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Virtual Labs in Science Education: A Comprehensive Review of Their Impact on Learning Outcomes

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Abstract

This journal is all about theoretical review based on analysis of 20 articles and journals, it presents a mixture of supportive and opposing perspectives. While many studies agree on the positive impact of virtual labs on student achievement and attitudes towards science and some dissenting views suggest a lesser influence on academic success. Nonetheless, there's a general agreement on the beneficial role of virtual labs in enhancing learning outcomes. Additionally, it highlights the positive attitudes students develop towards learning through virtual labs and the similar levels of skill development compared to traditional labs. Ultimately, it conclude that virtual labs offer promising prospects for improving educational outcomes and creating positive learning environments for students.

Keyword: Virtual laboratory, Practical Knowledge, Achievement , Science students, Critical Thinking skill, Scientific literacy ability, Attitude, Problem-solving skill.

Introduction

Laboratories are integral to science education, providing controlled environments for conducting experiments and achieving educational goals. Previous studies have demonstrated the various advantages of incorporating labs into science teaching. These benefits include promoting a deeper understanding of scientific concepts, addressing misconceptions, and improving students' skills in design, evaluation, and problem-solving. Additionally, science labs encourage curiosity, foster positive attitudes toward science, and enhance communication among students. By facilitating meaningful learning experiences, laboratory activities serve as a vital link between new information and comprehensionStudents use virtual labs for hands-on experimentation, visualizing complex concepts, practicing techniques, exploring scenarios, collaborating with peers, and receiving feedback from teachers, ultimately enhancing their learning experience in science and other subjects. . The popularity of virtual lab apps in India has increased due to government support, the rise in digital learning, their ability to enhance the learning experience, address resource constraints, adapt to remote learning needs, and support STEM education initiatives Virtual labs typically offer a range of features such as interactive simulations, data collection tools, virtual instruments, and real-time feedback mechanisms. They can cover various scientific disciplines including physics, chemistry, biology, engineering, and more. These platforms are especially valuable for distance learning, remote experimentation, and supplementing traditional laboratory instruction. Additionally, virtual labs often provide opportunities

for students to repeat experiments, manipulate variables, and explore concepts in ways that may not be feasible in a traditional lab setting.

There are various ways to define a virtual lab. It can be described as a computer program enabling students to conduct simulated experiments via the internet. Alternatively, it could be a collection of simulations, such as applets, flash-based demonstrations, or animations, allowing students to perform experiments remotely at any time. Virtual labs are particularly advantageous for conducting experimental-oriented problems without the expenses associated with maintaining physical labs. They are also beneficial when experiments involve hazardous chemicals or risky equipment. Moreover, virtual labs are used in systems aiming to replace physical machines with virtual machines on a single host server. Virtual lab gives real life experience. Anyone can operate any experiments from anywhere. It help children's to develops their scientific attitudes.

Background of the study

Virtual labs are becoming increasingly prevalent in education and training, offering numerous benefits for learners. These labs allow users to practice multiple times, at their own pace, and without the risk of harm to themselves or equipment. They provide access to costly or risky equipment, such as telescopes or electron microscopes, and cover a wide range of topics including radioactivity measurements and cell stimulation. Accessible via computers and mobile devices, virtual labs range from simple 2D games to interactive 3D simulations. They offer advantages over traditional labs, such as cost-effectiveness, easy access, time-saving, environmental safety, and adaptability, though they may lack the same level of interaction as conventional labs.

Several organizations have developed virtual laboratories, with initiatives like Go-Lab and LiLa providing remote frameworks and broader scopes. Commercial software packages like Labster offer immersive simulators with game-based components to engage learners. Virtual labs can also incorporate immersive technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), enhancing the learning experience and improving student skills, knowledge, and motivation.Discipline-specific virtual labs have been developed in fields like physics, engineering, biology, and chemistry, offering resources such as simulators, educational materials, and multimedia resources. These labs allow students to manipulate chemicals and perform experiments without additional costs or risks. However, there are challenges, such as the static nature of information provided by current virtual laboratories and the need to update labs based on student levels.

Labster offers a wide range of virtual laboratory simulations for higher education in biology, chemistry, physics, and engineering. PhET Interactive Simulations provides web and mobile simulations for physics, chemistry, biology, earth science, and math, fostering interactive learning experiences. Virtual Lab Apps by EduSmart supplements classroom teaching with virtual labs in physics, chemistry, and biology, enhancing students' understanding of practical concepts. iLab: Virtual Lab Experiments allows students to perform virtual experiments across physics, chemistry, and biology disciplines. Meanwhile, LabX provides virtual lab experiments with a user-friendly interface, catering to physics, chemistry, and biology education needs. BioDigital Human offers a detailed 3D atlas of the human body for anatomy and physiology study, while Labii and Lab Archives provide lab management platforms for organizing experiments and managing data, with Lab Archives focusing on electronic laboratory notebooks. Benchling offers virtual lab tools tailored for molecular biology research, and Chem Collective Virtual

Lab focuses on chemistry experiments and simulations for interactive learning. These apps cater to diverse scientific needs, from anatomy study to molecular biology research and chemistry education.

In India, virtual lab apps play a significant role in enhancing school children's learning experiences. One such app is e-Basta, developed by the Indian government, offering a wide array of digital learning resources, including virtual lab simulations across different subjects and grades. Amrita Virtual Lab provides interactive simulations and experiments in science and mathematics, covering topics like physics, chemistry, biology, and mathematics. Robolab focuses on robotics and STEM education, offering virtual lab modules for hands-on learning in robotics, coding, and electronics. Funtoot integrates virtual lab modules into its adaptive learning platform, providing interactive experiments to deepen students' understanding of scientific concepts. Byju's - The Learning App offers interactive lessons and virtual labs across various subjects, personalized to cater to individual learning styles. These virtual lab apps serve as valuable supplements to traditional classroom instruction, offering engaging and interactive learning opportunities for school children in India.

Practical knowledge involves hands-on experience, problem-solving abilities can developed through real life experience. It refers to information, skill, and understanding that can be directly applied to real-life task .Achievement not only measure in quantitative approach but also refer to notable accomplishments reached through one’s effort and skill. Scientific thinking not only restricted to science students only, it is for everyone whose attitude, ability, interest develop towards science. Critical thinking skill involve judgments, solve complex problems, analyze and evaluate of a problems. It includes skills such as reasoning, problem-solving, decision-making, and the ability to assess any problem.All the skills can developed through the use of virtual lab.

Literature Review

Several studies have developed into the integration of virtual laboratories alongside traditional hands-on learning to enhance student research skills and practices. According to Millar (2004), practical laboratory sessions often incur high costs, and many schools face shortages of laboratory materials and equipment. However, these cost constraints can be addressed through alternative teaching methods. Many experts advocate for a transformation in the chemical curriculum by integrating ICT, internet, and other modern technologies of the 21st century to enhance teaching and learning effectiveness. They hold a positive stance on ICT adoption, suggesting that these changes can enhance the learning environment. One such advancement is the utilization of Virtual Laboratories (VLab), which enable the conduct of diverse experiments at a reasonable cost.

In their paper , Euan Lindsay et al (2007) addresses a significant concern within virtual laboratories: the potential for students to become so immersed in the learning experience that they overlook the underlying hardware, sometimes even engaging in unrelated activities like playing video games. The ongoing research investigates the extent to which students actively participate in cognitive processes and how their knowledge is constructed within these virtual environments. The study presents a multi-site examination of four distinct virtual laboratories across different colleges, highlighting differences in engagement between inexperienced and experienced users. Furthermore, the paper discusses how students' motivation may be influenced by their reliance on the virtual lab environment.

El-Sabagh (2010) demonstrated that the utilization of virtual labs enhances comprehension, refines operational abilities, boosts learning engagement, and fosters innovation. The study compared the impact of a web-based virtual lab environment with traditional teaching methods on conceptual

understanding and science process skills among 4th-grade primary school students. Employing an instructional design model incorporating 3D animations and interactive experimental activities, the research found that while both groups initially exhibited equivalent levels of understanding and skills, the experimental group showed significantly superior performance in both areas following the intervention.

Tüysüz (2010) investigated the impact of a virtual laboratory on students' achievement and attitude in chemistry education, focusing on the "Separation of Matter" unit for 9th-grade students. Using a virtual laboratory with 16 virtual experiments, the study compared outcomes with traditional teaching methods. Findings indicated positive effects on achievement and attitudes, highlighting the potential of virtual labs to enhance learning experiences in chemistry education.

The study by Radhamani et al. (2014) investigated the impact of virtual biotechnology laboratories on student learning and performance in classroom settings. Employing a mixed-method approach, the study found that virtual labs effectively improved student learning outcomes, offering a cost-effective alternative to traditional labs. Theoretical frameworks guiding the investigation included concepts related to technology-enhanced learning and active learning. The study identified gaps in traditional laboratory practices, highlighting the potential of virtual labs to address resource constraints and enhance accessibility to lab experiences. Overall, the findings contribute to the growing body of literature supporting the integration of virtual laboratories into educational curricula.

According to Bortnik et al. (2017) conducted a pedagogical experiment to compare the effectiveness of traditional hands-on learning with blended learning, combining online and in-person components. Their study emphasized evaluating student lab reports, test results, and portfolios to measure the impact of integrating virtual laboratory components. The findings suggested that blending virtual and hands-on learning environments holds promise in enhancing student research skills and practices in analytical chemistry studies.In line with this, the study also investigated the efficacy of blended learning in tertiary education, particularly in enhancing research skills and practices. By utilizing a set of 10 criteria to evaluate student lab reports, the researchers sought to bridge the gap in understanding the influence of virtual laboratory components in traditional learning environments.

Ramadhan and Irwanto (2017) explored the utilization of virtual laboratories to enhance students' thinking abilities, skills, and scientific attitudes in science education. Employing a qualitative descriptive research method, they reviewed 23 articles published in Indonesia from 2011 to 2016. Findings highlighted the positive impact of virtual laboratories on various aspects of student learning, including problem-solving skills, critical thinking, creativity, and motivation. The study underscores the importance of integrating virtual laboratories into teaching practices to enhance learning outcomes and quality in science education.

The researcher Ranjan (2017) investigated the effectiveness of virtual laboratories in developing concepts and skills in physics education, specifically comparing them with traditional real-time physics laboratories. Utilizing a quantitative approach, the study involved 208 students divided into control and experimental groups. The research likely drew upon theories related to physics education, laboratory learning, and educational technology. Instruments such as pre-test and post-test assessments were used to measure learning outcomes and skills development. The study underscores the potential of virtual laboratories to address limitations associated with traditional labs and enhance students' understanding and skills in physics concepts, particularly focusing on the photoelectric effect. Overall, it highlights the importance of integrating virtual simulations as a valuable tool in physics education.

Baladoh, Elgamal, and Abas (2017) conducted a study to examine the efficacy of virtual laboratories in enhancing students' comprehension of concepts and their proficiency in managing electronic circuits. The experimental investigation took place in Mansoura vocational preparatory schools, specifically targeting hearing-impaired students in Egypt. The outcomes distinctly demonstrated the effectiveness of the virtual laboratory in enhancing students' academic performance and practical skills concerning electronic circuitry.

Ratamun and Osman (2018) conducted a study to evaluate the effectiveness of Virtual Lab compared to Physical Lab in mastering Science Process Skills for a chemistry experiment on salt. Additionally, they explored the impact of gender on skill mastery and examined the interaction effect between groups and gender on skill acquisition. Employing a quasi-experimental design with nonequivalent control group pre-test and post-test, the researchers utilized the Science Process Skill mastery test (SPST) to assess effectiveness. Purposive sampling was employed to select 4th-grade science stream students from Malaysia, resulting in 147 participants. The study likely draws on theories related to educational psychology, learning styles, and cognitive development to understand how different laboratory settings impact Science Process Skills mastery. Findings indicated that Physical Lab was more effective than Virtual Lab in enhancing skill mastery for the salt experiment, with no significant gender influence or interaction effect between groups and gender on skill acquisition. This study fills a gap in understanding the effectiveness of virtual and physical labs in mastering Science Process Skills for chemistry experiments and sheds light on gender differences in skill acquisition across different laboratory settings.

According to Ambusaidi et al. (2018) investigated the impact of virtual lab learning experiences on 9th-grade students' achievement and attitudes towards science and learning. Employing a quantitative approach, the study utilized pre-test and post-test assessments to measure student achievement and attitudes, with a control and experimental group consisting of 69 students. The research likely drew upon theories related to science education and technology integration, using instruments such as achievement assessments and attitude scales administered through questionnaires or surveys. While the study found no significant impact on academic achievement, it revealed positive attitudes towards learning through virtual labs. The research underscores the potential of virtual labs to enhance science education experiences but suggests further exploration and development of effective learning strategies in this domain.

Susmitha and Nayana (2019) investigated the effectiveness of Virtual Laboratory Classes (VLC) in improving the achievement of secondary school pupils in chemistry. Employing an experimental design with a pre-test—post-test non-equivalent group, the study compared the achievement of students taught using VLC with those taught using conventional activity-oriented methods. The research involved a total sample of 80 secondary school students, and statistical techniques such as Analysis of Variance (ANOVA) and Analysis of Covariance (ANCOVA) were utilized for data analysis. The study likely drew on theories related to instructional design, educational technology, constructivism, and experiential learning to understand the effectiveness of VLC in promoting chemistry learning practices. Primary tools employed included lesson transcripts based on VLC and conventional methods, as well as an achievement test in chemistry to measure students' academic performance. Findings suggested that VLC was more effective than conventional methods in improving students' achievement in chemistry, highlighting the importance of integrating technology-enhanced learning environments into traditional classroom settings. This study addressed the gap in understanding the effectiveness of VLC in secondary

school chemistry education, providing insights into the potential benefits of technology integration for enhancing learning outcomes.

The researchers Latifah, Ikhsan, and Sugiyarto (2019) investigated the impact of using a virtual chemistry laboratory (VCL) on students' cognitive learning achievement in chemistry education. Employing a quasi-experimental design with a post-test only approach, the study involved 163 eleventh-grade students from two high schools in Indonesia, randomly divided into three groups. Each group engaged in different learning activities: traditional laboratory practicum, VCL-based practicum, or a combination of both. Cognitive learning achievement was assessed using a multiple-choice test with 30 items, and statistical analysis, specifically ANOVA, was employed to analyze the data.. It investigated how students interact with virtual laboratory simulations, multimedia elements, and traditional laboratory experiences to develop their understanding of chemistry concepts. The study's findings suggest that incorporating virtual chemistry laboratories into chemistry education can positively impact students' cognitive learning achievement. Virtual laboratories offer a safe, efficient, and cost-effective alternative to traditional laboratory practicum, while multimedia elements enhance students' understanding and retention of chemistry concepts.One potential research gap identified in the study is the need for further investigation into the combination of practicum activities and multimedia presentations to achieve higher cognitive learning achievement. Additionally, future research could explore the effects of VCL on other academic performances, such as learning motivation, creativity, or scientific attitude.

A. A. Altalbe (2019)explores how the use of virtual labs impacts students' performance by examining the influence of usability and learning objectives. Altalbe presents a model based on the characteristics of model and laboratory learning objectives to comprehensively understand students' perceptions and outcomes from virtual lab usage. Survey data from 116 first-year engineering students were collected to reflect their individual experiences with virtual lab technologies. Statistical analysis and testing were conducted using the partial least squares structural equation modeling technique (PLS-SEM). The results suggest that the proposed model effectively captures students' viewpoints, and the components investigated are indeed relevant in representing the effects of using such virtual labs.

The study of Supahar and Widodo (2021) investigated the impact of integrating Virtual Laboratory (VL) with Problem-Based Learning (PBL) on enhancing science literacy and problem-solving skills among seventh-grade students. Their study utilized a Quasi-experiment with Nonequivalent Control Group Design and found that the combined approach significantly improved students' scientific literacy and problem-solving abilities. This research addresses a gap in understanding the effectiveness of VL and PBL integration specifically for junior high school students, offering valuable insights into enhancing science education through innovative pedagogical methods.

The researcher Koehler (2021) explored the influence of virtual labs on high school students' attitudes towards chemistry using a mixed-methods action research approach. Employing surveys and interviews, the study evaluated student attitudes pre- and post-engagement with virtual laboratories. The Attitude Toward the Subject of Chemistry Inventory (Bauer, 2008) served as the primary instrument for assessing attitudes, supplemented by author-conducted interviews. While the research didn't identify significant changes in attitudes before and after the virtual laboratory experience, it noted a general decline in students' perceptions of chemistry's interest and utility. This study fills a gap in understanding how virtual labs shape student attitudes towards chemistry, emphasizing the importance of ongoing assessment of their impact.

According to Trisnaningsih et al. (2021) explored the development of a virtual laboratory-based STEM approach with feedback to enhance critical thinking skills, focusing on the acid-base concept in science education. Their research followed a systematic development process, incorporating needs analysis, design, and development phases. Theoretical underpinnings likely include STEM education, virtual laboratory development, and pedagogical approaches to fostering critical thinking. Various research instruments such as interview questionnaires and feasibility assessments were employed. The study addresses gaps in traditional learning methods, emphasizing the importance of practical activities and effective learning media. Overall, the findings suggest the potential of virtual laboratories to improve critical thinking skills and enhance understanding of complex scientific concepts like acid-base chemistry.

Rutwik Patel and Abhinav Patel et al (2022)The literature review explores the growing relevance of virtual laboratories in secondary education to address the challenge of bridging theoretical concepts with practical understanding. It discusses various virtual laboratory implementations and methodologies, highlighting their role in enhancing hands-on learning experiences for students. By evaluating existing research, the review emphasizes the importance of innovative educational technologies in fostering scientific skills and knowledge among secondary students.

According to Ramy Elmoazen et al (2023) discusses the integration of learning analytics in virtual laboratories, focusing on empirical research between 2015 and 2021. It highlights the prevalence of studies in higher education, particularly in the medical field. Most studies utilize student log files to derive learning analytics, focusing on performance, activities, perception, and behavior. However, the landscape remains fragmented and exploratory, lacking common standards or platforms for collaboration and advancement in leveraging learning analytics for teaching and learning support.The result of this study showed that 48% of studies were conducted in higher education. The review emphasizes the need for common standards, protocols, or platforms to facilitate collaboration among educators and researchers in harnessing the full potential of learning analytics for enhancing teaching and learning experiences in virtual laboratories. Despite the variety of research domains, platforms, and analytical approaches explored, there is still untapped potential in leveraging learning analytics to its fullest extent in this context.

The study by Diah Puji Lestari et al(2023) investigates the impact of combining virtual laboratory with demonstration methods on lower-secondary school students' scientific literacy in a science course. Conducted with 102 students aged 12-14 in Yogyakarta, Indonesia, the quasi-experimental design includes three groups: experiment 1 (virtual laboratory + demonstration), experiment 2 (virtual laboratory only), and control (demonstration only). Scientific literacy is measured using pretest and post-test multiple-choice tests. Results indicate significant improvements in scientific literacy for all groups, with experiment 1 group showing the highest increase (84.5%). The study underscores the effectiveness of combining virtual laboratory and demonstration methods in enhancing scientific literacy among lower-secondary students.

Discussion

After examining 20 articles and journals, it's evident that virtual labs greatly influence children's learning outcomes and scientific attitudes, as supported by Bortnik (2017), Suphar & Widodo (2021), and Susmitha & Nayana (2019). Similarly, Latifah (2019), Tuysuz (2010), and Ramdhan (2017) argue for the positive effects of virtual labs on student achievement and attitudes. Radhamani (2014),

Trisnaningsih (2021), Ranjan (2017), and Diah Puji Lestari (2023) further suggest that virtual labs enhance student learning outcomes. These findings are reinforced by Elmoazen (2023) and Rutwik Patel and Abhinab Patel (2022). However, dissenting views from Koehler (2021) and Ratamun and Osman (2018) suggest that virtual labs may not significantly impact academic achievement. Ambusaidi (2018) proposes that while there may not be a significant impact on academic achievement, students generally exhibit positive attitudes towards learning through virtual labs. Meanwhile, El-Sabahh (2010) contends that there are similar levels of understanding and skill development in both virtual and traditional laboratories.

Coclusion

In conclusion, the examination of numerous articles and journals reveals a compelling body of evidence supporting the positive influence of virtual labs on children's learning outcomes and scientific attitudes. Studies by various researchers consistently demonstrate the benefits of virtual labs in enhancing student achievement, attitudes, and learning outcomes. While dissenting views exist, suggesting a lack of significant impact on academic achievement, the overall consensus suggests that virtual labs offer valuable opportunities for enhancing learning experiences. Furthermore, the acknowledgment of positive attitudes towards learning through virtual labs and the comparable levels of understanding and skill development in virtual and traditional laboratories contribute to the growing acceptance of virtual labs as effective educational tools. Thus, virtual labs represent a promising avenue for improving educational outcomes and fostering positive learning environments for students.

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