Journal of Education and Learning Technology (JELT)
ISSN 2720-7730
Volume 6 Issue 8 2025 pp 696 - 713
Available online at: https://noyam.org/journals/jelt/
DOI: https://doi.org/10.38159/jelt.2025691

A Systematic Review of Effectiveness and Factors Affecting the Usage of Virtual Science Laboratories in High Schools

Segun Michael Ojetunde [1]

[1] Department of Mathematics, Science and Technology Education, University of Johannesburg, Johannesburg, South Africa.

ABSTRACT

The integration of virtual laboratories (VLs) into school curricula has become widely accepted, with empirical studies demonstrating their effectiveness based on students' academic performance in various science subjects across different countries. However, a comprehensive analysis of their combined effectiveness has yet to be conducted, as noted in this review. Using the PRISMA guidelines, six databases were searched, resulting in the identification of 4,180 relevant articles. Ultimately, 13 articles were selected based on specific inclusion and exclusion criteria. The findings revealed that 38.46% of the studies focused on virtual Physics labs, 38.46% on Chemistry, and 23.08% on Biology. The studies indicated a significant improvement in students' performance in VLs. As compared to traditional ones. Factors such as gender, attitude, and school type were found to influence students' success with virtual labs. The study contributes to the existing research on individual and school factors affecting the adoption of new technology. Therefore, it is recommended that VLs be utilized either independently or alongside traditional labs, with particular attention given to female students. The study contributes to existing literature that enhances understanding of the significance and effectiveness of different types of science laboratories.

Correspondence
Segun Michael Ojetunde
Email: sojetunde@gmail.com

Publication History
Received:
17th March, 2025
Accepted:
10th July, 2025.
Published:
12th September, 2025.

To Cite this Article:
Ojetunde, Segun Michael. "A Systematic Review of Effectiveness and Factors Affecting the Usage of Virtual Science Laboratories in High Schools." *Journal of Education and Learning Technology* 6, no. 9(2025): 696 - 713. https://doi.org/10.38159/jelt.2025691.

Keywords: Virtual laboratory, Physics, Biology, Chemistry.

INTRODUCTION

Effective teaching and learning in the sciences necessitates that both learners and educators follow organized and systematic procedures. Due to the unique nature of scientific subjects, teaching scientific concepts requires methods that differ from traditional approaches. Experimentation stands out as a key technique in science education, which is why nearly all high school science subjects are taught through experimental processes.

Teachers sometimes interpret the objectives of science learning through experimental work as explicitly as it was specified in the curriculum.[1] In addition to the strong link between science experiments and learning goals, Logar, et.al., emphasized that experimentation helps bridge the gap between observation and critical thinking about observed phenomena. They further argued that experimentation serves as a connection between the real world and the conceptual understanding of it.[2]

[1] A. Hofstein, M. Kipnis, and I. Abrahams, *Teaching Chemistry – A Study Book* (Sense Publishers: Rotterdam, 2013).
[2] Ana Logar, Cirila Peklaj, and Vesna Ferk Savec, "Effectiveness of Student Learning during Experimental Work in Primary School.," *Acta Chimica Slovenica* 64, no. 3 (2017).

Experimental activities, despite their unique characteristics, do not occur in isolation during science teaching and learning. Traditionally, these activities take place in well-equipped and designated laboratories. Initially, laboratories were established to confirm and illustrate information learned in lectures or textbooks. Over time, they evolved into platforms for engaging students in investigations, discoveries, inquiry, and problem-solving activities.[3]

Subsequently, the role of the laboratory has expanded significantly, becoming central to the learning processes in science education.[4] Laboratory experiments are known to promote inquiry-based learning, allowing students to construct knowledge through scientific exploration. Additionally, students can make inferences during experiments that help them predict and explain observations in their immediate environments.[5] Furthermore, learning in a laboratory setting challenges students to identify problems, gather and analyze data, draw conclusions, and assess their own learning progress.[6]

Moreover, laboratory activities foster social interactions between teachers and students, as both engage in collaborative inquiries, creating a classroom environment that resembles a community of scientists.[7] Additionally, it has been reported that employing cooperative learning strategies in the science laboratory can lead to enhanced student achievement and productivity.[8]

However, studies have highlighted the limitations of science laboratories in providing comprehensive information that supports learning objectives and enhances student achievement in science subjects. Ural noted that changes observed during laboratory work alone do not guarantee that students fully understand the concepts being presented.[9] Similarly, it has been observed that many teachers prefer a "cookbook" approach to laboratory practice, which does not align with the open-ended teaching styles recommended by many curricula.[10]

Additionally, the National Safety Council estimates that approximately 5,000 safety-related accidents occur in American schools each year, with at least 10% of these involving science laboratories.[11] A study conducted by the Hong Kong Ministry of Education across 401 high schools revealed that 29% of reported injuries from 2011 to 2012 involved 348 students and four staff members. This led to the conclusion that laboratory accidents are a global issue, emphasizing the need for improved safety measures in school science environments.[12]

In recent years, particularly with the onset of the COVID-19 pandemic, the emphasis on school science safety has led to the widespread adoption of virtual laboratories.[13] This shift has facilitated the transition from traditional classroom laboratories to virtual environments. Virtual laboratories, as computer programs, enable students to conduct simulated experiments via the web or as standalone applications.[14] Diwakar described virtual laboratories as user-interactive, content-rich programs that emulate experimental protocols through simple click gestures, providing an authentic laboratory

---

3 Avi Hofstein and Per M. Kind, "Learning In and From Science Laboratories," in *Second International Handbook of Science Education* (Dordrecht: Springer Netherlands, 2012), 189–207, https://doi.org/10.1007/978-1-4020-9041-7_15.

4 Vincent N Lunetta, Avi Hofstein, and Michael P Clough, "Learning and Teaching in the School Science Laboratory: An Analysis of Research, Theory, and Practice," in *Handbook of Research on Science Education* (Routledge, 2013), 393–441.

5 Hasan Ozgur Kapici and Hakan Akcay, "Cognitive Theories of Learning on Virtual Science Laboratories," *Education Research Highlights in Mathematics, Science and Technology*, 2019, 107–26.

6 Wouter R. van Joolingen and Zacharias C. Zacharia, "Developments in Inquiry Learning," in *Technology-Enhanced Learning* (Dordrecht: Springer Netherlands, 2009), 21–37, https://doi.org/10.1007/978-1-4020-9827-7_2.

7 Avi Hofstein and Vincent N. Lunetta, "The Laboratory in Science Education: Foundations for the Twenty-first Century," *Science Education* 88, no. 1 (January 3, 2004): 28–54, https://doi.org/10.1002/sce.10106.

8 Hofstein and Lunetta, "The Laboratory in Science Education: Foundations for the Twenty-first Century."

9 Evrim Ural, "The Effect of Guided-Inquiry Laboratory Experiments on Science Education Students' Chemistry Laboratory Attitudes, Anxiety and Achievement.," *Journal of Education and Training Studies* 4, no. 4 (2016): 217–27.

10 Hofstein and Lunetta, "The Laboratory in Science Education: Foundations for the Twenty-first Century."

11 Cathy Mariotti Ezrailson, "Danger in the School Science Lab: Are Students At Risk?," in *Proceedings of the South Dakota Academy of Science*, vol. 92, 2013.

12 Zisheng Lu, "Analysis of China Students' Laboratory Accidents in the Past 39 Years and the Laboratory Management Reform in the Future," *Education for Chemical Engineers* 42 (January 2023): 54–60, https://doi.org/10.1016/j.ece.2022.12.001.

13 Rakhi Radhamani et al., "What Virtual Laboratory Usage Tells Us about Laboratory Skill Education Pre- and Post-COVID-19: Focus on Usage, Behavior, Intention and Adoption," *Education and Information Technologies* 26, no. 6 (November 9, 2021): 7477–95, https://doi.org/10.1007/s10639-021-10583-3.

14 Manisha Bajpai and Anil Kumar, "Effect of Virtual Laboratory on Students' Conceptual Achievement in Physics," *International Journal of Current Research* 7, no. 2 (2015): 12808–13.

experience.[15] Ibrahim noted that, compared to physical laboratories, virtual laboratories can enhance interactions between teachers and students during experiments and may also reduce the costs associated with experimentation.[16]

Jimoyiannis argued that virtual laboratories offer simulations that serve as alternative learning tools, helping students develop conceptual understandings while addressing gaps in their theoretical knowledge of physics.[17] Scholars have highlighted several advantages of virtual laboratories, including the ability to conduct time-consuming experiments in a shorter timeframe, perform hazardous experiments in a safe environment, recreate events that would be impossible to observe in a physical lab, provide a cost-effective alternative to traditional laboratories, allow students to learn at their own pace, and offer immediate feedback to help students track their learning progress.[18]

However, the adoption of virtual science laboratories for various high school subjects has not been widely documented. The onset of the COVID-19 pandemic in 2020, along with the subsequent lockdown of school activities, has prompted some schools to integrate virtual laboratories. [19] Nevertheless, the lack of comprehensive findings on the usage and effectiveness of virtual laboratories underscores the need for this systematic review. The study aims to examine previous research on the use and effectiveness of virtual laboratories in Physics, Chemistry, and Biology at the high school level, as well as to identify potential factors that may hinder their effectiveness.

Several systematic reviews have examined the use of virtual laboratories. For instance, Reeves and Crippen conducted a review focusing on virtual laboratories for undergraduate science and engineering courses, analyzing articles published between 2009 and 2019. Their findings indicated that virtual labs primarily aim to enhance student motivation, with limited exploration of individual experiences or social learning aspects.[20] Similarly, Triejunita et.al., reviewed virtual laboratories for learning and found that they significantly increase student motivation and participation, as well as improve learning outcomes.[21] Potkonjak et.al., also explored virtual laboratories in science, technology, and engineering education, concluding that either real laboratories should be made accessible remotely or should be fully replicated as software-based virtual labs.[22] They argued that virtual laboratories generally offer advantages over remote access to real labs. Byukusenge et.al., focused on the effectiveness of virtual laboratories in teaching Biology, revealing that these labs effectively enhance students' conceptual understanding, laboratory skills, motivation, and attitudes toward the subject, while also being safer and more cost-effective than traditional labs.[23] Additionally, Santos and Prudente conducted a meta-analysis on the effectiveness of virtual laboratories in science education, finding that virtual labs have a medium effect size (g = 0.587) in improving student achievement in science.[24]

---

[15] Shyam Diwakar et al., "Usage and Diffusion of Biotechnology Virtual Labs for Enhancing University Education in India's Urban and Rural Areas," in *Virtual Reality in Education: Breakthroughs in Research and Practice* (IGI Global, 2019), 433–53.

[16] Dogan Ibrahim, "Engineering Simulation with MATLAB: Improving Teaching and Learning Effectiveness," *Procedia Computer Science* 3 (2011): 853–58.

[17] Athanassios Jimoyiannis et al., "Preparing Teachers to Integrate Web 2.0 in School Practice: Toward a Framework for Pedagogy 2.0," *Australasian Journal of Educational Technology* 29, no. 2 (2013).

[18] Amosa Isiaka Gambari, Halima Kawu, and Oluwole Caleb Falode, "Impact of Virtual Laboratory on the Achievement of Secondary School Chemistry Students in Homogeneous and Heterogeneous Collaborative Environments," *Contemporary Educational Technology* 9, no. 3 (July 16, 2018): 246–63, https://doi.org/10.30935/cet.444108.

[19] Radhamani et al., "What Virtual Laboratory Usage Tells Us about Laboratory Skill Education Pre- and Post-COVID-19: Focus on Usage, Behavior, Intention and Adoption."

[20] Shalaunda M. Reeves and Kent J. Crippen, "Virtual Laboratories in Undergraduate Science and Engineering Courses: A Systematic Review, 2009–2019," *Journal of Science Education and Technology* 30, no. 1 (February 9, 2021): 16–30, https://doi.org/10.1007/s10956-020-09866-0.

[21] Chessa Nur Triejunita, Atina Putri, and Yusep Rosmansyah, "A Systematic Literature Review on Virtual Laboratory for Learning," in *2021 International Conference on Data and Software Engineering (ICoDSE)* (IEEE, 2021), 1–6, https://doi.org/10.1109/ICoDSE53690.2021.9648451.

[22] Veljko Potkonjak et al., "Virtual Laboratories for Education in Science, Technology, and Engineering: A Review," *Computers & Education* 95 (April 2016): 309–27, https://doi.org/10.1016/j.compedu.2016.02.002.

[23] Céline Byukusenge, Florien Nsanganwimana, and Albert Paulo Tarmo, "Effectiveness of Virtual Laboratories in Teaching and Learning Biology: A Review of Literature," *International Journal of Learning, Teaching and Educational Research* 21, no. 6 (June 30, 2022): 1–17, https://doi.org/10.26803/ijlter.21.6.1.

[24] Marc Lancer Santos and Maricar Prudente, "Effectiveness of Virtual Laboratories in Science Education: A Meta-Analysis," *International Journal of Information and Education Technology* 12, no. 2 (2022): 150–56, https://doi.org/10.18178/ijiet.2022.12.2.1598.

However, most reviews examining the effectiveness of virtual science laboratories have not differentiated between studies focused on high school and those on higher education. Additionally, they often overlook the institutional and student characteristics that influence the effectiveness of virtual laboratories in teaching science subjects. This presents a significant gap that the present review aims to address. A previous study by Stuckey-Mickell and Stuckey-Danner surveyed 38 participants from Africa, Europe, and America and discovered a preference among students for physical laboratories over other types of laboratories.[25]

The present study, therefore, aims to provide comprehensive findings on the use and effectiveness of virtual laboratories by conducting an in-depth review of existing experimental studies related to the use of virtual laboratories in teaching science subjects at the secondary school level. The research questions guiding this review are:

1. What are the research methodologies of the studies that assessed the effectiveness of virtual laboratories?
2. In which subject area at the high school level is VL most used?
3. How effective are virtual laboratories in different subject areas at the high school level?
4. What are students' characteristics that moderate the effectiveness of VL at the high school level?

METHODOLOGY

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, updated to reflect recent conceptual and practical advancements in the field of systematic reviews, were adopted for this review. PRISMA served as a framework for the subsequent steps in the review process, which included: search strategies, selection criteria, data collection process, data items, risk of bias in individual studies, summary measures, synthesis of results, and risk of bias across studies.

Search Strategies

One of the approaches used for systematically mapping the literature involved designing search strategies to capture all possible articles related to the review's title. This process began by developing keywords that align with the variables specified in the review title.

After creating the keywords, a test search was conducted on Google Scholar to refine and develop effective search strings. This step aimed to ensure a precise and comprehensive search for relevant articles. The search strings were crafted based on the research questions posed in the study, as follows:

The search strings developed were utilized to search databases including IEEE Xplore, ERIC, and Scopus, alongside three AI-driven databases: Litmap, Consensus, and Open Knowledge Map. This comprehensive search resulted in a total of 4,180 identified articles. Among these, 2,595 entries were found in various formats such as magazines, dissertations, conference papers, book chapters, and reports. The total number of peer-reviewed articles in English published between 2010 and 2024, which fell within the scope of the review, amounted to 1,585.

"Virtual lab" or "Virtual laboratory" or "virtual chemistry lab" or "virtual chemistry laboratory" or "virtual biology lab" or "Virtual biology laboratory" or "Virtual physics lab" or "Virtual Physics laboratory".

Selection Criteria

The eligibility criteria for selecting articles for the review focused on studies conducted at the secondary school level that examined the effectiveness of virtual laboratories in Chemistry, Physics, and Biology from 2010 to 2023. Priority was given to quasi-experimental studies that included moderating variables. The reviewed articles qualified for inclusion based on the following criteria:

[25] Tracey A Stuckey-Mickell and Bridget D Stuckey-Danner, "Virtual Labs in the Online Biology Course: Student Perceptions of Effectiveness and Usability," *MERLOT Journal of Online Learning and Teaching* 3, no. 2 (2007): 105–11.

- relate to the use of VL for teaching and learning science subjects such as physics, chemistry, and biology in secondary or high school;
- describe VL used in the high school context;
- describe the effectiveness of virtual laboratories' use of science pedagogy;
- published in a peer-reviewed journal in the English language only;
- published between January 2010 and July 2024.

Exclusion criteria were marked out as:

- published in a book chapter, in the form of conference proceedings, or in another format such as blogs, opinion pieces, presentations, technical reports, etc.;
- not focused on secondary science subjects such as Physics, Chemistry, and Biology;
- not published in a peer-reviewed journal;
- published in other languages apart from English; and
- studies on the use and effectiveness of virtual laboratories that were carried out among tertiary education students.

Quality Assessment and Data Extraction

To ensure the quality of the review process, several checks were conducted, including the removal of duplicates and the filtering out of lower-quality articles. This was accomplished using two approaches, as illustrated in Figure 1. Firstly, the data (articles retrieved from each database) were downloaded and imported into a systematic review web-based application called Rayyan. This step helped avoid duplication and facilitated preliminary screening by allowing the examination of titles and abstracts of all collected articles. The second phase involved a thorough manual examination of the content of the articles after many irrelevant ones had been filtered out using Rayyan. During this phase, the established exclusion and inclusion criteria were applied to select the most relevant articles for the review.

.

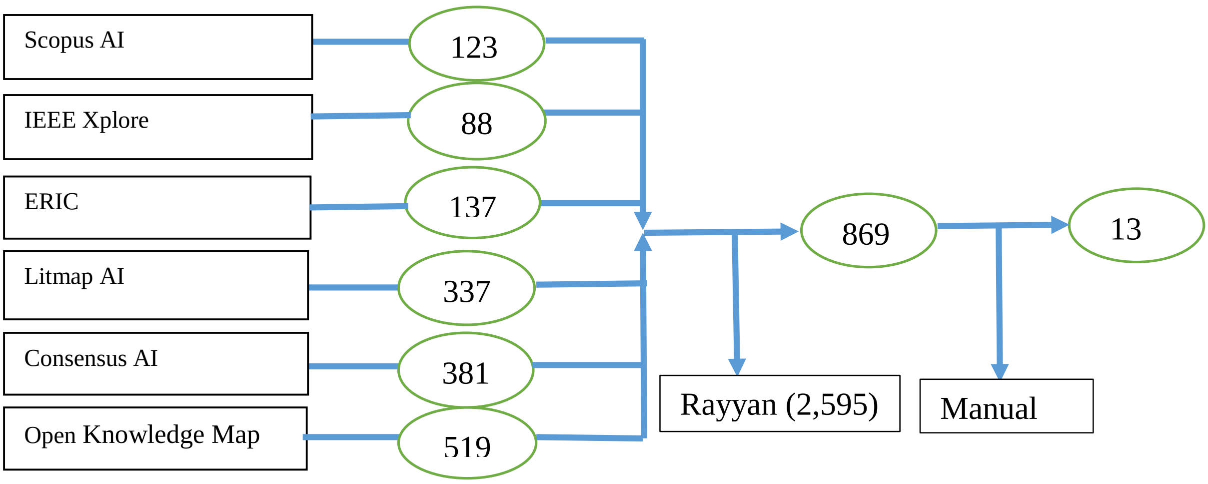

Figure 1: Selected Databases and the Corresponding Number of Articles

After removing documents in the form of magazines, dissertations, conference papers, book chapters, reports, and other non-peer-reviewed materials using Rayyan, a total of 869 peer-reviewed full-text articles remained. These articles were then screened manually, and ultimately, 13 articles were deemed eligible, as illustrated in the adopted PRISMA framework for article selection in Figure 2. Data was extracted from the eligible 13 articles according to the outline presented in Table 1. For coding and mapping the data to refine it for the systematic review, the data extraction process followed the guidelines and procedures established by the Evidence for Policy and Practice Information and Coordinating Centre.[26]

[26] Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI Center). "Guidelines for the extraction of information and quality assessment of primary studies in educational research, "Guidelines for the Extraction of Information and Quality

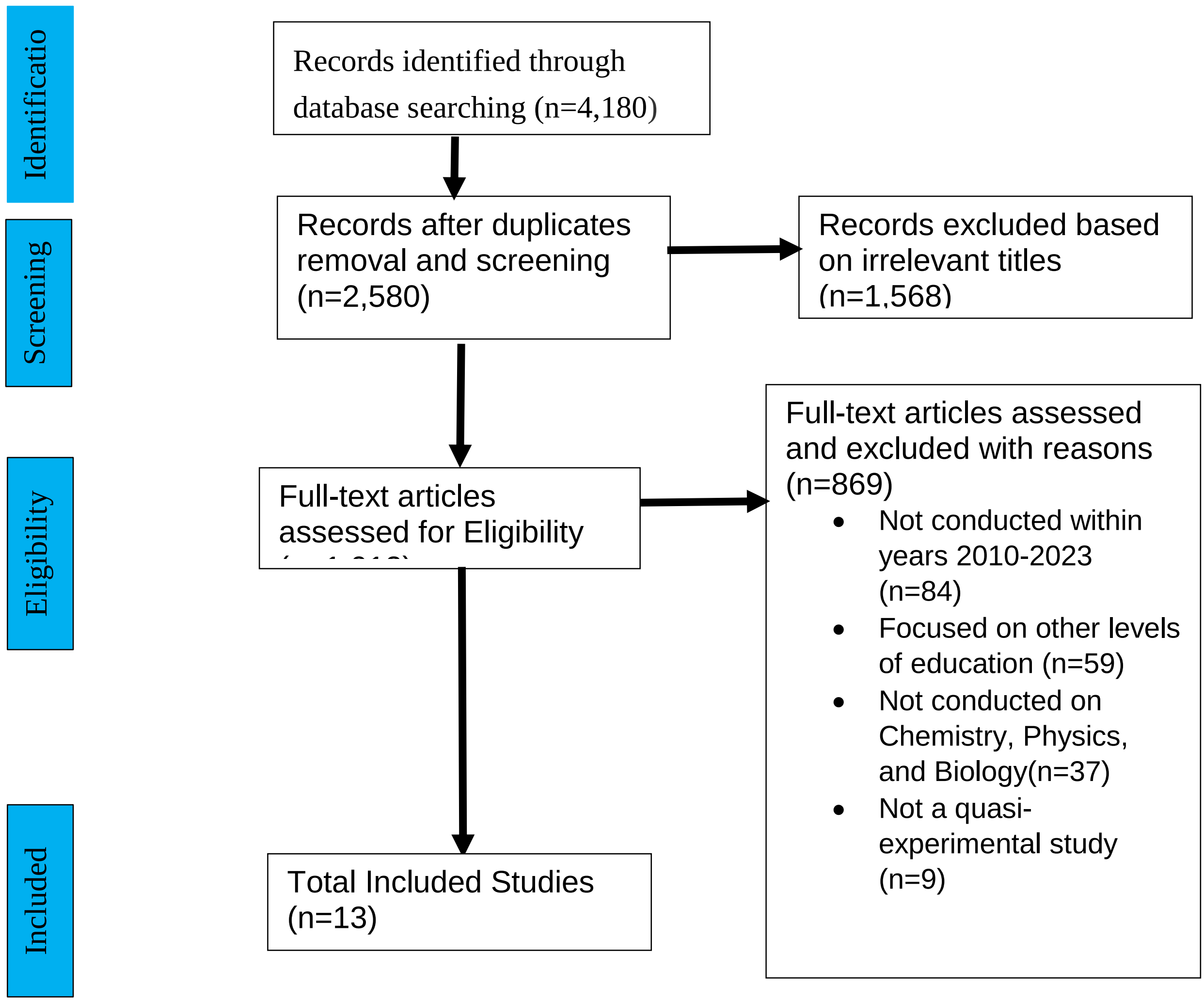

Figure 2: Adapted PRISMA Framework for Article Selection

Data extraction was conducted using the following parameters: year of publication, subject area on which the study was conducted, country where the study was carried out, design of the study, moderating variables used, number of participants, mean scores of each form of laboratory, and the results emanated from the study.

Assessment of Primary Studies in Educational Research," 2003, https://eppi.ioe.ac.uk/cms/Resources/Tools/tabid/184/Default.aspx#Guidelines.

Table 1: List of Articles Eligible for Data Extraction and the Extracted Data

Authors and year	Subject area	Country	Design Type	Control	Moderating Variable	Participant	Mean	Result
Mohammed et al. (2020)	Physics	Nigeria	Pre-test-post-test	Real-Lab	Gender (no difference was recorded)	67 students	VL= 86.0, RL=72.0	A combination of VLE and the Conventional method is the most effective, followed by VLE, while the Conventional method is the least effective.
TÜYSÜZ, C. (2010)	Chemistry	Turkey	Pre-test-post-test	Real-Lab	No moderation	341 students	VL= 10.67 RL=5.40	VL had positive effects on students' achievements and attitudes compared to traditional teaching methods.
Yaki et al., (2020)	Biology	Nigeria	Pretest-Posttest	Real-Lab	Gender (Not significant)	60 Students	VL= 56.0 RL=45.82	The experimental group had a significant performance improvement, and it was found to be gender friendly.
Okafor, et al., (2018)	Chemistry	Nigeria	Pre-test-post-test	Real-Lab.	(Gender: significant) (School type: not significant)	164 students	VL= 14.75 RL=12.32	There is a significant effect of the virtual Chemistry Laboratory over the Conventional one on students' achievement during acid-base titration experiments, such that the females performed better than the males.
Oser, R. & Fraser, B.J. (2015)	Biology	USA	Post-test Only	Real Lab.	Gender (favour male) & attitude	322 students	VL=2.90, RL=2.78	No significant differences between instructional groups suggest that the promise of using these technological interventions in school classrooms might not be fulfilled.
Manyilizu, M. C. (2023)	Chemistry	Tanzania	Post-test only	Real & Paper	No moderation	26 students	VL=57.0 RL=43.0	Students who first attended a virtual laboratory performed better in a real laboratory than

								those who first attended a real laboratory.
Hamed, G. & Aljanazrah (2020)	Physics	Palestine	Post-test only	Real-Lab.	No moderation	90 students	VL=3.07, RL=3.42	Virtual and Real laboratory should be combined (no significant difference)
Papalazarou et al., (2023)	Physics	Greece	Pretest Post-test	Real-Lab.	Attitude	20 students	VL=50.83, RL= 59.0	The study revealed no statistically significant difference regarding students' experimentation in either lab mode. Moreover, students' attitudes towards both virtual and physical labs were similarly positive.
Mosqueda, M. C. (2023)	Physics	Philippine s	Pre-test Post-test	Real-Lab.	No moderator	40 students	VL= 33.35, RL=32.0	A significant difference between the experimental and control groups was found.
Hermansyah et al., (2019)	Physics	Indonesia	Pre-test-Post-test	Real Lab.	No moderator	53 students	VL=63.5, RL =30.5	The mean increase in the achievement of the experimental group is higher than the control group.
Ambusaidi et al., (2018)	Chemistry	Oman	Pretest-Posttest	Real-Lab.	No Moderator	69 students	VL=9.59, RL=7.36	The virtual lab has no significant impact on students' academic achievement or their attitudes toward science.
Byukusenge et al. (2024)	Biology	Rwandan	Pretest-posttest	Real Lab.	Gender	168 students	VL=80.1 RL=40.7	The intervention is important to improve students' attitudes toward the learned topics; however, the effect of gender was not significant.
Alhashem & Alfailakawi (2023)	Chemistry	Kuwait	Pre-test Posttest	Real Lab.	No Moderator	22 Students	VL=3.75 RL=3.51	No significant differences were observed between the two groups concerning the technical aspects of the experiments.

PRESENTATIONS OF RESULTS

The data extracted from each article is summarized in Table 1, and the results are presented subsequently. As illustrated in Figure 3, only one article was published in 2010, with no publications until 2015. Subsequent years saw additional articles being published.

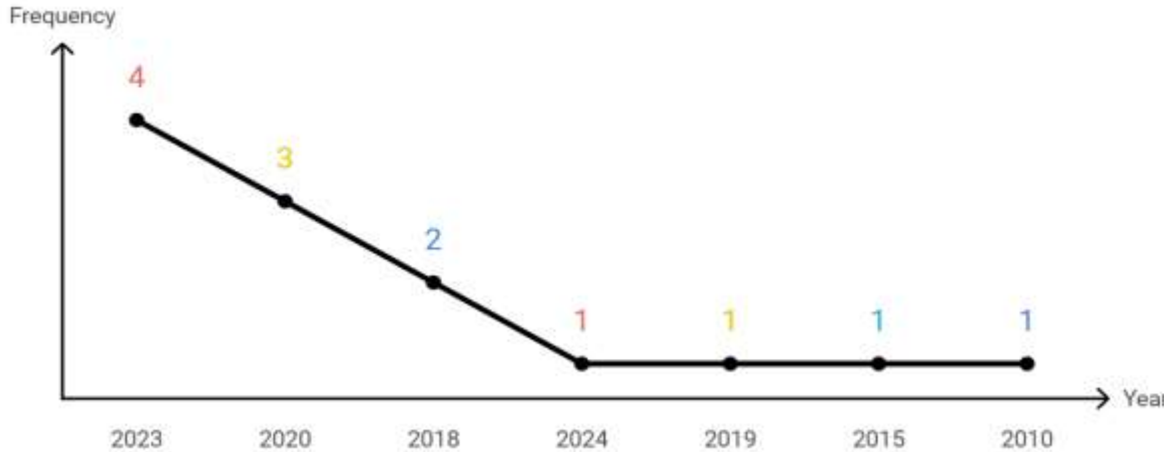

Figure 3: Distribution of Articles by year of Publishing

The chart indicates an initial data point with low frequency in 2010, followed by a slight increase in 2015. There was a consistent number of publications in 2019, a further growth in frequency in 2018, and a notable rise in 2020, culminating in peak frequency observed in 2023. However, a decline in frequency was noted in 2024. This decline highlights the need for a systematic review of the use of virtual laboratories for science teaching among high school learners. The countries where studies on the effectiveness of virtual laboratories were conducted are presented in Table 2.

Table 2: Distribution of Articles by Country of Study

Country	Frequency	Percentage
Nigeria	3	23.08
USA	1	7.69
Turkey	1	7.69
Philippines	1	7.69
Tanzania	1	7.69
Greece	1	7.69
Oman	1	7.69
Indonesia	1	7.69
Palestine	1	7.69
Rwanda	1	7.69
Kuwait	1	7.69

The results in Table 2 indicate that three articles were conducted in Nigeria.[27]

[27] Abdullahi Mohammed et al., "Effects of Virtual Laboratory Experiments on Students' Academic Performance in Physics Practical," *British Journal of Education* 8, no. 5 (2020): 26–39; N P Okafor, R O Okunuga, and T O Ojo, "Effect Of Virtual Chemistry Laboratory Sofware (Vcls) On Secondary School Students'achievement In Acid-Base Titrations Experiment," *Journal Of The Nigerian Academy Of Education* 16, no. 2 (2020); Akawo Angwal Yaki, Mohammed Babagana, and Zainab Abubakar, "Effects of Virtual Laboratory Simulation Package and Demonstration Instructional Strategy on the Achievement of Secondary School Students in Biology," 2020.

In contrast, only one study was conducted in each of the following countries: the USA,[28] Turkey,[29] the Philippines,[30] Tanzania,[31] Greece,[32] Oman,[33] Indonesia,[34] Palestine,[35] Rwanda,[36]and Kuwait.[37]

Research Question 1: What are the research methodologies of the studies that assessed the effectiveness of virtual laboratories?

The results regarding the design that were utilized to address the research questions posed are presented below.

Table 3. Form of Quasi-Experimental Design Used in the Selected Articles

Design	Frequency	Percentage
Pretest & Post-test	10	76.92%
Post-test only	3	23.08%

The results in Table 3 indicate that two types of quasi-experimental designs were utilized in the selected articles. Specifically, 76.92% employed a pretest-posttest design, while 23.08% used a posttest-only design, with real-life laboratories serving as the control group. This suggests that the majority of studies in the selected articles favored the pretest-posttest design.

Research Question 2: In which subject area at the high school level is VL most used?

The distribution of the articles by subject areas is presented in Table 4. The results in the table reflect the subject areas where virtual laboratories are most developed, highlighting trends in research focus across the fields of Chemistry, Physics, and Biology.

Table 4. Distribution of Articles by Subject Areas in Sciences

Subject Area	Frequency	Percentage
Physics	5	38.46%
Chemistry	5	38.46%
Biology	3	23.08%

[28] Rachel Oser and Barry J Fraser, "Effectiveness of Virtual Laboratories in Terms of Learning Environment, Attitudes and Achievement among High-School Genetics Students," *Curriculum and Teaching* 30, no. 2 (2015): 65–80.

[29] Cengiz Tüysüz, "The Effect of the Virtual Laboratory on Students' Achievement and Attitude in Chemistry," *International Online Journal of Educational Sciences* 2, no. 1 (2010): 37–53.

[30] Clint Erven H. Mosqueda, "Effect of Utilizing Interactive Virtual Lab on Students Performance in Physics," *International Journal of Advanced Research* 11, no. 05 (May 31, 2023): 1718–41, https://doi.org/10.21474/IJAR01/17041.

[31] Majuto Clement Manyilizu, "Effectiveness of Virtual Laboratory vs. Paper-Based Experiences to the Hands-on Chemistry Practical in Tanzanian Secondary Schools," *Education and Information Technologies* 28, no. 5 (May 11, 2023): 4831–48, https://doi.org/10.1007/s10639-022-11327-7.

[32] Nikolaos Papalazarou, Ioannis Lefkos, and Nikolaos Fachantidis, "The Effect of Physical and Virtual Inquiry-Based Experiments on Students' Attitudes and Learning," *Journal of Science Education and Technology* 33, no. 3 (June 29, 2024): 349–64, https://doi.org/10.1007/s10956-023-10088-3.

[33] Abdullah Ambusaidi et al., "The Impact of Virtual Lab Learning Experiences on 9th Grade Students' Achievement and Their Attitudes towards Science and Learning by Virtual Lab," *Journal of Turkish Science Education* 15, no. 2 (2018): 13–29.

[34] H Hermansyah et al., "Guided Inquiry Model with Virtual Labs to Improve Students' Understanding on Heat Concept," *Journal of Physics: Conference Series* 1153 (February 2019): 012116, https://doi.org/10.1088/1742-6596/1153/1/012116.

[35] Ghadeer Hamed and Ahmad Aljanazrah, "The Effectiveness of Using Virtual Experiments on Students' Learning in the General Physics Lab," *Journal of Information Technology Education: Research* 19 (2020): 977–96, https://doi.org/10.28945/4668.

[36] Céline Byukusenge, Florien Nsanganwimana, and Albert Paulo Tarmo, "Investigating the Effect of Virtual Laboratories on Students' Academic Performance and Attitudes towards Learning Biology," *Education and Information Technologies* 29, no. 1 (2024): 1147–71.

[37] Fatimah Alhashem and Abdullah Alfailakawi, "Technology-Enhanced Learning through Virtual Laboratories in Chemistry Education," *Contemporary Educational Technology* 15, no. 4 (October 1, 2023): ep474, https://doi.org/10.30935/cedtech/13739.

Table 4 indicates that 38.46% of the selected articles reported findings on virtual laboratories in both Physics and Chemistry, while 23.08% focused on Biology. From this data, it can be inferred that most articles published in virtual laboratories pertain to Physics and Chemistry.

Research Question 3: How effective are virtual laboratories in different subject areas at the high school level?

Table 5. presents the mean students' achievements when utilizing virtual and real-life science laboratories. For the majority of the virtual science laboratories studied, their effectiveness was compared with that of traditional real laboratories, and the results are detailed in the table. This comparison highlights the impact of each laboratory type on student performance in various science subjects.

Table 5: Mean Students' Achievement in the Use of Science Laboratory (VL Vs. RL)

Selected Article	VL (Mean)	RL (Mean)
Article I	86.00	72.00
Article II	10.67	5.40
Article III	56.00	45.80
Article IV	14.75	12.32
Article V	2.90	2.78
Article VI	57.00	43.00
Article VII	3.07	3.42
Article VIII	50.82	59.00
Article IX	33.35	32.00
Article X	63.50	30.50
Article XI	9.59	7.36
Article XII	80.1	40.7
Article XII	3.75	3.51

The results in Table 5.1 indicate that only Article VII reported that the mean students' achievement using real laboratories exceeded that of virtual laboratories (VLs).[38] In contrast, other studies found that the mean students' achievement for VLs surpassed that of real-life laboratories, etc.[39] Figure 4 provides a graphical representation of the mean difference in students' achievements using the two types of laboratories.

[38] Hamed and Aljanazrah, "The Effectiveness of Using Virtual Experiments on Students' Learning in the General Physics Lab."

[39] Tüysüz, "The Effect of the Virtual Laboratory on Students' Achievement and Attitude in Chemistry"; Oser and Fraser, "Effectiveness of Virtual Laboratories in Terms of Learning Environment, Attitudes and Achievement among High-School Genetics Students"; Mohammed et al., "Effects of Virtual Laboratory Experiments on Students' Academic Performance in Physics Practical"; Yaki, Babagana, and Abubakar, "Effects of Virtual Laboratory Simulation Package and Demonstration Instructional Strategy on the Achievement of Secondary School Students in Biology"; Papalazarou, Lefkos, and Fachantidis, "The Effect of Physical and Virtual Inquiry-Based Experiments on Students' Attitudes and Learning."

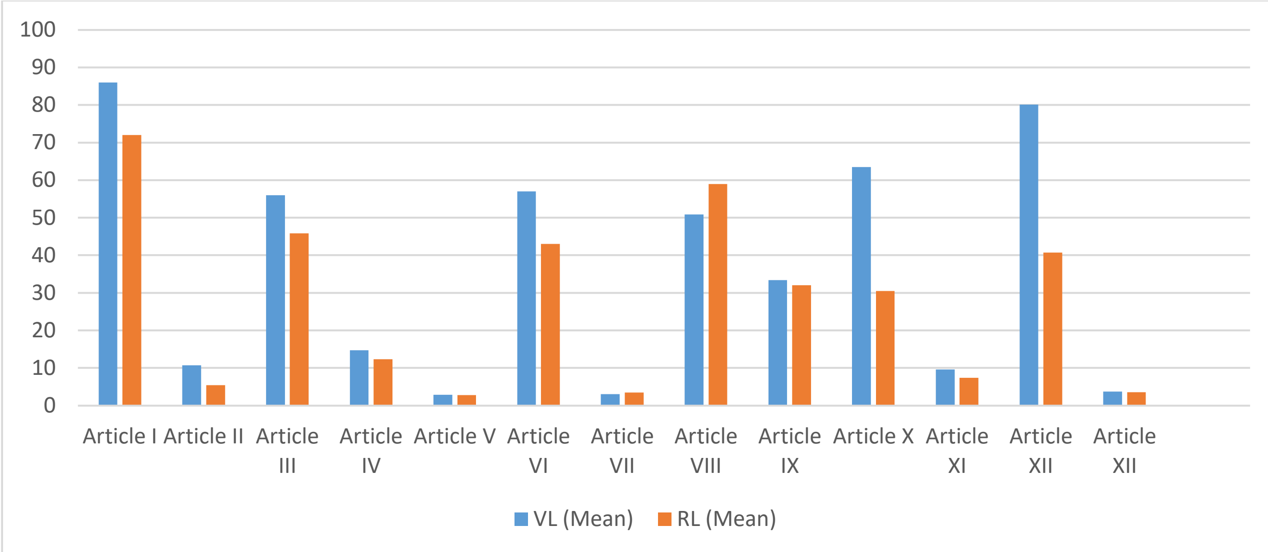

Figure 4: Comparison of Students' Mean Achievement Using Virtual and Real-life Laboratory

Figure 4 illustrates the pattern of students' mean achievements using virtual laboratories (VLs) and real-life laboratories (RLs). It can be concluded that VLs generally have higher mean scores in most of the articles, while real-life laboratories appear to lag behind. The results in Table 5 are organized by different subject areas to identify significant differences in mean students' achievement between VLs and RLs. These findings are further detailed in Tables 6, 7, and 8.

Table 6: Effect of VL on Students Achievement in Physics

Effect	Frequency	Percentage
Significant	3	60.0%
Not Significant	2	40.0%

The results indicate that 60.0% of studies examining the effect of virtual physics laboratories on students' academic achievement found significant results, while 40% reported no significant effects. This implies that virtual physics laboratories are generally more effective than real physics laboratories. The effectiveness of virtual chemistry laboratories is detailed in Table 6.

Table 7: Effect of VL on Students' Achievement in Chemistry

Effect	Frequency	Percentage
Significant	3	60.0%
Not Significant	2	40.0%

Table 7 reveals that 60.0% of studies examining the effectiveness of virtual chemistry laboratories compared to real-life laboratories show significant differences in students' achievements. This indicates that students who used virtual laboratories performed significantly better than those who used real-life laboratories. In contrast, only 40.0% of similar studies found no significant difference in academic achievement. Table 8 presents findings on the effects of virtual biology laboratories on students' achievements.

Table 8: Effects of VL on Students' Achievement in Biology

Effect	Frequency	Percentage
Significant	2	66.66%
Not Significant	1	33.33%

The results from Table 8 reveal that 66.66% of the articles reported a significant mean difference in Biology achievement between students taught using virtual biology laboratories (VLs) and those taught using actual laboratories. Conversely, 33.33% of the studies found no significant differences. This indicates that a greater proportion of studies reported significant differences in student achievement, highlighting the effectiveness of virtual biology laboratories.

Research Question 4: What are students' characteristics moderating the effectiveness of VL at the high school level?

The various moderating variables identified in the selected studies are reported in Table 9. From the table, it can be observed that 23.08% of the selected articles utilized gender as the sole moderating variable in their research. This highlights the focus on gender differences in the context of virtual laboratory effectiveness.

Table 9: Moderating Variables in the Selected Articles

Variable	Frequency	Percentage
Gender Only	3	23.08
Gender and Attitude	1	7.69
Attitude only	1	7.69
Gender and School Type	1	7.69
Not Moderated	7	53.85

Additionally, 7.69% of the selected articles considered both gender and attitude as moderating variables, 7.69% used attitude only, and another 7.69% examined the relationship between gender and school type. In contrast, 53.85% of the articles did not incorporate any moderating variables. The results indicate that gender, attitude, and school type are the common moderating variables influencing the adoption of virtual science laboratories.

DISCUSSION

The results from the review indicate that virtual science laboratories are more commonly used for Physics and Chemistry practicals compared to Biology. This trend may be attributed to the fact that Physics and Chemistry procedures do not involve living organisms as specimens, unlike Biology. Moreover, Physics and Chemistry practicals primarily rely on measurement and observation, which can be easily conducted in a virtual environment. In contrast, Biology practicals require skills that extend beyond mere observation, including an understanding of the structure, texture, and features of the observed specimens, which may not be learnt using a virtual laboratory. This finding supports the work of Swan and O'Donnell, who noted that activities in virtual Biology are more complex, leading students to spend considerable time observing pictures, slides, and diagrams of cells and other content that they may not have had the opportunity to explore in class or in actual laboratories. Additionally, this aligns with the findings of Pascoin and Carvalho, who reported that simulations and animations are key characteristics of virtual chemistry laboratories, providing essential conditions and contexts for effective teaching and learning of scientific phenomena.[40]

The results also indicate that virtual laboratories (VLs) are more effective than real-life laboratories, as evidenced by the significantly higher mean achievements of students using VLs compared to those in traditional laboratories. This finding is consistent with Okafor, whose study in Nigeria demonstrated a significant advantage of virtual chemistry laboratories over conventional ones in students' achievements during acid-base titration experiments.[41] Similarly, Yaki et.al., found that the experimental group using virtual laboratories in Nigeria showed significantly improved performance in Biology compared to the traditional real-life laboratory group.[42] In Tanzania, Manyilizu reported that students who first attended a VL performed better in virtual experiments than those who started with physical laboratories.[43] Hermansyah et.al., in Indonesia, also observed that the mean increase in the achievement of the experimental group using virtual laboratories was higher than that of the control group.[44] However, these outcomes contrast with the findings of Oser and Fraser, who reported no significant difference in achievements between the experimental and control groups in their study in the USA.[45] Additionally, Hamed & Aljanazrah found no significant difference in students' achievements in Physics experiments between the two types of laboratories in their study conducted in Palestine.[46]

Also, students' attraction to technology—likely a key factor in their positive attitudes toward learning with virtual laboratories—could also have influenced the results. The findings indicate that virtual laboratories for Physics, Biology, and Chemistry are generally more effective than traditional laboratories, as reported by most of the selected articles. Additionally, the results reveal that gender, attitude, and school type are significant variables that can influence students' learning experiences through virtual laboratories. This aligns with studies by Ojetunde and Ramnarain, which highlighted a significant gap between men and women using online platforms, suggesting that gender differences are crucial in research-based methods, including laboratory experiments.[47] The findings regarding gender are consistent with those related to students' attitudes toward using virtual laboratories. Literature indicates that most technology acceptance theories incorporate attitude as a determining factor in the acceptance and use of technology.[48] Furthermore, this aligns with Tüysüz, whose findings indicated that positive attitudes distinguished students who performed better in assignments involving virtual laboratories from those who preferred traditional laboratories.[49]

---

[40] Alessandro Félix Pascoin and José Wilson P Carvalho, "Representações Quantitativas Em Laboratórios Virtuais Para o Ensino de Química," *Revista de Ensino, Educação e Ciências Humanas* 22, no. 2 (2021): 152–59.

[41] Okafor, Okunuga, and Ojo, "Effect of Virtual Chemistry Laboratory Sofware (VCLs) on Secondary School Students'achievement in Acid-Base Titrations Experiment."

[42] Yaki, Babagana, and Abubakar, "Effects of Virtual Laboratory Simulation Package and Demonstration Instructional Strategy on the Achievement of Secondary School Students in Biology."

[43] Manyilizu, "Effectiveness of Virtual Laboratory vs. Paper-Based Experiences to the Hands-on Chemistry Practical in Tanzanian Secondary Schools."

[44] Hermansyah et al., "Guided Inquiry Model with Virtual Labs to Improve Students' Understanding on Heat Concept."

[45] Oser and Fraser, "Effectiveness of Virtual Laboratories in Terms of Learning Environment, Attitudes and Achievement among High-School Genetics Students."

[46] Hamed and Aljanazrah, "The Effectiveness of Using Virtual Experiments on Students' Learning in the General Physics Lab."

[47] S.M. Ojetunde, A. M. Adebayo, and T. Sangodoyin, "Online Learning Platforms' Induced Education Inequalities and Special Education Students' Learning Attitude during Covid-19 Pandemic Homestay in the University of Ibadan," *Journal of Education and Practice* 12, no. 23 (August 2021), https://doi.org/10.7176/JEP/12-23-08; M. Gail Jones, Ann Howe, and Melissa J. Rua, "Gender Differences in Students' Experiences, Interests, and Attitudes toward Science and Scientists," *Science Education* 84, no. 2 (March 2000): 180–92, https://doi.org/10.1002/(SICI)1098-237X(200003)84:2<180::AID-SCE3>3.0.CO;2-X.

[48] Martin Fishbein and Icek Ajzen, *Predicting and Changing Behavior: The Reasoned Action Approach* (Psychology press, 2011).

[49] Tüysüz, "The Effect of the Virtual Laboratory on Students' Achievement and Attitude in Chemistry."

Discussion Summary

The findings of this study indicate that virtual laboratories are more effective than real-life laboratories for teaching science at the high school level. It was also observed that significantly more research has focused on the use of virtual laboratories in teaching Physics and Chemistry practicals compared to other science subjects, particularly Biology. Key factors affecting students' achievement in assignments involving virtual laboratories include gender, attitudes, and school ownership (type), with gender emerging as a particularly influential variable. Therefore, it can be said that virtual science laboratories for Physics, Chemistry, and Biology are effective, and their effectiveness is influenced by various student and school characteristics.

RECOMMENDATIONS

Based on the findings of the review, it is recommended that virtual laboratories (VLs) be deployed in teaching Physics, Biology, and Chemistry subjects at the high school level. However, teachers should strive to maintain a balance between using virtual and real-life laboratories, especially when experiments involve real-life objects, such as in Biology practicals. Additionally, since students' attitudes are a key factor influencing their achievements in assignments involving virtual science laboratories, it is recommended that teachers actively foster positive attitudes toward the use of VLs. This is particularly important for female students, who may be more affected by activities associated with technology, especially in the context of virtual laboratories. Encouraging a supportive and engaging learning environment can enhance academic performance and help bridge any gender gaps in technology use.

CONCLUSION

The aim of this review is to examine the effectiveness of virtual laboratories and the factors that affect their adoption as an alternative to traditional labs. It can be concluded that various learner and school-related factors impact the effectiveness of virtual laboratories, even though they prove useful for experiments in chemistry, biology, and physics. While the gender of learners plays a role in the use of virtual labs, it is also crucial to incorporate conventional laboratories alongside virtual ones, as students may be unfamiliar with navigating virtual environments.

BIBLIOGRAPHY

Alhashem, Fatimah, and Abdullah Alfailakawi. “Technology-Enhanced Learning through Virtual Laboratories in Chemistry Education.” *Contemporary Educational Technology* 15, no. 4 (October 1, 2023): ep474. https://doi.org/10.30935/cedtech/13739.

Ambusaidi, Abdullah, Ali Al Musawi, Sulaiman Al-Balushi, and Khadija Al-Balushi. “The Impact of Virtual Lab Learning Experiences on 9th Grade Students’ Achievement and Their Attitudes towards Science and Learning by Virtual Lab.” *Journal of Turkish Science Education* 15, no. 2 (2018): 13–29.

Bajpai, Manisha, and Anil Kumar. “Effect of Virtual Laboratory on Students’ Conceptual Achievement in Physics.” *International Journal of Current Research* 7, no. 2 (2015): 12808–13.

Byukusenge, Céline, Florien Nsanganwimana, and Albert Paulo Tarmo. “Effectiveness of Virtual Laboratories in Teaching and Learning Biology: A Review of Literature.” *International Journal of Learning, Teaching and Educational Research* 21, no. 6 (June 30, 2022): 1–17. https://doi.org/10.26803/ijlter.21.6.1.

———. “Investigating the Effect of Virtual Laboratories on Students’ Academic Performance and Attitudes towards Learning Biology.” *Education and Information Technologies* 29, no. 1 (2024): 1147–71.

Diwakar, Shyam, Rakhi Radhamani, Gopika Sujatha, Hemalatha Sasidharakurup, Akhila Shekhar, Krishnashree Achuthan, Prema Nedungadi, Raghu Raman, and Bipin Nair. “Usage and Diffusion of Biotechnology Virtual Labs for Enhancing University Education in India’s Urban and Rural Areas.” In *Virtual Reality in Education: Breakthroughs in Research and Practice*, 433–53. IGI Global, 2019.

Erven H. Mosqueda, Clint. “Effect of Utilizing Interactive Virtual Lab on Students Performance in Physics.” *International Journal of Advanced Research* 11, no. 05 (May 31, 2023): 1718–41. https://doi.org/10.21474/IJAR01/17041.

Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI Center). “Guidelines for the extraction of information and quality assessment of primary studies in educational research. “Guidelines for the Extraction of Information and Quality Assessment of Primary Studies in Educational Research,” 2003. https://eppi.ioe.ac.uk/cms/Resources/Tools/tabid/184/Default.aspx#Guidelines.

Ezrailson, Cathy Mariotti. “Danger in the School Science Lab: Are Students At Risk?” In *Proceedings of the South Dakota Academy of Science*, Vol. 92, 2013.

Fishbein, Martin, and Icek Ajzen. *Predicting and Changing Behavior: The Reasoned Action Approach*. Psychology press, 2011.

Gambari, Amosa Isiaka, Halima Kawu, and Oluwole Caleb Falode. “Impact of Virtual Laboratory on the Achievement of Secondary School Chemistry Students in Homogeneous and Heterogeneous Collaborative Environments.” *Contemporary Educational Technology* 9, no. 3 (July 16, 2018): 246–63. https://doi.org/10.30935/cet.444108.

Hamed, Ghadeer, and Ahmad Aljanazrah. “The Effectiveness of Using Virtual Experiments on Students’ Learning in the General Physics Lab.” *Journal of Information Technology Education: Research* 19 (2020): 977–96. https://doi.org/10.28945/4668.

Hermansyah, H, G Gunawan, A Harjono, and R Adawiyah. “Guided Inquiry Model with Virtual Labs to Improve Students’ Understanding on Heat Concept.” *Journal of Physics: Conference Series* 1153 (February 2019): 012116. https://doi.org/10.1088/1742-6596/1153/1/012116.

Hofstein, A., M. Kipnis, and I. Abrahams. *Teaching Chemistry – A Study Book*. Sense Publishers: Rotterdam, 2013.

Hofstein, Avi, and Per M. Kind. “Learning In and From Science Laboratories.” In *Second International Handbook of Science Education*, 189–207. Dordrecht: Springer Netherlands, 2012. https://doi.org/10.1007/978-1-4020-9041-7_15.

Hofstein, Avi, and Vincent N. Lunetta. “The Laboratory in Science Education: Foundations for the Twenty-first Century.” *Science Education* 88, no. 1 (January 3, 2004): 28–54. https://doi.org/10.1002/sce.10106.

Ibrahim, Dogan. “Engineering Simulation with MATLAB: Improving Teaching and Learning Effectiveness.” *Procedia Computer Science* 3 (2011): 853–58.

Jimoyiannis, Athanassios, Panagiotis Tsiotakis, Dimitrios Roussinos, and Anastasia Siorenta. “Preparing Teachers to Integrate Web 2.0 in School Practice: Toward a Framework for Pedagogy 2.0.” *Australasian Journal of Educational Technology* 29, no. 2 (2013).

Jones, M. Gail, Ann Howe, and Melissa J. Rua. “Gender Differences in Students’ Experiences, Interests, and Attitudes toward Science and Scientists.” *Science Education* 84, no. 2 (March 2000): 180–92. https://doi.org/10.1002/(SICI)1098-237X(200003)84:2<180::AID-SCE3>3.0.CO;2-X.

Joolingen, Wouter R. van, and Zacharias C. Zacharia. “Developments in Inquiry Learning.” In *Technology-Enhanced Learning*, 21–37. Dordrecht: Springer Netherlands, 2009. https://doi.org/10.1007/978-1-4020-9827-7_2.

Kapici, Hasan Ozgur, and Hakan Akcay. “Cognitive Theories of Learning on Virtual Science Laboratories.” *Education Research Highlights in Mathematics, Science and Technology*, 2019, 107–26.

Logar, Ana, Cirila Peklaj, and Vesna Ferk Savec. “Effectiveness of Student Learning during Experimental Work in Primary School.” *Acta Chimica Slovenica* 64, no. 3 (2017).

Lu, Zisheng. “Analysis of China Students’ Laboratory Accidents in the Past 39 Years and the Laboratory Management Reform in the Future.” *Education for Chemical Engineers* 42 (January 2023): 54–60. https://doi.org/10.1016/j.ece.2022.12.001.

Lunetta, Vincent N, Avi Hofstein, and Michael P Clough. “Learning and Teaching in the School Science Laboratory: An Analysis of Research, Theory, and Practice.” In *Handbook of Research on Science Education*, 393–441. Routledge, 2013.

Manyilizu, Majuto Clement. “Effectiveness of Virtual Laboratory vs. Paper-Based Experiences to the Hands-on Chemistry Practical in Tanzanian Secondary Schools.” *Education and Information Technologies* 28, no. 5 (May 11, 2023): 4831–48. https://doi.org/10.1007/s10639-022-11327-7.

Mohammed, Abdullahi, T A Daniel, A R Lasisi, and C M Dania. “Effects of Virtual Laboratory Experiments on Students’ Academic Performance in Physics Practical.” *British Journal of Education* 8, no. 5 (2020): 26–39.

Ojetunde, S.M., A. M. Adebayo, and T. Sangodoyin. “Online Learning Platforms’ Induced Education Inequalities and Special Education Students’ Learning Attitude during Covid-19 Pandemic Homestay in the University of Ibadan.” *Journal of Education and Practice* 12, no. 23 (August 2021). https://doi.org/10.7176/JEP/12-23-08.

Okafor, N P, R O Okunuga, and T O Ojo. “Effect of Virtual Chemistry Laboratory Sofware (VCLs) on Secondary School Students’ Achievement in Acid-Base Titrations Experiment.” *Journal of the Nigerian Academy of Education* 16, no. 2 (2020).

Oser, Rachel, and Barry J Fraser. “Effectiveness of Virtual Laboratories in Terms of Learning Environment, Attitudes and Achievement among High-School Genetics Students.” *Curriculum and Teaching* 30, no. 2 (2015): 65–80.

Papalazarou, Nikolaos, Ioannis Lefkos, and Nikolaos Fachantidis. “The Effect of Physical and Virtual Inquiry-Based Experiments on Students’ Attitudes and Learning.” *Journal of Science Education and Technology* 33, no. 3 (June 29, 2024): 349–64. https://doi.org/10.1007/s10956-023-10088-3.

Pascoin, Alessandro Félix, and José Wilson P Carvalho. “Representações Quantitativas Em Laboratórios Virtuais Para o Ensino de Química.” *Revista de Ensino, Educação e Ciências Humanas* 22, no. 2 (2021): 152–59.

Potkonjak, Veljko, Michael Gardner, Victor Callaghan, Pasi Mattila, Christian Guetl, Vladimir M. Petrović, and Kosta Jovanović. “Virtual Laboratories for Education in Science, Technology, and Engineering: A Review.” *Computers & Education* 95 (April 2016): 309–27. https://doi.org/10.1016/j.compedu.2016.02.002.

Radhamani, Rakhi, Dhanush Kumar, Nijin Nizar, Krishnashree Achuthan, Bipin Nair, and Shyam Diwakar. “What Virtual Laboratory Usage Tells Us about Laboratory Skill Education Pre- and Post-COVID-19: Focus on Usage, Behavior, Intention and Adoption.” *Education and Information Technologies* 26, no. 6 (November 9, 2021): 7477–95. https://doi.org/10.1007/s10639-021-10583-3.

Reeves, Shalaunda M., and Kent J. Crippen. “Virtual Laboratories in Undergraduate Science and Engineering Courses: A Systematic Review, 2009–2019.” *Journal of Science Education and Technology* 30, no. 1 (February 9, 2021): 16–30. https://doi.org/10.1007/s10956-020-09866-0.

Santos, Marc Lancer, and Maricar Prudente. “Effectiveness of Virtual Laboratories in Science Education: A Meta-Analysis.” *International Journal of Information and Education Technology* 12, no. 2 (2022): 150–56. https://doi.org/10.18178/ijiet.2022.12.2.1598.

Stuckey-Mickell, Tracey A, and Bridget D Stuckey-Danner. “Virtual Labs in the Online Biology Course: Student Perceptions of Effectiveness and Usability.” *MERLOT Journal of Online Learning and Teaching* 3, no. 2 (2007): 105–11.

Triejunita, Chessa Nur, Atina Putri, and Yusep Rosmansyah. “A Systematic Literature Review on

Virtual Laboratory for Learning." In *2021 International Conference on Data and Software Engineering (ICoDSE)*, 1–6. IEEE, 2021. https://doi.org/10.1109/ICoDSE53690.2021.9648451.
Tüysüz, Cengiz. "The Effect of the Virtual Laboratory on Students' Achievement and Attitude in Chemistry." *International Online Journal of Educational Sciences* 2, no. 1 (2010): 37–53.
Ural, Evrim. "The Effect of Guided-Inquiry Laboratory Experiments on Science Education Students' Chemistry Laboratory Attitudes, Anxiety and Achievement." *Journal of Education and Training Studies* 4, no. 4 (2016): 217–27.
Yaki, Akawo Angwal, Mohammed Babagana, and Zainab Abubakar. "Effects of Virtual Laboratory Simulation Package and Demonstration Instructional Strategy on the Achievement of Secondary School Students in Biology," 2020.

ABOUT AUTHOR

Segun Michael Ojetunde is a postdoctoral fellow, Center for Advanced Learning Technologies in STEAM (CALSTEAM), Department of Mathematics, Science and Technology Education, University of Johannesburg, South Africa. He has a special interest in educational evaluation, science, and technology.