ETDC Indonesian Journal of Research and Educational Review
Volume 4, No. 2, 2025, pp 275 - 284
e–ISSN 2809-3682
p–ISSN 2809-7505

https://doi.org/10.51574/ijrer.v4i2.2742

EFFECTS OF USING VIRTUAL LABORATORY EXPERIMENTS ON STUDENTS' ACHIEVEMENT IN CHEMISTRY

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Article Info

Article history:

Received January 06, 2025
Revised February 25, 2025
Accepted March 14, 2025

Keywords:

Achievement in Chemistry;
CPAT;
Experiments;
High School Students;
Virtual Learning Environments.

ABSTRACT

The study examined the effect of the use of Virtual Laboratory Experiments (VLE) on students' achievement in chemistry. The study employed two hypotheses and two research questions. The design used was quasi-experimental, specifically the pretest-posttest non-equivalent control group one. The study's participants were 2,918 secondary school senior students in Delta, Nigeria. We selected 87 students from intact classes in two schools, using purposive and random selection methods. Three experts verified the data collected using the Chemistry Practical Achievement Test (CPAT). Using Kuder-Richardson Formula 20, we established the internal consistency and found a coefficient of 0.78. We used the mean, standard deviation, and analysis of covariance to analyze the study's data. Considering the research, students who were instructed in chemistry via VLE achieved better than those who trained applying DTI in relation to the mean scores of achievements. Additionally, there was a notable difference in the mean achievement score between students who were instructed in chemistry using the Demonstration Teaching Method (DTM) and those who were educated in chemistry using VLE. It was suggested that chemistry teachers receive regular training on how to incorporate contemporary technology into the instruction and learning of chemistry, particularly regarding the application of virtual chemistry laboratory experiments. This is because virtual learning environments (VLEs) may be utilized to guarantee that experiments are taught frequently and serve as a workaround for inadequate laboratory supplies and equipment.

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1. INTRODUCTION

Education is considered a dynamic discipline that adapts to the varying requirements of students, society, and advancements in technology (Haleem et al., 2022). One important component of this dynamism is the incorporation of experiments into the educational process. Experiments in education extend beyond the usual classroom setting, offering students hands-on experiences that promote critical thinking, problem-solving, and a deeper grasp of the subjects being studied (Avwiri, 2016; Ndihokubwayo & Ndihokubwayo, 2019; Kotsis, 2024). The most compelling evidence for accepting scientific hypotheses comes from experiments. According to the scientific method, we must ask questions and carry out tests to support or refute them in a way that yields objective results. Experiments are essential to the progress of science because they evaluate the truth of ideas, axioms, or chemical events with theoretical foundations before these are turned into laws or theorems (Smith & Williams, 2020; Dyachenko et al., 2024). Experiments also educate students on how to be more observant and inquisitive, as well as how to ask questions, explore new research routes, and discover new ways to answer a question or solve a problem. However, experiments are often carried out in most secondary schools' laboratories, where the feature is that of an integrated laboratory for all school science subjects such as chemistry, physics, and biology.

The teaching of chemistry would be impossible without laboratory experiments (Kolil & Achuthan, 2024). This is because laboratory experiments foster scientific methods, scientific thinking, and the development of conceptual knowledge (Kotsis, 2024). They also help students learn how to do practical tasks like planning an experiment, gathering data, and analyzing and interpreting the experience. Despite the significance of laboratory experiments, many secondary schools do not have operational labs, and when they do, the experiments are rarely repeated to guarantee sufficient learning for students (Byukusenge et al., 2024). There are several ways to explain inadequate laboratory facilities and a lack of ongoing experimentation in secondary education.

Lack of financial support for materials and equipment in Nigerian secondary education contributes to subpar laboratory chemistry experiments, which leave students with little to no practical experience, inadequate resources, and limited time for hands-on work in school. The blame also extends to the students' low involvement in lab activities. In addition, chemical supplies and equipment are not just expensive; they also require expensive safety measures and waste management. Avwiri (2020); Gondden & Gongden (2019) claim that teachers are not well-versed in chemistry. In remote learning environments, it might be challenging to offer hands-on laboratory experiences, especially in synchronous settings where equipment needs to be replicated at every location or in asynchronous settings where students rely on simulations.

Chemistry labs in most schools are often limited to preparing students for external exams like the National Examination Council (NECO) and the West African Senior School Certificate Examination (WASSCE) due to the challenges. According to Gondden (2021), the inadequacy of appropriate and frequent laboratory chemistry experiments is one of the reasons secondary students perform poorly academically in chemistry practicals and chemistry classes overall. We must address the issue of insufficient functional chemistry labs and the need for repeated experiments in a practical manner. The utilization of virtual laboratory experiments is one potential approach to solving the issue, as evidenced by the literature.

According to Potkonjak et al. (2016); Gongden et al. (2020), virtual labs are interactive digital simulations of laboratory activities that are often used in real-world laboratory environments. The interface of a virtual laboratory is identical to one of a real, physical laboratory. Virtual labs mimic the instruments, apparatus, examinations, and procedures utilized in biology, physics, chemistry, biochemistry, and other fields (Hernández-de-Menéndez et al., 2019). It enables the students to take part in laboratory-based learning activities without the expenses and restrictions connected with a physical laboratory. It can therefore greatly enhance actual laboratory experiences (Raman et al., 2022). Using virtual laboratories offers several advantages, one of which is the freedom for learners to participate in self-paced learning. Technology makes it simpler for them to participate in, prepare for, and do laboratory experiments at their convenience, regardless of time or location (Ay & Yilmaz, 2015).

According to Nja et al. (2019), conducting practical experiments before transitioning to a virtual laboratory leads to the most advanced learning and achievement for authentic experiments. As a basis for their knowledge, technology and science students conduct virtual laboratory experiments. This wonderful virtual laboratory platform often informs students about their educational journey before they arrive at the actual laboratory to conduct their experiments (Hu-Au, 2024). Thus, by gaining an insight into how the actual laboratory seems and feels, students can better prepare and invest effort in conducting real laboratory experiments. The most appealing aspect of a virtual laboratory is its easy and enjoyable application (Fei et al., 2022). However, Dyrberg et al. (2017) state that both learners and teachers face different challenges while using virtual laboratories.

Due to the high cost of electricity tariffs and internet subscriptions, power outages and inadequate internet connections are common problems in secondary school settings (Li et al., 2018). Another issue is that students lack the necessary computer abilities, and chemistry teachers who want to use virtual laboratories lack technical know-how (Avwiri, 2021; Makamu & Ramnarain, 2023). Since many schools do not possess the technology needed for virtual laboratory work, students are not always receptive to this type of instruction. Furthermore, researchers claimed that, even when repeated, experiments done in virtual labs fail to offer students sufficient facts about the idea being taught when utilized as a stand-alone teaching tool (Chen et al., 2024). Some individuals hold the belief that students who receive their education solely in virtual laboratories lack the ability to conduct similar experiments in physical labs.

Within the secondary education level, gender has a big influence on students' job choices and subject preferences (Kotsis, 2024). Numerous studies have examined the influence gender has on students' chemistry achievement and other science courses throughout the years, including those by Ezeudu (2013), Gongden (2016), Gongden & Gongden (2019), and others. But studies on disparities between boys and girls in chemistry proficiency have shown conflicting findings, which have often been explained by the information that boys and girls are exposed to chemistry-related learning resources to varying degrees. Ajayi & Ogbeba (2017) found that gender did not significantly affect students' chemistry success, even though both students performed equally.

Another study established that when chemistry was taught via computer animation, gender posed a substantial influence on the boys and girls’ academic advancement

(Ikwuka & Samuel, 2017). Gongden (2016) found that male students outperformed female students when they were taught chemistry using analogies. Chikendu (2018) also observed that girls do better compared to boys in terms of achievement and level of interest in chemistry when the subject is taught using instructional computer animation. Thus, it is essential to find out if secondary chemistry concepts that are experiment-based (such as volumetric and salt analysis) would differ much from those taught using actual laboratory experiments in terms of academic accomplishment. Once again, further research is needed to determine how gender affects students' chemistry achievement, as gender disparities still exist among secondary school students in chemistry and their academic performance.

Research Questions

I. What are the mean scores of students' achievement taught using virtual laboratory experiments (VLE) and those trained using demonstration teaching method (DTM)?

II. What is the interaction effect between teaching techniques and students' gender on Chemistry academic achievement

Hypotheses

I. There is no significant difference in mean scores of achievements between students trained using virtual laboratory experiments (VLE) and those instructed using demonstration teaching methods (DTM).

II. There is no significant interaction between teaching techniques and students' gender Chemistry academic achievement.

2. METHOD

The study used the non-randomized control group design with pretest-posttest as part of its quasi-experimental research methodology. In this research, 2,918 senior secondary year two students offering chemistry from Delta State, Nigeria's Warri South district, made up the population. 87 SS2 students were chosen as a sample using a multi-phase selection process that included purposive and random sampling methods. We used the Chemistry Practical Achievement Test (CPAT) as a research tool. An objective, multiple-choice test with 50 items covering volumetric and salt analysis constituted the CPAT.

The study instrument was confirmed by three specialists from Nnamdi Azikiwe University in Awka, Nigeria: two from the Science Education Department and one from the Department of Educational Foundations (Measurement and Evaluation). CPAT's dependability was assessed using the Kuder-Richardson Formula 20 (KR-20), which produced a reliability index of 0.78. Teachers in the sampled schools' normal chemistry classes participated in the project. A screen display of virtual chemical experiments accompanied by an audio description was applied to instruct experimental groups. As students conducted the practical activity themselves, they listened to the virtual demonstrations and instructions again in the chemical lab. We delivered the lesson each week using computer simulations, animated practical tutorials, and virtual laboratory software demos. The experiment was structured and recorded for presentation in the lab. Using the instructor demonstration technique, the control group received instructions. Students were divided into groups of eight in the control group, and after the teacher demonstrated the task, only one student completed the practical exercise while the others observed and took notes on their readings and other pertinent data.

Students received the CPAT as a pretest and posttest following therapy. The data were examined using the average and standard deviation, and the researchers tested their ideas using Analysis of Covariance (ANCOVA) with a significance level of 0.05. If the p-value was 0.05 or lower, the null hypotheses were rejected; if it was higher than 0.05, they were not rejected. If the probability value (p-value) was lower than or equal to 0.05 ($P \leq 0.05$), the null hypotheses were rejected; if the p-value exceeded 0.05 ($P > 0.05$), they were not rejected.

3. RESULTS AND DISCUSSION

Results

Research Question 1: What are the mean scores of students' achievement taught using virtual laboratory experiments (VLE) and those trained using demonstration teaching method (DTM)?

Table 1. Mean scores students' Achievement trained Chemistry using VLE and DTM

Source of Variation	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Gained Mean
VLE	41	21.32	5.54	79.61	2.97	58.29
DTM	46	30.70	8.38	64.24	10.33	33.54

Table 1 demonstrates that students instructed in chemistry utilizing VLE had a pretest mean score of achievement of 21.32 and a posttest mean score of achievement of 79.61, with a gained mean achievement score of 58.29. Students taught chemistry using DTM had a pretest mean score of 30.70 and a posttest mean score of 64.24, resulting in a gain of 33.54. Students educated in chemistry applying DTM had a less homogenous posttest and pretest score (8.38) than those instructed using VLE (5.54). Again, utilizing VLE led to an additional homogeneous score after the treatment, whereas the utilization of DTM decreased homogeneity of scores among the control students' group after treatment.

Hypothesis one:

There is no significant difference in the mean scores of students' achievement instructed using virtual laboratory experiments (VLE) and those trained using demonstration teaching method (DTM).

Table 2. Students' Mean Scores of Achievements trained Chemistry applying VLE and DTM

Source of variation	SS	Df	MS	F	P-value	Decision
Corrected Model	5463.439[a]	4	1365.860	23.264	.000	
Intercept	33408.589	1	33408.589	569.037	.000	
Pretest	51.906	1	51.906	.884	.350	
Method	2835.754	1	2835.754	48.300	.000	Sig.
Gender	78.058	1	78.058	1.330	.252	Not Sig.
Method * Gender	181.791	1	181.791	3.096	.082	Not Sig.
Error	4814.285	82	58.711			
Total	454829.000	87				
Corrected Total	10277.724	86				

Table 2 illustrates a significant principal consequence of the intervention on pupils' chemistry achievement: $F(1, 82) = 48.300$, $P < 0.05$. Therefore, we rejected the null hypothesis, indicating that students who received chemistry instruction using VLE demonstrated significantly higher academic achievement compared to those who received lessons using DTM.

Research Question 2: What is the interaction effect between teaching techniques and students' gender on Chemistry academic achievement?

Table 3. Male and Female Students' Mean Scores of Achievements instructed Chemistry utilizing VLE and DTM

Method	Gender	n	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Gained Mean
VLE	Male	25	20.68	6.23	80.08	3.58	59.40
	Female	16	22.31	4.25	78.88	1.46	56.57
DTM	Male	27	30.96	8.72	62.19	8.90	31.23
	Female	19	30.32	8.08	67.16	11.71	36.84

Table 3 displays that male students trained in chemistry applying VLE had a mean achievement score of 59.40, while female students had a mean achievement score of 56.57, with male students obtaining a greater gain score of mean achievement and a more homogeneous score in the posttest (1.46) than females (3.58). Male students instructed in chemistry using DTM had an increased mean score of achievement of 31.23, but female students had a mean of 36.84, with females having a higher gain in score of mean achievement and a less homogeneous posttest score (11.71) than males (8.90).

Hypothesis Two: There is no significant interaction between teaching techniques and students' gender Chemistry academic achievement.

Table 2 shows that gender does not significantly affect students' achievement, with $F(1, 82) = 1.330$, $P > 0.05$, and there is also no significant interaction between teaching methods and gender on students' chemistry grades, with $F(1, 82) = 3.096$, $P > 0.05$.

Therefore, we rejected the null hypothesis, suggesting that the impact of teaching technique and gender on the academic achievement of chemistry students was not significant. Figure 1 illustrates the nature of the interaction.

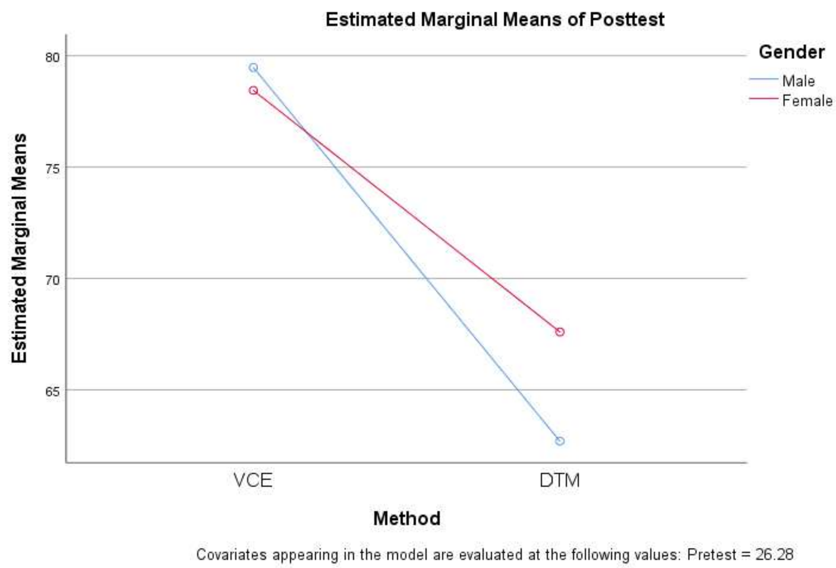

Figure 1. Plot of interaction between teaching approaches and students' gender on chemistry achievement

Figure 1 shows a non-significant and disordinal interaction between teaching strategies and gender on chemistry achievement. This observation signified that the instructional methods are gender sensitive.

Discussion

In collaboration with Dyrberg et al. (2017), who found that VLE has lots of potential to enhance real-world laboratory skills, the study's results demonstrated that the students who received chemistry instruction utilizing VLE had significantly greater accomplishment ratings compared to students that were educated using the teacher demonstration teaching method. The application of VLE may have sparked and maintained students' curiosity about learning, leading to the study's conclusion. Additionally, it led to a generally favorable attitude about learning through the usage of VLE, which otherwise encouraged students to actively participate in the learning process. As a result of active engagement, students could observe the actual chemical process in virtual surroundings, which helped them grasp the concept more deeply. Consequently, the application of virtual laboratories gave students the chance to easily enhance their learning experiments and develop their experiment-related abilities.

The study's results also could be elucidated since students had the chance to go over the experiments until they mastered them since virtual laboratory experiments had lower financial costs and time. Students may study at their speed and assess themselves by repeating the exercises, which gives them a more profound understanding of the parts that seem difficult to grasp. The immediate feedback that comes with using a VLE also prompted students to try out other reagents and experimental setups, which promoted meaningful learning and improved students' interest. The study's results are consistent with those of Atsuwe & Ene (2019) and Dyrberg et al. (2017), who exposed that the virtual laboratory's student group performed noticeably better on the biology accomplishment exam than the conventional laboratory group students.

Additionally, the study's findings demonstrated that neither gender nor teaching technique had a significant interaction effect on students' chemistry success. Both boys and girls were able to study at their pace using VLE, so there was no noticeable difference in the students' average achievement scores or the non-significant interaction effect. Regarding the amount of exposure to and engagement with the learning materials, there was no bias. Consequently, both boys and girls had an equal chance to comprehend the topics. While both students performed equally, this study's findings, which are consistent with Ajayi & Ogbeba (2017), showed that gender had no discernible impact on students' chemistry success. However, the study's results contradict those of Chikendu (2018), who found that girls do better compared to boys in relation to academic accomplishment and chemical excitement when the topic was taught using instructional computer animation.

4. CONCLUSION

The study's conclusions demonstrated students who received chemistry instruction via VLE outperformed those who received instruction by DTM in areas of success. The work found that VLE offered students a more realistic grasp of volumetric and qualitative analytical principles in chemistry, amounting to a more comprehensive learning experience than the demonstration technique. Therefore, it has been demonstrated that the usage of VLE has learning effects that are comparable to those of regular experiments, but it goes beyond that standard demonstration to provide students with a better grasp of chemistry.

As a suggestion, to allow secondary schools to effectively employ virtual laboratory experiments, the government and school officials ensure that these facilities are operational and furnished with computers and other digital accessories. Teachers of chemistry ought to get regular training regarding how to include contemporary technology in chemistry instruction and learning, particularly virtual lab chemistry experiments. The use of VLE ensures the regular teaching of experiments and serves as a solution for insufficient lab supplies and equipment. Additionally, a laboratory should be set up such that every chemistry student can access equipment that makes conducting experimental verification easy and secure while being supervised by the instructor.

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