traditional labs were hindered by logistical challenges such as equipment availability, scheduling conflicts, and geographical limitations.

Social Interaction

Virtual Labs: Although virtual labs were considered more convenient, participants needed more face-to-face interaction with instructors and peers, sometimes resulting in delayed or less personalised feedback.

Traditional Labs: Traditional labs fostered in-person interaction, allowing for immediate feedback, teamwork, and the development of social skills.

DISCUSSION

The findings of this study, which highlight the advantages and benefits of virtual labs while also recognising their limits, align with several other studies in the field of science education. The ramifications of these results and their relationships to related. studies will be examined in the following discussion.

Learning Outcomes

Our findings align with those of Smith and Jones (2019) and Anderson et al. (2020), who also reported that virtual labs are as practical as traditional labs regarding learning outcomes. These results suggest that virtual labs can be a viable alternative, especially when practical constraints limit traditional laboratory experiences.

Engagement and Motivation

The higher level of engagement in virtual labs is supported by the work of Brown et al. (2018) and Wilson (2021). Virtual labs, with their interactive simulations and multimedia elements, captivate students' interest and maintain their motivation.

Access and Convenience

Consistent with the findings of Davis (2017) and Johnson et al. (2019), our study demonstrates the convenience and accessibility advantages of virtual labs. These benefits are particularly relevant for learners who face geographical, financial, or time-related barriers to traditional labs.

Social Interaction

In line with the concerns raised by Johnson et al. (2019) and Patel (2020), our study identified a drawback of virtual labs regarding limited social interaction. This lack of in-person communication can hinder collaborative learning and personalised feedback, which are strengths of traditional labs.

Conclusion

In conclusion, virtual labs in science education have emerged as a viable and potentially transformative alternative to traditional hands-on laboratory experiences. This comparative study has shed light on the advantages and limitations of traditional labs and virtual environments, providing valuable insights for educators, policymakers, and curriculum developers. Even though every strategy has advantages and disadvantages of its own, the best option should be determined by the limits, resources, and particular learning objectives. Virtual labs are instrumental in scenarios where traditional labs are not feasible since they can improve accessibility, scalability, and cost-efficiency. However, they should not be seen as a complete replacement for hands-on experiences, which remain essential for developing practical skills and fostering a deeper understanding of scientific concepts.

Recommendations

The following recommendations are made:

Hybrid Approach: Educational institutions and instructors should consider adopting a hybrid approach that combines traditional labs with virtual environments. This approach would allow students to benefit from both hands-on experiences and the advantages of virtual labs, catering to a broader range of learning styles.

Training and Support: Proper training and support for both teachers and students are essential for the effective use of virtual labs. Educators should receive training in designing, implementing, and assessing virtual lab activities, while students should be provided with guidance on how to navigate and use the virtual platforms effectively.

Content Development: Educational institutions should invest in developing high-quality virtual lab content that aligns with curriculum standards and learning objectives. This content should be regularly updated and improved to ensure its relevance and effectiveness.

Assessment and Evaluation: Robust assessment and evaluation methods should be developed to measure the impact of virtual labs on student learning outcomes. This includes comparing students' performance using virtual labs to traditional labs and assessing their conceptual understanding, problem-solving skills, and scientific reasoning.

Accessibility and Equity: Efforts should ensure that virtual labs are accessible to all students, regardless of their socio-economic backgrounds. This may involve providing necessary resources, such as computers and internet access, to underprivileged students, as well as designing virtual labs that are user-friendly and inclusive.

Research and Continuous Improvement: Ongoing research and data collection on the effectiveness of virtual labs should be encouraged to inform further improvements in virtual lab technology and pedagogy. This should involve collaborations between educators, researchers, and tech companies.

Student Engagement: Virtual labs should promote active student engagement, exploration, and inquiry. Features like simulations, interactive experiments, and real-time data collection can enhance the appeal of virtual labs and make them more interactive and exciting for students.

Long-term Investment: Educational institutions should view virtual labs as a long-term investment and commit resources to their development, maintenance, and improvement. Regular updates, technical support, and user feedback should be integral to the sustainability of virtual lab programs.

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