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Effectiveness of virtual labs in teaching chemical reactions in 9th-Grade Chemistry

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Abstract

The objective of this study is to explore students' perceptions about virtual lab applications and examine the effect of using virtual labs on their academic performance. The study employed a convergent parallel mixed-method approach. Employing a quasi-experimental design, the study was carried out in a Bhutanese school with 71 ninth-grade students from two sections (A and B). The participants were divided into an experimental group (n=35), which used virtual labs and a control group (n=36), which received conventional instruction. In addition, five students from the experimental group were purposively selected for semi-structured interviews to gather in-depth qualitative data. A pre-test and post-test were administered to each group. The quantitative data was analyzed using Cohen's d effect size and t-tests, while the qualitative data was analyzed thematically. Pre-test results showed no significant differences between the groups, indicating comparable baseline knowledge. While the control group showed no significant improvement, the experimental group demonstrated a significant difference in post-test scores ($p < .001$, Cohen's $d = 3.81$). Interview findings revealed that students found virtual labs engaging, interactive, and beneficial for understanding abstract concepts. They appreciated the flexibility, accessibility, and cost-effectiveness of virtual labs. However, technical issues such as unstable internet connectivity posed challenges that impacted the learning experience and data accuracy. Therefore, this study recommends that relevant stakeholders provide professional training prior to the implementation of virtual lab applications in teaching. It also encourages future researchers to replicate similar study across other subjects to evaluate the effectiveness of this approach.

Keywords: *Academic achievement, Challenges, Effectiveness, Virtual labs.*

INTRODUCTION

To maximize learning outcomes, technology integration into the classroom is essential, particularly in science education. Virtual laboratories, which utilize simulations and interactive models, offer an innovative approach to enhancing student engagement and conceptual understanding (Repnik & Grubelnik, 2010). They make difficult scientific ideas more approachable by giving students practical experience in a safe digital setting.

Virtual laboratories have been found to enhance student performance, critical thinking, and problem-solving, unlike traditional teaching methods (Madhuri & Goteti, 2022; Ramadhan & Irwanto, 2017; Yildirim, 2021). They are particularly effective in addressing challenges associated with abstract scientific concepts by providing visualization and interactive experimentation (Tüysüz, 2010).

Virtual labs are more likely to be the most successful in Bhutanese educational settings, especially in isolated regions with severe infrastructure and material shortages for practical science experiments. This lack of resources creates a significant barrier to teaching key concepts, such as chemical reactions, which are fundamental to students' understanding of chemistry (Limboo et al., 2021). Chemical reactions are a core component of the grade 9 chemistry curriculum and are essential for building students' foundational understanding of matter, chemical changes, and energy transformation. Thus, virtual labs can bridge this gap by offering interactive simulations that visually represent chemical processes, allow students to manipulate

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variables, and provide immediate feedback that enhances conceptual clarity and fosters inquiry-based learning (Royal Education Council, 2020). Consequently, this study aims to evaluate how well virtual labs can enhance ninth-grade students' conceptual comprehension of chemical reactions.

Research Objectives:

This study aims to explore the effectiveness of virtual laboratories in teaching chemical reactions to ninth-grade students. It also explored the students' perceptions, including both benefits and challenges they encountered during virtual simulations. Specifically, the research is guided by the following objectives:

1. To investigate the effectiveness of virtual lab application to enhance conceptual understanding of the scientific concepts (chemical reactions).
2. To explore the benefits and opportunities students experience while learning chemical reactions through virtual laboratories.
3. To explore the challenges students, face when learning chemistry using virtual lab simulations

LITERATURE REVIEW

A laboratory is a place in the school where students observe and learn about nature using tools and materials or secondary data sources (Hofstein & Kind, 2012). Virtual laboratories are usually computer-based interactive environments that help users perform some tasks normally done in a laboratory through an interface capable of simulation, animation, and visualization (El-Sabagh, 2011; Santos & Prudent, 2022). The simulation allows students to experience the steps in a novel, hands-on fashion and encourages them to engage with the laboratory scene. Animations provide a visual, diagrammatic way to convey the concepts of an experiment more effectively than text-based or possibly passive illustrations. Virtual labs, therefore, use visualization techniques to engage students with a lab environment and promote an enjoyable science learning experience (Duhani et al., 2023). This type of educational technology fosters customized learning that reduces concerns regarding equipment, chemicals, time, and space.

By allowing individual students to conduct experiments, virtual labs have improved student success by increasing motivation for the lesson (Arjamand & Khattak, 2013). However, Bozkurt and Sarıkoç (2008) argued that some real experiments can be dangerous and are not suitable for individual implementation. In traditional laboratories, students are often required to conduct experiments within a specific time frame. In contrast, virtual laboratories impose no such constraints; thus, students get more time to designing experiments, analyzing results, and interpreting findings at their own pace (Bell, 1999; Duhani et al., 2023; Finkelstein et al., 2005). Furthermore, research has shown that virtual laboratories simplify and facilitate the learning process. They have also proven to be valuable resources for teaching scientific content that is difficult, repetitive, or abstract in nature (Akkağıt & Tekin, 2012). In addition, simulations have been found to develop 21st-century skills such as critical thinking, creativity, problem-solving, inquiry, and effective communication (Ramadhan & Irwanto, 2017). The use of virtual labs has enhanced student achievement, deepened comprehension of scientific concepts, and made the learning process more engaging (Celik et al., 2020). As a result, simulated virtual learning has gained popularity in the field of education as an effective approach for promoting student learning, motivation, and academic success.

Several studies that used virtual laboratories in various science classes showed varying degrees of effectiveness. Despite the aforementioned advantages, using virtual labs has numerous drawbacks. Virtual labs are criticized for failing to impart hands-on skills in scientific procedures and manual methods such as precision, coordination and practice (Hawkins & Phelps, 2013). Students in the virtual lab do not use actual materials and equipment because the experiment does not exist in the real world, which disregards carefulness and responsibility for self-learning. Potkonjak et al. (2016) revealed that in a virtual lab, students feel more like they are playing a video game than participating in a learning environment. These disadvantages emphasize the necessity of a well-rounded scientific education that combines both simulated and practical experiences in a balanced manner.

According to Ramadhan and Irwanto's (2017) review of 23 publications, virtual laboratories significantly enhanced students' motivation, interest, perception, problem-solving, critical thinking, creativity, conceptual understanding, science process skills, lab skills, and learning outcomes. Similarly, Yildirim (2021) conducted a quasi-experiment in which he split the sample into an experimental and a control group. The findings showed that the academic performance of the students improved significantly in the experimental group with the application of the virtual laboratory. Additionally, virtual lab application enables the concretization of abstract subjects, which positively supported students' interest, excitement, and motivation and contributed to meaningful learning. Tatenov et al. (2023) also evaluated the efficacy of an inorganic chemistry virtual laboratory using a quasi-experimental design with 50 students: 25 in an experimental group that used the virtual lab and 25 in a control group that used traditional labs. The results indicated significant gains in conceptual understanding, scientific process skills, tool handling, logical thinking, creativity, and motivation. According to the majority of students, the virtual lab improved their understanding of difficult ideas and practical abilities in scenarios like the COVID-19 pandemic.

Despite their numerous advantages, virtual labs have faced ongoing criticisms. A key concern is that they may not effectively build students' practical laboratory skills or their familiarity with physical equipment (Hawkins & Phelps, 2013). Some students report feeling disconnected from real-world laboratory practices, often viewing virtual labs as more of a game than a serious learning tool (Potkonjak et al., 2016). In an Ethiopian study, Tesfaye and Bekele (2021) observed that although virtual labs enhanced students' theoretical understanding, many struggled to translate that knowledge into actual laboratory tasks due to the absence of hands-on experience. Likewise, research by Ncube et al. (2023) in Zimbabwe highlighted students' dissatisfaction with limited experiment flexibility and frequent technical glitches, both of which hindered their engagement.

Furthermore, technical challenges remain a significant barrier, particularly in rural and under-resourced contexts. Hossain et al. (2022) reported that in Bangladesh, over 60% of students faced issues such as inadequate internet access, outdated devices, and inconsistent platform performance during virtual science classes. These constraints often diminish the potential benefits of virtual labs and highlight the need for robust infrastructure and localized support systems to ensure effective implementation.

Despite these limitations, most researchers advocate for a blended approach, integrating both virtual and physical laboratories to maximize learning outcomes. Reyes et al. (2024) emphasize that virtual labs should complement, not replace, hands-on experiences to support the development of scientific inquiry skills and practical competence. This balanced integration can provide an engaging and effective science education model, particularly in settings with logistical and financial constraints where full-fledged physical laboratories may not always be feasible. Therefore, it is an imperative to carry out research in different context to critically evaluates the effectiveness of virtual labs from students' perspectives and their application in chemistry.

THEORETICAL CONTEXT

David Kolb's (1984) experiential learning theory, which draws its principles and foundations from John Dewey's work, gave rise to the integration of virtual applications into teaching and learning processes (Ouyang & Stanley, 2014). Dewey accentuated the significance of active student participation and practical application in effective learning. Kolb further developed this concept, "learning by doing," advocating for learning through experience and action (Kolb & Kolb, 2005). The heart of his theory lies in the individual learner's active engagement and interpretation of experiences (Ouyang & Stanley, 2014). The use of virtual applications in learning environments fosters active learners with interactive platforms for experimentation and immediate feedback (Dyrberg et al., 2017) thereby allowing learners to learn by doing, enhancing deeper engagement and knowledge retention (Gallagher et al., 2005; Evans et al., 2004). Therefore, virtual labs serve as a powerful tool for aligning teaching practices with the principles of experiential learning theory, fostering a student-centred learning experience.

RESEARCH METHOD

This research used a convergent parallel mixed-method design to explore the effectiveness of virtual labs as the intervention associated with the pragmatic worldview. The study participants comprised 71 ninth-grade students from two sections (A and B) from one of the schools in Bhutan. Section A (n = 36) served as the control group (CG), while Section B (n = 35) constituted the experimental group (EG). A quasi-experimental design was adopted, leveraging existing class divisions for group allocation. Additionally, five students were purposively selected from the EG for semi-structured interviews to gather in-depth qualitative data.

Both the experimental and control groups administered a pre-test consisting of 10 items (5 multiple-choice and 5 short answers) to assess their baseline understanding of chemical reactions. The pre-test questions were carefully designed and validated by three experienced researchers to ensure content and face validity. Further, to check validity of the test items, researchers conducted pilot test involving 30 grade 9th students. Consequently, its reliability check was done using Cronbach Alpha Coefficient test in SPSS. Test indicated the Cronbach Alpha value above 0.8. According to Tavakol and Dennick (2011), the acceptable range of Cronbach Alpha Coefficient is in between 0.7-0.9. The EG received 300 minutes (6 periods) of instruction on chemical reactions using virtual labs. In contrast, the CG received conventional teacher-cantered instruction on the same topic. The effectiveness of the intervention was evaluated through post-tests administered to both groups using the same instrument as the pre-test.

Qualitative data was gathered through semi-structured interviews conducted with the five purposively selected students from the EG. These interviews aimed to explore their experiences, perspectives, and perceived challenges associated with using virtual labs as a learning tool. The interview questions were validated by experts to ascertain their clarity and relevance to the research objectives.

Quantitative data was analyzed using inferential and descriptive statistics. Descriptive statistics were computed to summarize the data, while inferential statistics were used to compare the pre-test and post-test scores of both the EG and CG. Pre-test and post-test results within the EG and CG were compared using paired sample t-tests. The independent sample t-tests were applied for the between-group comparisons framework. The qualitative data from semi-structured interviews was analyzed using six-phase framework for thematic analysis developed by Braun and Clarke (2006). This method involves familiarizing oneself with the data, generating initial codes, identifying and reviewing themes, defining and naming them, and producing a coherent report. It allows for a detailed and systematic interpretation of patterns within the data.

FINDING

To compare the students' performance, pre-test and post-test were administered before and after the intervention. The pre-test was aimed to assess the homogeneity of students' learning abilities and to ensure comparability between the control group (CG) and experimental group (EG) before the intervention. Post-test data was designed to analyse the effect of virtual labs in learning chemistry.

The pre-test results revealed no significant difference in understanding of knowledge of chemical reaction between EG and CG prior to the intervention of the study. The independent samples t-test ($t = 1.02$, $p > .05$, $p = .294$) supports the null hypothesis, indicating no statistically significant difference between the groups.

Furthermore, Cohen's d value (d=0.39) indicates a small size effect between the groups, revealing that both groups had similar levels of academic performance before the use of virtual labs (see table 1). Therefore, these findings confirm that the groups were statistically comparable, allowing valid comparison after intervention. This initial equivalence strengthens internal validity and aligns with the quasi-experimental requirement of baseline homogeneity, supporting the appropriateness of attributing post-intervention differences to the treatment condition.

Table 1. Independent sample t-test on pre-test result

	Group	N	Mean	Mean differences	Std. Deviation	Df	T	p-value	Cohen's d
Pre-test	Control	36	9.86	-.88	3.47	69	1.02	.294	0.39
	Experimental	35	8.99		3.51				

A significant level of $p<0.05$
Cohen's d value: d=0.2 - small effect, d=0.5 - medium effect, d=0.8 - large effect

A paired samples t-test was performed to compare pre-test and post-test scores within both the EG and CG. In the CG, the differences between pre- and post-test scores were not statistically significant ($t(35)=-0.795$, $p=0.43$), with a small effect size ($d=0.27$). Conversely, the EG showed a statistically significant improvement in post-test scores compared to pre-test scores ($t(34)=-11.12$, $p<0.001$), indicating a very large effect size ($d=3.81$). These findings suggest that the intervention applied to the EG led to a substantial improvement in performance, whereas the CG showed minimal change (see table 2).

The exceptionally large effect size observed in the EG can be partially attributed to the low baseline conceptual understanding of chemical reactions, high instructional intensity of the virtual lab intervention, and reduced variability in post-test performance. In addition, the novelty of virtual laboratories in the Bhutanese classroom context may have contributed to heightened engagement and learning gains.

Table 2. Comparison of pre-test and post-test within experimental and control groups (Paired Sample t-test).

Student Code		Mean	N	Mean difference	t-test	Df	p-value	Cohen's d
Control	Pretest	9.86	36					
	Posttest	10.11	36	0.25	-.795	35	0.43	0.27
Experimental	Pretest	08.99	35					
	Posttest	13.44	35	4.46	-11.12	34	0.00	3.81

Cohen's d value: d=0.2-small effect, d=0.5-medium effect, d=0.8-large effect

The interview analysis substantiated the students' perspectives and attitudes towards simulation, validating their inclination towards virtual laboratories. All participants uniformly expressed their appreciation for the engaging and interactive nature of learning facilitated by virtual simulators. For instance, Student 1 (S1) articulated, "Engaging in activities virtually aids students in comprehending concepts more easily, and the prospect of acquiring knowledge through this approach is consistently exciting and enjoyable." Moreover, S1, S2, and S3 expressed that virtual laboratory affords them opportunities to explore, experiment, discuss, and deepen their understanding of various topics. Consequently, all participants concurred that virtual labs constitute a superior platform for students to delve into and comprehend abstract concepts in chemistry.

The participants unanimously acknowledged the flexibility and accessibility offered by virtual labs in the context of chemistry education. Notably, S1, S3, and S4 highlighted that virtual lab is not only cost-effective but also manageable from any location and at any time. Correspondingly, S2 emphasized, "Virtual labs in chemistry provide a simulated environment where users can conduct experiments, analyses results, and save time, thereby reducing the time investment required for practical experiments." Intriguingly, S5 added, "We acquire information rapidly through virtual labs that help us to understand the abstract concepts. It facilitates learning about various chemicals, previously unknown, by providing insights into their reactive properties." Although the majority of students attested to the safety, affordability, and time-saving attributes of virtual labs, S5 expressed concerns about the potential limitation in capturing the authentic real-world representation compared to traditional labs. Nevertheless, S5 acknowledged a preference for virtual labs due to inadequate laboratory facilities and safety concerns associated with traditional experiments.

The study further highlighted the significant barriers faced by students while using virtual labs in the classroom. Network issues, as reported by S1 and S2, disrupted the seamless progression of experiments in the classroom. Persistent software glitches and connectivity problems, noted by S1 and S3, posed challenges to the learning experience, affecting the accuracy of quantitative analysis. Additionally, S3 added that the distraction posed by the mobile phones on students is also causing a financial burden on parents for data charges. Therefore, addressing these challenges is imperative to enhance the efficacy of virtual labs in chemistry education, necessitating solutions for technical issues, resource provision, sensory simulation, and network connectivity.

DISCUSSION

The result revealed that the students who learned chemical reactions using virtual labs performed better than the students taught using a teacher-centred approach. The study found a significant difference in the post-test scores of participants in the Experimental Group (EG) and Control Group (CG). This finding is consistent with Penjor et al. (2022), who reported that simulation approaches increase the academic performance of class IX students in Bhutan. Similarly, other studies (Baladoh et al., 2017; Redha, 2010; Tuysuz, 2010; Yildirim, 2021; Kusmawan, U. et.al., 2026) concur that students exposed to virtual laboratory applications demonstrate improved academic performance in science learning.

This improvement can be theoretically explained through Constructivism, which emphasizes that learners construct knowledge actively through interaction with learning environments rather than passively receiving information. In this context, virtual laboratories enable students to manipulate variables, observe outcomes, and construct conceptual understanding of chemical reactions through direct experiential engagement. Thus, learning becomes an active process of knowledge construction rather than memorization.

Further research indicates that virtual labs are enjoyable, engaging, and promote active learning. They enable learners to explore, experiment, discuss, and cultivate a deeper understanding of various topics. These findings align with Celik et al. (2020), who argue that virtual labs enhance learning by making science more engaging and conceptually accessible, ultimately improving academic achievement. This is because virtual labs transform science learning into an interactive experience, allowing students to visualize abstract processes that are otherwise difficult to observe in traditional classrooms. Additionally, Akkağıt and Tekin (2012) highlight that virtual lab is particularly effective in teaching abstract and complex scientific concepts by simplifying instructional processes and improving conceptual clarity.

These outcomes can further be interpreted through Experiential Learning Theory, which explains learning as a cyclical process involving concrete experience, reflective observation, and active experimentation. Virtual laboratories replicate this cycle by allowing learners to repeatedly test hypotheses, observe outcomes, and refine understanding, thereby strengthening conceptual retention in chemistry.

Moreover, the study revealed that virtual labs provide learners with opportunities for self-directed exploration. This aligns with Alenezi (2019), who found that simulations promote inquiry-based learning by enabling students to explore and construct scientific explanations independently. Participants also highlighted cost-effectiveness, safety, and time efficiency as major advantages of virtual laboratories. This supports previous research (Kusmawan, U. 2017; Arjamand & Khattak, 2013; Tankut, 2008), which reports that many schools face challenges in conducting real experiments due to high cost, time constraints, and safety risks. Virtual labs address these issues by allowing experiments to be conducted in safe, controlled, and cost-effective simulated environments. Furthermore, Finkestein et al. (2005) noted that virtual labs remove time limitations, enabling students to design, analyze, and interpret experiments at their own pace.

From a cognitive perspective, these advantages can be explained using Cognitive Load Theory, which suggests that learning is optimized when unnecessary cognitive burden is reduced. Virtual laboratories minimize extraneous cognitive load by visually representing abstract chemical processes, allowing students to focus on essential conceptual understanding rather than procedural difficulties.

However, the results also revealed several challenges in implementing virtual labs. Network disruptions, inadequate ICT facilities, and high data costs significantly hindered smooth classroom integration. Additionally, concerns were raised regarding the limited ability of virtual labs to replicate authentic real-world experimental conditions. Potkonjak et al. (2016) argue that virtual laboratories lack physical realism, which may reduce students' sense of responsibility and careful handling of materials. Furthermore, students may perceive simulations as game-like environments, potentially reducing seriousness in learning. Hawkins and Phelps (2013) also highlight limitations in developing hands-on laboratory skills and manipulative techniques through virtual platforms.

These limitations can be interpreted through Situated Learning Theory, which emphasizes that meaningful learning is rooted in authentic, real-world contexts. While virtual laboratories are highly effective in developing conceptual understanding, they may not fully develop embodied laboratory skills that arise from direct interaction with physical materials and real experimental environments.

CONCLUSION

The study found that students' academic performance in chemistry was significantly impacted by virtual labs. The experimental and control groups' post-test scores showed a statistically significant mean difference when virtual labs were used (MD = 0.23 and 4.46, respectively). This finding indicates a substantial effect size for the intervention ($p = 0.001$), further corroborated by the large Cohen's d-value of 3.81. Based on these findings, the study recommends future research endeavors to replicate this investigation across diverse chemistry topics to ascertain the generalizability of the intervention's effectiveness.

Additionally, the study strongly encourages chemistry teacher to integrate technology into their instructional practices to expand their teaching approaches and promote interactive learning. The positive impact of virtual labs on students' comprehension of chemical reactions and their self-exploration of concepts highlights the potential for technology to enhance chemistry education significantly. However, participants also reported challenges in integrating virtual labs into the teaching and learning process. A major issue identified was unstable network connectivity, which hindered effective learning and increased the time required for instructional activities. This challenge has been widely observed across the country. Nevertheless, the government, local leaders, and school administrations are actively seeking solutions to address this issue in a timely manner. In the digital era, ensuring reliable internet connectivity for educational purposes is imperative to maximize the benefits of technology-enhanced learning.

REFERENCES

Abdous, M., He, W., & Yen, C. J. (2012). Technical issues in distance learning: A review of the literature. *Journal of Education and Practice, 3*(3), 78-84. DOI: https://doi.org/10.7176/JEP/16-3-01

Akkagıt, F. S., & Tekin, A. (2012). The effect of simulation-based education to the achievements of secondary school students in the course of basic electronics and measurement. *Journal of Education, 13*(2), 1- 121. DOI: https://doi.org/10.46328/ijtes.141

Al-Duhani, F., Mohd Saat, R., & Abdullah, M. N. (2023). Effectiveness of Virtual Laboratory on Grade Eight Students' Spatial Ability. *International Journal of Education, Psychology, and Counseling, 8*(49), 211–228. DOI: https://doi.org/10.35631/ijepc.849015

Alenezi, A. (2019). Simulation in teaching within the health and engineering faculties of Saudi universities: Computer Applications. *An International Journal (CAIJ)*, *6*(1), 1-8 https://www.academia.edu/download/60473572/6319caij0120190903-81012-t15h3.pdf

Arjamand, M. J., & Khattak, M. D. (2013). *Virtual labs: A new horizon for localised distance* education [paper presentation]. 27th Annual Conference of Asian Association of Open Universities 2013, Islamabad, Pakistan. DOI: https://doi.org/10.1007/s10639-017-9640-z

Baladoh, S. M., Elgamal, A. F. & Abas, H. A. (2017). Virtual lab to develop achievement in electronic circuits for hearing-impaired students. *Education and Information Technologies,* (5), 2071. DOI: https://doi.org/10.1007/s10639-016-9532-7

Bell, J. (1999). The biology labs on-line project: Producing educational simulations that promote active learning. *Interactive Multimedia Electronic Journal of Computer Enhanced Learning, 1*(2), 1-10 http://imej.wfu.edu/articles/1999/2/01/index.asp.

Bozkurt, E., & Sarikoc, A. (2008). Can the vırtual laboratory replace the traditional laboratory in physics education? *Selcuk University Ahmet Keleşoğlu Faculty of Education Journal, 25,* 89–100. DOI: https://doi.org/10.53444/deubefd.1731595

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology.*Qualitative Research in Psychology*, *3*(2), 77–101. DOI: https://doi.org/10.1191/1478088706qp063oa

Buczynski, A. M., & Hansen, D. L. (2010). Virtual labs in the online biology course: Student perceptions of effectiveness and usability. *Journal of Online Learning and Teaching, 6*(1), 18-29. http://hdl.handle.net/10125/69287

Bugarso, J.S., Cabantugan, R.E., Tapiculin, Q.E., & Malaco,A.C. (2021). Students' Learning Experiences and Preference in Performing Science Experiments Using Hands-on and Virtual Laboratory. *Indonesian Journal of Teaching in Science, 1(*2). 147-152. DOI: https://doi.org/10.17509/ijotis.v1i2.41122

Celik, C., Guven, G., & Cakir, N.K. (2020). Integration of mobile augmented reality (MAR) applications into biology laboratory: Anatomic structure of the heart. *Res. Learn. Technol*, 28. DOI: https://doi.org/10.25304/rlt.v28.2355

Efe, H. A. & Efe, R. (2012). Evaluating the effect of computer simulations on secondary biology instruction: An application of bloom's taxonomy. *Scientific Research and Essays, 6* (10), 2137-2146. DOI: https://doi.org/10.5897/SRE10.1025

El-Sabagh, H.A.E. (2011). *The Impact of a Web-Based Virtual Lab on the Development of Students' Conceptual Understanding and Science Process Skills* [PhD thesis]. Dresden University of Technology, Educational Technology Department, Faculty of Education. https://d-nb.info/1013549376/34

Falode, O. C. (2014). *A bates' actions evaluation of virtual physics laboratory package for Senior Secondary School students in Nigeria*. (Unpublished Ph.D dissertation]. University of Ilorin, Nigeria.

Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B., Perkins, K. K., Podolefsky, N. S., & Reid, S. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Special Topics–Physics Education Research, 1*(1),1-8. DOI: https://doi.org/10.1103/PhysRevSTPER.1.010103

Hawkins, I., & Phelps, A. (2013). Virtual laboratory vs. traditional laboratory: which is more effective for teaching electrochemistry? *Chemistry Education Research and Practice,* (4), 354-636. DOI: https://doi.org/10.1039/C3RP00070B

Hawkins, I., & Phelps, A. (2013). Virtual laboratory vs. traditional laboratory: which is more effective for teaching electrochemistry? *Chemistry Education Research and Practice,* (4), 354-636. DOI: https://doi.org/10.1039/C3RP00070B

Hofstein, A., & Kind, P. M. (2012). *Learning in and from science laboratories.* Springer Verlag. DOI: https://doi.org/10.1007/978-1-4020-9041-7_15

Hossain, M. A., Rahman, A., & Akter, F. (2022). Digital divide and the implementation of virtual labs in rural Bangladesh: Challenges and implications. *Bangladesh Education Journal*, 21(1), 33–48.

Huang, C. (2003). Changing learning with new interactive and media-rich instruction environments: virtual labs case study report. *Comput. Med. Imaging Graph. 27*, 64–157. DOI: https://doi.org/10.1016/S0895-6111(02)00089-7

Kusmawan, U., Ferdiana, R., Sukmayadi, D., Anas, Z., Wijayanti, S. W., & Noviyanti, M. (2026). Bridging the AI Gap: Validating Student Preference for Dialogic, Co-Agency, and Ethical Learning in Indonesia. *Ianna Journal of Interdisciplinary Studies* , *8*(1), 445–458. Retrieved from https://iannajournalofinterdisciplinarystudies.com/index.php/1/article/view/1449

Kusmawan, U. (2017). Online Microteaching: A Multifaceted Approach to Teacher Professional Development. *Journal of Interactive Online Learning*.15(1). https://www.ncolr.org/jiol/issues/pdf/15.1.3.pdf

Limboo, A.S., Waiba, P.S., Giri, N., & Rinchen, S. (2021). Safety practices in the Chemistry Laboratories of higher secondary schools of Samtse District: A case Study in Bhutan. *Journal of Humanities and Education Development (JHED), 3*(1), 97-111.

Linnenbrink-Garcia, L., & Hmelo-Silver, C. E. (2017). Problem-based learning and the online laboratory. *Journal of Chemical Education, 94*(9), 1182-1187.

Madhuri, J.V., & Prakash Goteti, L.N.S. (2022). Using virtual laboratories in Chemistry through guided inquiry-based approach. *Journal of Positive School Psychology, 6* (2), 369 – 374.

Ncube, L., Dube, C., & Sibanda, T. (2023). Perceptions of students and teachers on virtual laboratories in Zimbabwean science classrooms. *Journal of e-Learning and Knowledge Society*, 19(3), 112–130.

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrovic, V. M., V. M., & Jovanovic, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education, 95*, 309-327.

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrovic, V. M., & Jovanovic, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education,* 95, 309-327

Ramadhan, M.F.,& Irwanto. (2017). Using virtual labs to enhance students' thinking abilities, skills, and scientific attitudes. *International Conference on Educational Research and Innovation*, 494-499.

Redha, H. (2010). Effective use of virtual lab for enquiry and demonstration in teaching chemistry on the development of scientific thinking. *Journal of Science Education, 13*(6), 61-106, Egypt. (In Arabic).

Repnik, R., & Grubelnik, V. (2010). E-learning materials for 3rd grade of primary school- physics, International Journal of Emerging Technologies in Learning. *(iJET), 5*(2), ''MIPRO 2009'', March, 43.

Reyes, R. L., Isleta, K. P., Regala, J. D., & Bialba, D. M. R. (2024). Enhancing experiential science learning with virtual labs: A narrative account of merits, challenges, and implementation strategies. *Journal of Computer Assisted Learning*. DOI: https://doi.org/10.1111/jcal.13061

Reyes, R., Liu, Z., & Park, Y. (2024). Balancing hands-on and simulated learning: A framework for hybrid science laboratories in education. *Education and Information Technologies*, 29(1), 12–30.

Santos, M.L., & Prudente, M. (2022). Effectiveness of Virtual Laboratories in Science Education: A Meta-Analysis. *International Journal of Information and Education Technology, 12*(2). DOI: https://doi.org/10.18178/ijiet.2022.12.2.1598

Sari, U., & Guven, G. B. (2013). The effect of interactive whiteboard supported inquiry-based learning on achievement and motivation in physics and views of prospective teachers toward the instruction. *Journal of Science and Mathematics Education, 7*(2), 110-143. DOI: https://doi.org/10.12973/nefmed204

Simsek, F. (2017). Effect of using animation and simulation in science course on academic success and knowledge retention of students. *International Journal of Education Science and Technology, 3*(3), 112- 124.

Stefanovic, M., Tadic, D., Nestic, S., & Djordjevic, A. (2013). An assessment of distance learning laboratory objectives for control engineering education. *Computer Applications in Engineering Education, 23*(2), 191–202.

Ankut, U.S. (2008). *The effect of computer assisted instruction to academic success and continuity for the course of social studies in primary school 7th class.* [Unpublished master's thesis]. Cukurova University Institute of Social Sciences, Adana.

Tatenov, A., Sarsenbaeva, Z., Azimbaeva, G., Tugelbaeva, K., & Zaurbekova, N. (2023). Evaluating the effectiveness of a virtual laboratory for inorganic chemistry education. *Research in Science & Technological Education*, 1–13. DOI: https://doi.org/10.1080/02635143.2023.2275139

Tesfaye, M., & Bekele, T. (2021). Effects of virtual laboratory simulations on students' laboratory skills in Ethiopian secondary schools. *African Journal of Educational Studies in Mathematics and Sciences*, 17(2), 88–101.

Tuysuz, C.(2010). The effect of the virtual laboratory on students' achievement and attitude in chemistry Inter. *Online J. Educ. Sci. 2* (37).

Yildirim,F.S. (2021). The Effect of Virtual Laboratory Applications on 8th Grade Students' Achievement in Science Lesson. *Journal of Education in Science, Environment and Health, 7*(2). DOI: https://doi.org/10.21891/jeseh.837243