Comparative Effects of Virtual and Physical Laboratory Practical Activities on Secondary School Students' Achievement in Chemistry

Jack, Gladys Uzezi (PhD) & Shidawa, Emobwejwa Bwefwa
Department of Science Education, Taraba State University, P.M.B. 1167, Jalingo, Nigeria

Abstract

The study compared the effectiveness of virtual and physical laboratory activities on secondary school students' achievement in chemistry in Jalingo Education Zone, Taraba State. A quasi-experimental design was adopted for the study. The population comprised all secondary school two students offering chemistry, from which a sample size of 87 was obtained after purposive sampling of two schools, which were randomly assigned to the virtual and physical laboratory groups. A 50-item Acid Base Titration Achievement Test (ABTAT) was used for data collection. The reliability index of 0.94 was obtained for the instrument using Kuder Richardson 20 formula after a pilot test was conducted. Mean and standard deviation were used to answer research questions, while Analysis of Covariance (ANCOVA) was used to test the hypotheses. It was found that no significant difference existed in the achievement of students exposed to virtual and physical laboratory activities ($p>0.05$); and an insignificant difference based on gender between the two groups. It was concluded that a virtual laboratory can match a physical laboratory in enhancing students' achievement in chemistry; hence, it could be incorporated into students' lab experiences.

Keywords: Virtual, physical, laboratory, titration, gender

Introduction

Science plays a pivotal role in the development of a country as it first makes the citizens scientifically literate, which then ushers in technological and economic prosperity. This has prompted several nations of the world, including Nigeria, to adopt the teaching and learning of science. In secondary schools in Nigeria, science teaching and learning is usually promulgated through science subjects such as biology, chemistry, and physics, among others. The focus of this study was on chemistry. Chemistry, like other science subjects, helps the students to be scientifically literate. Olugbuyi et al. (2023) defined chemistry as the branch of science that deals with the study of compositions and properties of matter. Learning chemistry at the secondary school level will make students able to provide explanation to simple chemical phenomena that occur in their immediate environment. These phenomena include changes in physical states of objects, combustion of petroleum, and colorization and decolorization that accompany chemical processes, among others. Additionally, learning chemistry at the secondary school level will make the students attain the objectives of teaching chemistry at this level as enshrined in the National Educational Research and Development Council, NERDC,

chemistry curriculum. When these objectives are attained, students' achievement will be greatly improved.

Academic achievement has been defined by Eze et al. (2020) to be an indicator of the extent to which a learner has accomplished specific goals that were the focus of activities in instructional environments, especially in schools. Students' achievement represents how effective students' learning was and how well the instructional programme was implemented. In Taraba State, data from the Ministry of Education revealed that students' achievement in West African Senior School Certificate Examinations is low, as more than half of the students taking the exams constantly fail to get the credit grade (C). Philip (2023) stated that practical activities take up 40% of students' external examination marks in chemistry. Furthermore, Olugbuyi et al. (2023) posited that chemistry is a laboratory science and cannot be effectively taught without laboratory activities. This infers that before students must be able to provide explanation for the aforementioned natural phenomena and attain the objectives enshrined in the chemistry curriculum, they must be exposed to sufficient laboratory activities. The foregoing also infers that students' low achievement in chemistry in Taraba State is not farfetched from low exposure to practical activities. For example, Adamu and Achufusi-Aka (2020) found that the extent of integration of practical activities in chemistry lessons in Taraba State is low.

According to Usman et al. (2021), science and technology educators believe that laboratories have been the most important means of instruction in science since the 19th century. Laboratory practical activities are activities that allow students to plan investigations, use scientific reasoning, manipulate equipment, record data, analyse, present, and discuss their results, and come up with conclusions (National Science Teachers Association, 2007 as cited in Uwitonze & Nizeyimana, 2022). These activities impact students' achievement because students' understanding is enhanced when they learn by doing. There are different approaches to laboratory practical activities. In this study, physical laboratory and virtual laboratory are considered.

Conventionally, practical activities in schools take place in a special building called the laboratory. This laboratory, in this context, could be called the physical laboratory. One of the advantages of practical activities that are conducted in physical laboratories has been stated by Chiu et al. as cited in Penn and Ramnarain (2019). These experiments provide students with the opportunity to experience real-life applications of concepts they have learned. Another benefit is that products and results are sometimes tangible. For instance, students may learn

how to make soap and after the process, they will be able to produce and handle the soap they have made. Nevertheless, time limitation and shortage of equipment and chemicals were found in Ndihokubwayo (2017) to be problems that hinder effective physical practical activities. Furthermore, Omilani et al. (2016) posited that these issues have forced chemistry teachers to adopt a fire brigade approach to practical activities where students are exposed to rapid practical activities only a few weeks before their external examinations. Nevertheless, practical activities in chemistry in physical laboratories are common and widely practiced to date. However, the barriers to effective physical laboratory activities, coupled with the rapidly growing application of technology to education, exploring alternatives to physical laboratory has made it possible for virtual practicals to be conducted.

Virtual laboratories are laboratory simulations that provide objects that are virtual representations of real objects used in 'physical' laboratory environments (Asiksoy, 2023). Virtual laboratory is one of the offshoots of growing advancements in technology in education. Computers can now be utilized with various virtual laboratory software such as Praxilabs (which was used in this study), PhET simulation, and Labster among others to provide laboratory experience for students in chemistry. Virtual laboratory activities are greeted by several benefits: Winkelmann et al. (2020) argued that virtual laboratories allow the visualization of abstract objects that cannot be displayed in real physical laboratories. Asiksoy (2023) further stressed that virtual laboratory allow risky experiments to be carried out comfortably. However, this could make learners be insensitive to failure and danger in a real situation (Assem, 2023). Virtual laboratory also requires high-end computers without which practical cannot be possible. In the face of these pros and cons, another problem with virtual laboratories that may cloud the minds of chemistry teachers, students, and other stakeholders is whether would it be effective. Can it enhance students' learning outcomes as much as the traditional physical laboratory that students are accustomed to?

Faulconer and Morgan (2021) opined that there is no single answer for which approach to laboratory activity works the most effectively. Teachers of chemistry in the 21st century have a puzzle to solve: either stick to physical laboratory practical activities or be technology-compliant by embracing practical activities through virtual laboratories. Different studies related to virtual and physical laboratories conducted under different conditions and in different locations have produced varying results. For instance, Pember and Achor (2017) found that there is no significant difference in the achievement of students who did practicals through virtual or physical laboratory means. Similarly, in a more recent study by Papalazarou et al.

(2024), it was observed that students' understanding of students who engaged in physical practical activities and virtual practical activities did not differ significantly. Alternatively, Mohammed et al. (2021) found that students who did practical through virtual laboratory significantly outperformed their counterparts in the physical laboratory group. These conflicting findings necessitate exploring this endeavor to find evidence and empirical-based answers to which practical approach enhances students' achievement more.

Amongst the factors that determine students' achievement and has gained attention in recent studies is the gender of the students. Ogunyemi and Bamidele (2019) asserted that gender involves the identification of the responsibilities assigned to opposite sexes. The problem that concerns gender, especially in science classrooms, is that science learning and practices are open to both males and females. When there is preferential treatment or stereotype of one gender over the other, it triggers underperformance and underachievement. For instance, it is commonly believed that females have better verbal abilities while males have better mathematical skills (Skaalvik and Skaalvik cited in Gambari et al., 2017). This bias could be embedded in the teacher's choice of strategy of instruction and has formed the basis for empirical studies in the past, consequently yielding different findings. For instance, the findings of Manju (2020) and Nkok (2021) on gender differences after students have been exposed to virtual laboratories showed that both male and female students do not statistically differ in their achievement. However, Alabi (2021) in the similar study found that gender differences exist as using virtual laboratories favored female students more than male students. For studies that exposed students to the physical laboratory, Abakpa et al. (2016) and Abidoye (2022) both found that the strategy favours both male and female students equally; however, Ugwuoti and Ugochukwu (2022) found a conflicting result that female students are more favoured in terms of achievement using this strategy. These conflicting results also underscored the need to explore gender differences alongside the effectiveness of the practical methods in question. It is in light of the above that the study investigated the comparative effects of virtual and physical laboratory activities on secondary school students' achievement in chemistry.

Purpose of the study

The study;

i. Determined the achievement of students exposed to practical activities through virtual laboratory and physical laboratory.
ii. Ascertained the achievement of male and female students exposed to the virtual laboratory.

iii. Found out the achievement of male and female students exposed to the physical laboratory.

Research questions

i. What is the mean achievement score of students exposed to practical activities through virtual laboratory and physical laboratory?
ii. What is the mean achievement score of male and female students exposed to virtual laboratories?
iii. What is the mean achievement score of male and female students exposed to the physical laboratory?

Hypotheses

Ho_1: There is no significant difference in the mean achievement score of students exposed to practical activities through virtual laboratory and physical laboratory.

$H_{0}2$: There is no significant difference in the mean achievement of male and female students exposed to virtual laboratory.

$H_{0}3$: There is no significant difference in the mean achievement of male and female students exposed to physical laboratory.

Methodology

The study employed a quasi-experimental design of pre-test and post-test non-equivalent groups. This is because intact classes will be used to establish the effects of virtual and physical laboratories on students' achievement. The population comprised all the 5361 secondary school II students taking chemistry in the 44 co-educational public secondary schools in Jalingo Education Zone of Taraba State. The time scope was the 2024/2025 academic session while the content scope was the topic acid-base reaction in chemistry.

The sample size of 87 was obtained through purposive sampling. Two schools were purposively sampled with the purposive sampling criteria being the availability and functionality of chemistry laboratory and the possession of functional computers with which students will perform practical activities. The sampled schools were randomly assigned into experimental group 1 and experimental group 2.

A 50-item Acid Base Titration Achievement Test (ABTAT) was used for data collection. The ABTAT was face and content validated by experts in Science Education and Measurement and Evaluation from Faculty of Education, Taraba State University. A reliability index of 0.94 was obtained for ABTAT using Kuder Richardson 20 formula.

Students in experimental groups 1 and 2 were both given the instrument as pre-test before the commencement of treatment by the trained research assistants, who were the chemistry teachers of the sampled schools. Thereafter, students in experimental group 1 were exposed to virtual laboratory practicals using Praxilabs package while students in experimental group 2 were exposed to the physical laboratory experimentation. Treatment lasted for four weeks, and ABTAT was given to the students to collect post-test data. Mean and standard deviation were used to answer research questions raised, while Analysis of Covariance (ANCOVA) was used to test all the hypotheses formulated at 0.05 level of significance.

Results

Answering Research Question 1: What is the mean achievement score of students exposed to practical activities through virtual laboratory and physical laboratory?

Table 1: Mean and standard deviation of students' achievement based on group

Groups		Pre-Test	Post-Test	Mean Gain
	Mean	12.98	31.70	18.72
Virtual Lab	n	44	44	
	Std. Deviation	3.26	4.78	
	Mean	13.40	31.63	18.23
Physical Lab	n	43	43	
	Std. Deviation	3.68	7.03	

Table 1 shows that at pre-test, students in the virtual laboratory group had a mean of 12.98, and a standard deviation of 3.26. At post-test, the mean achievement was 31.70 with standard deviation of 4.78. This means that the students in this group gained 18.72 marks as a result of the treatment. Similarly, students in the physical laboratory group had a pre-test score of 13.40 with standard deviation of 3.68 and post-test score of 31.63 with standard deviation of 7.03 representing the mean gain of 18.23. The mean gain difference between students' in virtual and physical lab group is 0.49, but to ascertain, it was tested with hypothesis one (H_{01}).

Testing Null Hypothesis 1 (H_{01}): There is no significant difference in the mean achievement of students exposed to practical activities through virtual laboratory and physical laboratory.

Table 2: ANCOVA of difference in achievement of students based on group

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	5.915[a]	2	2.958	.081	.922
Intercept	5196.203	1	5196.203	143.042	.000
Pre-test	5.787	1	5.787	.159	.691
Groups	.253	1	.253	.007	.934
Error	3051.418	84	36.326		
Total	90299.000	87			
Corrected Total	3057.333	86			

From Table 2, F (1, 84) = 0.007, p = 0.934 > 0.05. Since the p-value is greater than 0.05, this means the difference in achievement between the two groups is not significant. Consequently, hypothesis 1 is accepted.

Answering Research Question 2: What is the mean achievement of male and female students exposed to virtual laboratories?

Table 3: Mean and Standard deviation of students' achievement in virtual laboratory group based on gender

Gender		Pre-test	Post-test	Mean gain
Male	Mean	12.67	31.76	19.09
	n	21	21	
	Std. Deviation	2.94	4.44	
Female	Mean	13.26	31.65	18.39
	n	23	23	
	Std. Deviation	3.57	5.17	

Table 3 shows that at pre-test, male students in the virtual laboratory group had a mean of 12.67 and a standard deviation of 2.94. At the post-test, the mean achievement was 31.76 with a standard deviation of 4.44. This represents a gain of 19.09 marks as a result of the treatment. Similarly, female students in the virtual laboratory group had a pre-test score of 13.26 with a

standard deviation of 3.57 and a post-test score of 31.65 with a standard deviation of 5.17 representing a mean gain of 18.39. The mean gain difference between male and female students in the virtual lab group is 0.7, but to ascertain this was tested with hypothesis two (H_{02}).

Testing Null Hypothesis 2 (H_{02}): There is no significant difference in the mean achievement of male and female students exposed to virtual laboratory.

Table 4: ANCOVA of achievement of students in virtual laboratory group based on gender

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	5.095a	2	2.548	.107	.899
Intercept	2339.801	1	2339.801	98.284	.000
Vpre-achieve.	4.963	1	4.963	.208	.650
Vgender	.322	1	.322	.014	.908
Error	976.064	41	23.806		
Total	45209.000	44			
Corrected Total	981.159	43			

From Table 4, F (1, 41) = 0.014, p = 0.908 > 0.05. Since the p-value is greater than 0.05, this means the difference in achievement of male and female students in the virtual laboratory group is not significant. Consequently, hypothesis 2 is accepted.

Answering Research Question 3: What is the mean achievement of male and female students exposed to the physical laboratory?

Table 5: Mean and standard deviation of student's achievement in the physical laboratory group based on gender

Gender		Pre-Test	Post-Test	Mean Gain
	Mean	12.57	31.71	19.14
Male	n	21	21	
	Std. Deviation	3.79	5.13	
	Mean	13.18	31.55	18.37
Female	n	22	22	
	Std. Deviation	3.47	8.59	

Table 5 shows that at the pre-test, male students in the physical laboratory group had a mean of 12.57, and a standard deviation of 3.79. At the post-test, the mean achievement was 31.71 with a standard deviation of 5.13. This represents a gain of 19.14 marks as a result of the treatment. Similarly, female students in this group had a pre-test score of 14.18 with a standard deviation of 3.47 and a post-test score of 31.55 with a standard deviation of 8.59 representing a mean gain of 17.37. The mean gain difference between male and female students in the physical lab group is 0.77, but to ascertain it, was tested with hypothesis three ($H_0$3).

Testing Null Hypothesis 3 ($H_0$3): There is no significant difference in the mean achievement of male and female students exposed to physical laboratory.

Table 6: ANCOVA of the achievement of students in the physical laboratory group based on gender

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	2.352a	2	1.176	.023	.978
Intercept	2678.159	1	2678.159	51.660	.000
Ppre-achieve.	2.045	1	2.045	.039	.844
Pgender	.733	1	.733	.014	.906
Error	2073.695	40	51.842		
Total	45090.000	43			
Corrected Total	2076.047	42			

From Table 6, F (1, 40) = 0.014, p = 0.906 > 0.05. Since the p-value is greater than 0.05, this means the difference in achievement of male and female students in the physical laboratory group is not significant. Consequently, hypothesis 3 is accepted.

Discussion of Findings

The findings of the study indicated that students in the virtual laboratory group outperformed and outgained their counterparts in the physical laboratory group; however, the difference was not significant. The insignificant difference observed in this finding signifies that the virtual laboratory has the same effect on the student's achievement in chemistry as the physical laboratory does. This further spells that virtual laboratory enhances students' achievement since it is widely believed and proven that physical laboratory activities enhance students' achievement. This demonstrated the potency of the virtual laboratories could be attributed to

the students' rising technology compliance. It proves that the students are willing to integrate and adopt technology for learning purposes. Additionally, since virtual laboratory is relatively a newer approach to laboratory practical activities, the students' interest in exploring it with keenness. This translated into high achievement that was able to match and even surpass that of students from the physical laboratory group, albeit, with the difference not significant. This is in line with Pember and Achor (2017) who found that no significant difference exists in the achievement of students whether they did physical practical or virtual practical. It is also consistent with the findings of Papalazarou et al. (2024) who found that the understanding of students does not differ significantly when taught through virtual laboratory or physical laboratory. The findings disprove the findings of Mohammed et al. (2021), who observed that a significant difference exists in the achievement of students based on the mode of practical activity in favor of a virtual laboratory group.

It was found that no significant difference exists in the mean achievement of male and female students in the virtual laboratory group. The virtual laboratory practical was conducted by each student. In other words, both male and female students were given equal opportunity to perform every bit of the practical activities themselves. This proved instrumental in removing gender dichotomy or bias and consequently it could be responsible for the similar academic achievement results found between male and female students. This finding corroborates the findings of Manju (2020) and Nkok (2021) who both found that male and female students learning through computer aided simulation do not have a significant difference in their achievement. However, the findings contradict the findings of Babalola and Alabi (2021) who observed that there is a significant difference by gender among students exposed to virtual laboratory practical activities in favour of female students.

The findings showed that male students exposed to physical laboratory practical activities gained more than their female counterparts. However, this difference was found not to be statistically significant. Again, the physical laboratory activities were conducted such that male and female students were given equal access to equipment, reagents, and tasks. There was no preferential treatment, and this enabled both male and female students to learn at their own pace. This finding is in line with Abakpa et al. (2016) and Abidoye (2022) who both found that exposing male and female students to practical activities in a physical building as opposed to virtual laboratory brings about no significant differences in their achievement. Nevertheless, the finding disagrees with Ugwuoti and Ugochukwu (2022) who found that there is a statistical

significant difference in the achievement of male and female students who learned through laboratory facilities in favour of female students.

Conclusion and Recommendations

The 21st century has been marked by tremendous growth in applications of technology or computers in solving educational problems, and this study has proven yet again that technology is rapidly taking over the learning process. The study has demonstrated that virtual laboratories have the potential to match physical laboratory by improving students' achievement as much as physical laboratory would.

Based on the conclusion drawn from the study, recommendations are made as follows:

1. School administrators should provide and equip physical laboratories for practical activities in chemistry, as they still occupy indisputable positions in the teaching and learning of chemistry.
2. The secondary school administrators and chemistry teachers in Jalingo Education Zone and, by extrapolation, Taraba State, should provide virtual laboratory experiences for students, as it is potent enough to complement physical laboratories if not to substitute it completely.
3. Both physical and virtual laboratories could be used when there is a need to eliminate gender dichotomy in the chemistry classroom since it does not favour one gender over the other.

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