Effect of Virtual Laboratory Experiments on Secondary School Students' Retention in Chemistry in Jalingo Educational Zone, Taraba State

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Abstract
Inadequacies accompanying physical laboratory have made it necessary to find a complementary alternative. In line with this, the study explored the effect of virtual laboratory experiments on students' retention in chemistry. A quasi-experimental research design was adopted for the study. The population comprised 5361 secondary school two students in Jalingo Education Zone, Taraba State, Nigeria. Multistage sampling was used to select 106 students from two intact classes: one of which was assigned to experimental group while the other was the control group. Students were pre-tested, four weeks of treatment followed; thereafter, Acid-Base Titration Achievement Test (ABTAT) was used for data collection. Two weeks later, ABTAT was reshuffled and renamed Acid-Base Retention Test (ABRT). The instrument was validated by three experts, and a reliability of index of 0.94 was obtained using KR-20. Mean and standard deviation were used to answer the research questions while Analysis of Covariance (ANCOVA) was used to test the null hypotheses at 0.05 level of significance. Virtual laboratory students retained significantly higher than physical laboratory students ($p<0.05$). No significant difference was found in the retention of male and female students in the virtual laboratory group and there was no significant interaction effect of the practical methods and gender on students' retention in chemistry ($p>0.05$). The study concluded that virtual laboratory is effective in improving students' retention in chemistry, and recommended that chemistry teachers in conjunction with school administrators should make provision for virtual laboratory experiments for students.

Keywords: Virtual laboratory, Physical laboratory, Experiments, Students' retention, Chemistry

Introduction

Technology-based learning such as virtual experiments can positively impact secondary school students' retention in chemistry by providing a safe, engaging, and interactive learning environment that complements or replaces traditional laboratory experiences. Key concepts include the role of virtual labs in enhancing understanding of abstract concepts, improving practical skills, and boosting student engagement and confidence in science.

Science is instrumental towards the economic and technological development of a country, and science learning yields scientific literacy which is related to technological advancement (Jack

& Shidawa, 2025). Students' learning of science at the secondary level is aimed at helping them explain and understand natural phenomena happening in their environments and preparing them for future careers in science. This can only be possible if the science teaching and learning process is effective. In this regards, one of the factors considered in this study that could be used to ascertain if the learning process is effective or not is students' knowledge retention.

Retention as viewed by Coleman (2022) is the ability to commit information acquired into one's long-term memory so a person can easily recall it and put that knowledge to use in the future. Knowledge retention goes beyond memorisation (as anybody can do that) but focuses on embedding knowledge into memory for retrieval when and where necessary (Cloke, 2024). Retention is crucial because it helps the students to apply what they have learned in a different or real-life situation. Poor retention often leads to poor achievement which means the objectives of instructional process have not been attained. Good knowledge retention ability is needed for effective science learning, especially, learning of chemistry. The feasibility of these heights requires students to have proper comprehension of what they learn in chemistry and to store what they have comprehended into their long-term memory. Research shows that an average learner forgets 70% of what they learned within 24 hours and 90% of what they learned in a week if they do not make an effort to retain it (Coleman, 2022). According to Cloke (2024), difficulty in retention is attributable to ineffective learning, information overload and low engagement in chemistry.

Chemistry plays a vital role in national development by providing foundational knowledge and skills applicable across various sectors. It derives advancements in areas like agriculture, medicine, and energy, fostering economic growth and improving the quality of life. Furthermore, chemistry education equips individuals with critical thinking and problem-solving skills, crucial for a skilled workforce and national progress. Key areas in chemistry practical at the secondary school level include: titration, and volumetric analysis, thermochemistry, chemical kinetics, qualitative analysis, solubility, flame tests, and physical chemistry. These areas cover essential skills for conducting experiments, analysing data, and understanding chemical principles. Olugbuyi et al. (2023) stated that for chemistry to be effectively taught (such that retention can be enhanced), laboratory practical activities need to be incorporated because chemistry itself is a laboratory science. This infers that practical activities that traditionally takes place in physical laboratories impact students' retention.

The physical laboratory as posited by Kareem (2020) allows students to interact directly with gathered data, acquire manipulative skills, and enhance intellectual understanding; and the empirical nature of science subjects such as chemistry makes laboratory activities necessary for effective science learning. Learners are provided with means of active learning and increased engagement through laboratory experimentations, which provide students with the opportunity to experience real-life applications of learned concepts (Penn & Ramnarain, 2019). The students also experience hands-on authentic chemistry learning where products are tangible and they gain science process skills in a real environment. It is evident that physical laboratory activities better prepares students to learn science in such a way that the learning is meaningful and transfer of learning becomes enhanced; and these laboratories are the most important means of instruction in science (Usman et al., 2021).

Nevertheless, there is the pressing issue of the rising cost of equipment and reagents. Laboratory reagents are recurring since they are exhaustible and need to be replaced as soon as they are used up. Most times, the reagents needed are not provided making practical nearly impossible for students. It is said that learners do not forget what they do or see but when there are no reagents, they will not be able to do or see anything. When the reagents are available in little quantities, there will be no chances for repetition of experiments. Also, some practical activities in chemistry are hazardous and not environmentally friendly. Furthermore, although considered trivial, there is the bottleneck of lack of mobility of physical laboratories as these laboratories are immovable. Onuh and Okigbo (2019) asserted that when these challenges are taken into consideration, looking for appropriate alternatives becomes inevitable. The alternative will not necessarily seek to replace physical laboratory entirely but complement it; especially when there is practical need and the reagents are not readily available or in overcoming the bottleneck of immobility. Technology has helped in providing an alternative route for practical activities for students in chemistry through virtual laboratories.

Virtual laboratory is an interactive environment where simulated experiments can be carried out (Wästberg et al., 2019). An advantage attached to it is that students acquire basic skills and knowledge for work in a laboratory without the risk of incidents in a real laboratory. The choice of the virtual laboratory interactive learning is obvious in the light that technology compliance is on the rise. Since individuals patronise technological gadgets, then the teaching and learning of science which is dynamic, ought to tilt towards incorporating technology into its pedagogy. In order to utilize virtual chemistry laboratory for class instruction, the teacher could pick an already programmed package from one of the many virtual laboratory service providers such as Praxilabs (which was used in this study), PhET simulation, Labster among others. Virtual laboratories provide safer environment for chemistry practical since there are no dangers of burns or release of harmful radiation. With it, practical activities can be conducted at anytime and anywhere; there is neither time nor space restriction. The most enticing benefit of virtual laboratories with regards to retention is that the reagents are not exhaustible. Students can perform practical activities as often as they want. The forgoing shows that virtual laboratory could enhance students' retention in chemistry. But could it enhance it as much as physical laboratory to be considered a suitable alternative?

Previous studies have produced conflicting results. For instance, Agboola and Haruna (2017) found that a statistically significant difference exists in the retention ability of students exposed to virtual laboratory practical and those exposed to physical laboratory practical in favour of virtual laboratory. Akin to that finding, Ejimonu et al. (2023) found that retention of students who performed experiments using computer was significantly higher than those who performed experiments in the real laboratory. In a turn of events, the study by Usman et al. (2021) demonstrated that students in the physical laboratory group showed a significantly better retention than their counterparts who did practical activities in a virtual laboratory. These conflicting findings, and the fact that none of the studies were conducted in Taraba state, none utilised Praxilabs virtual laboratory and none was in chemistry constituted a gap which the current study filled. Another retention influencing factor is gender, and studies on gender (Ajayi & Ogbeba, 2017; Eze et al., 2020; Hagos & Andargie, 2022; Owoyemi & Adesina, 2021; Tukura et al., 2020) and interaction of gender and instructional strategies or methods (Egara & Mosimege, 2023; Nkok, 2021; Nkok, 2022; Okeke, 2018), have not produced consistent results on students' retention. In the light of this problem, inconsistent findings, under-exploration of Praxilabs virtual laboratory package and gap in location that this study sought to determine the effect of virtual laboratory on secondary school students' retention in chemistry in Taraba State.

Objectives of the Study

The study determined:

4. the retention of students who did chemistry experiments through virtual laboratory and physical laboratory;

5. the retention of male and female students who did chemistry experiments through virtual laboratory; and

6. the interaction effect of practical methods and gender on students' retention in chemistry.

Research Questions

The study answered the following questions:

i. What is the mean retention score of students who did chemistry experiments through virtual laboratory and physical laboratory?

ii. What is the mean retention score of male and female students who did chemistry experiments through virtual laboratory?

iii. What is the interaction effect of practical methods and gender on students' retention in chemistry?

Hypotheses

Ho_1: There is no significant difference in the mean retention score of students who did chemistry experiments through virtual laboratory and physical laboratory.

Ho_2: There is no significant difference in the mean retention score of male and female students who did chemistry experiments through virtual laboratory.

Ho_3: There is no significant interaction effect of practical methods and gender on students' retention in chemistry.

Methodology

A quasi-experimental design of pre-test, post-test non-equivalent group was adopted for the study. The study was conducted in Jalingo Education Zone of Taraba State. The population comprised 5631 secondary school two (SS2) students taking chemistry subject in the 44 coeducational public schools in the zone. Sample size of 106 was arrived at with 54 in the experimental group and 52 in the control group using multistage sampling; with purposive sampling technique used at each stage (Zone, schools, & class). Two schools were purposively sampled based on the availability of functional laboratory and adequate computers with which the study was conducted. One intact class was randomly selected from each of the schools and was further randomly assigned to experimental and control groups. Students in the experimental group did practical using Praxilabs virtual laboratory while students in the control group did conventional physical laboratory practical. Treatment was provided on acid-base titration and lasted for four weeks with test of retention coming two weeks later after treatment. The study was conducted in the 2024/2025 academic session.

A 50-item Acid Base Retention Test (ABRT) which was a reshuffled Acid Base Titration Test (ABTAT) was used for data collection. ABTAT was validated by two experts in Science Education and one expert in Measurement and Evaluation from Taraba State University, Jalingo. A reliability index of 0.94 was obtained for the instrument through Kuder Richardson 20 formula. In the administration of treatment, permission was obtained from the principals of the sampled schools and thereafter, the regular chemistry teachers of the two schools were briefed on how to implement treatment and collect data. Manuals for virtual and physical laboratory practical were given to them as well as the instrument for data collection. Pre-test data was first collected; four weeks of treatment followed; post-test data was collected with ABTAT which indicated the achievement of the students. Two weeks later, the ABTAT was reshuffled and renamed ABRT and administered to the students. The data collected at this stage indicated students' knowledge retention.

Mean and standard deviation were used for answering research questions while Analysis of Covariance (ANCOVA) was used to test the null hypotheses at 0.05 level of significance. Statistical analyses were carried out using the statistical package for social sciences (SPSS).

Results

The results were presented in tables starting with the research questions and then the null hypotheses followed.

Research Question 1: What is the mean retention score of students taught chemistry using virtual laboratory practical activities and students taught chemistry using physical laboratory practical activities?

Table 1: Mean and standard deviation of students' mean retention score by practical methods

Practical Methods		postABTAT	Retention	Mean lost
	Mean	31.50	30.31	1.19
Virtual Laboratory	N	54	54	
	Std. Deviation	4.40	4.78	
	Mean	31.13	24.38	6.75
Physical Laboratory	N	52	52	
	Std. Deviation	6.86	4.95	

Table 1 shows that at post-test students in the virtual laboratory group had a mean achievement score of 31.50 with standard deviation of 4.40 and at post post-test, this mean score dropped to 30.31 with standard deviation of 4.78. This means that the students in the virtual laboratory group lost 1 mark on average after two weeks of treatment. Students in the control group exposed to physical laboratory practical had a mean achievement score of 31.13 with standard deviation of 6.86 and at post post-test, this mean score dropped to 24.38 with standard deviation of 4.95. This means that the students in the physical laboratory group lost over 6 marks on average after two weeks of treatment.

Research Question 2: What is the mean retention score of male and female students taught chemistry using virtual laboratory practical activities?

Table 2: Mean and standard deviation of the mean retention score of students in the virtual laboratory group by gender

Gender		postABTAT	Retention	mean loss
Male	Mean	31.40	30.40	1.00
	N	25	25	
	Std. Deviation	4.27	5.37	
Female	Mean	31.59	30.24	1.35
	N	29	29	
	Std. Deviation	4.59	4.31	

Table 2 shows that at post-test male students in the virtual laboratory group had a mean achievement score of 31.40 with standard deviation of 4.27 and at post post-test, this mean score dropped to 30.40 with standard deviation of 5.37. This means that the male students in the virtual laboratory group lost 1 mark on average after two weeks of treatment. Female students exposed to virtual laboratory practical activities had a mean achievement score of 31.59 with standard deviation of 4.59 and at post post-test, this mean score dropped to 30.24 with standard deviation of 4.31. This means that the female students in the virtual laboratory group lost 1.35 marks on average after two weeks of treatment.

Research Question 3: What is the interaction effect of gender and method of laboratory practical activities on the retention of students in chemistry?

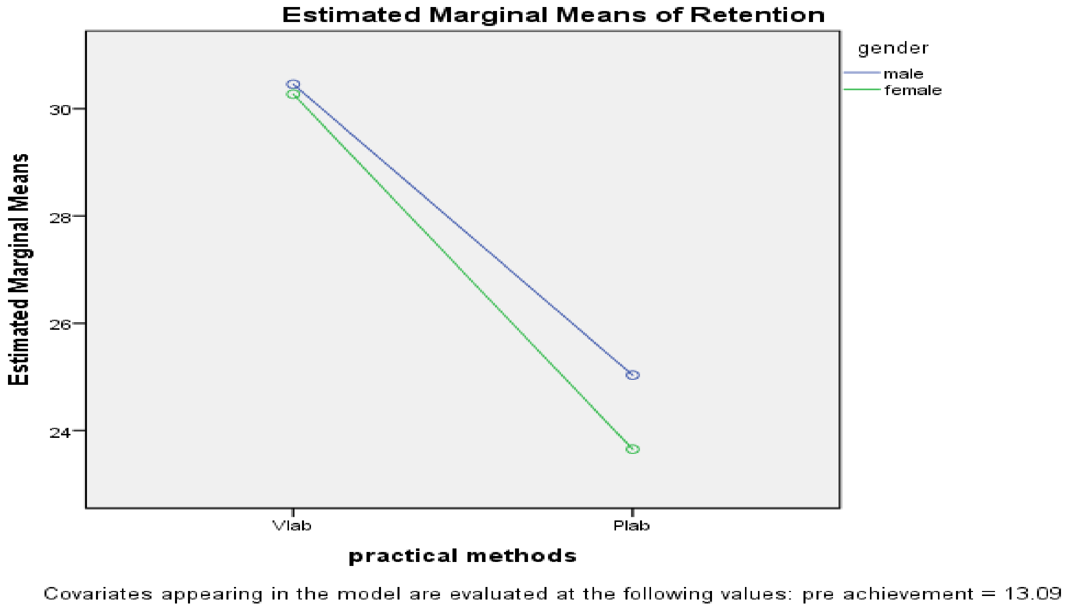

Figure 1: Plot of interaction effect of methods of practical and gender on students' retention

Figure 1 shows that in the experimental group (virtual laboratory group), male students had a higher mean retention score than their female counterparts. Similarly in the control group (physical laboratory group), the male students also showed a higher mean retention score than their female counterparts. From the plots of practical methods and gender shown on the figure above, the two lines are not parallel. There is a slight intersection on the virtual laboratory group's axis. This indicates that there is an interaction effect of methods of practical activities and gender on students' retention.

Research Hypothesis 1: There is no significant difference in the mean retention score of students taught chemistry using virtual laboratory practical activities and students taught chemistry using physical laboratory practical activities.

Table 3: ANCOVA result of retention of students in the virtual laboratory and physical laboratory groups

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	942.973a	2	471.486	19.817	.000
Intercept	4797.976	1	4797.976	201.663	.000
PreABTAT	11.372	1	11.372	.478	.491
Pract. Method	**942.824**	**1**	**942.824**	**39.628**	**.000**
Error	2450.584	103	23.792		
Total	83007.000	106			
Corrected Total	3393.557	105			

Dependent variable: retention

Table 3 shows that F (1,103) = 39.628; p = 0.000 < 0.05. This means result of test of significance is lower than the benchmark 0.05; consequently, the null hypothesis is rejected. This implies that there is a significant difference in the retention score of students taught chemistry using virtual laboratory and those taught using physical laboratory.

Research Hypothesis 2: There is no significant difference in the mean retention score of male and female students taught chemistry using virtual laboratory practical activities.

Table 4: ANCOVA result of retention of students in the virtual laboratory group by gender
Dependent variable: retention

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	1.478a	2	.739	.031	.969
Intercept	2928.464	1	2928.464	123.414	.000
VpreABTAT	1.140	1	1.140	.048	.827
Gender	**.381**	**1**	**.381**	**.016**	**.900**
Error	1210.170	51	23.729		
Total	50837.000	54			
Corrected Total	1211.648	53			

Table 4 shows that F (1, 51) = 0.016; p = 0.900 > 0.05. This means result of test of significance is higher than the benchmark 0.05; consequently, the null hypothesis is accepted. This implies that there is no significant difference in the mean retention score of male and female students taught chemistry using virtual laboratory

Research Hypothesis 3: There is no significant interaction effect of gender and methods of practical activities on the retention of students in chemistry.

Table 5: ANCOVA result of interaction effect of gender and practical methods on students' retention

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	967.303a	4	241.826	10.067	.000
Intercept	4515.522	1	4515.522	187.972	.000
preABTAT	18.057	1	18.057	.752	.388
Groups	947.611	1	947.611	39.447	.000
Gender	15.827	1	15.827	.659	.419
Pract. method * gender	**9.301**	**1**	**9.301**	**.387**	**.535**
Error	2426.253	101	24.022		
Total	83007.000	106			
Corrected Total	3393.557	105			

Table 5 shows that interaction of practical methods and gender, F (1,101) = 0.387; p = 0.535 > 0.05. This means result of test of significance is higher than the benchmark 0.05; consequently, the null hypothesis is accepted. This implies that there is no significant interaction effect of methods of practical activities and gender on students' retention.

Discussion of Findings

The findings of the study revealed that students in the virtual laboratory group showed a significantly higher retention than their counterparts in the physical laboratory group. The keenness demonstrated by students to participate actively and explore the computer-based practical method catalyzed their retention abilities. Furthermore, the students manipulated the experiments themselves and tested statements against observation. They also had opportunities to repeat the practical activities as problem of shortage of reagents was completely eliminated with virtual laboratory. Where students in the virtual laboratory could run and rerun about 10 practical activities in an hour, their counterparts in the physical laboratory struggled to do so. While this is possible in the physical laboratory, it is not economical. This opportunity for repeated experiments helped students to retain longer what they learned as they did practical. This significant difference in favour of virtual laboratory is consistent with the findings of Agboola and Haruna (2017) who found a statistically significant difference exists in the retention ability of students exposed to virtual laboratory and those exposed to physical laboratory practical in favour of virtual laboratory. It also agrees with Ejimonu et al. (2023) who found that retention of students who performed experiments using computer was significantly higher than those who performed experiments in the real laboratory. The finding however disagrees with Usman et al. (2021) who observed that students in the physical laboratory ground showed a significantly better retention than their counterparts who did practical activities in a virtual laboratory.

In retention, the findings revealed no significant difference between male and female students exposed to virtual laboratory activities. This further proves that virtual laboratory play a unifying role on students' learning outcome with respect to gender. This insignificant difference with respect to retention strengthens the fact that the male and female students were provided equal opportunities to do practical by themselves. Since doing enhances retention, male or female, retention can be enhanced if learning occurs by doing. This is consistent with the findings of Nkok (2021) who found that although male students exposed to computer simulation activities retained more than female students, the difference is insignificant. It also corroborates Usman et al. (2021) who found that no significant difference existed between the retention of male and female students exposed to virtual laboratory activities. But, the finding disagrees with Egara and Mosimege (2023) who found that upon exposure to simulation, there was a significant difference in the retention of male and female students, in favour of female students.

There was no significant interaction effect of method of practical activities and gender on students' retention. This is consistent with Nkok (2022) who found no significant interaction effect of treatment and gender on students' retention. Egara and Mosimege (2023) also reported no statistically significant interaction effect of strategies and gender on students' retention. Similarly, it agrees with Okeke (2018) who found there is no significant interaction effect of strategies and gender on students' retention in chemistry.

Conclusion

The study concludes that virtual laboratory is effective in improving students' retention in chemistry. Virtual laboratory mode of practical activities also enhances both male and female students' retention without depending on gender. It does this by providing opportunities for repeating experiments without number while varying the experimental conditions. This opportunity is exclusive for both genders. The findings alludes that virtual laboratory has a future in practical aspects of chemistry pedagogy and with time, it will be wholly welcomed not to replace the physical laboratory but to serve as an efficient alternative in cases where physical laboratory fall short.

Recommendations

The following recommendations were provided following the findings of the study.

1. Chemistry teachers in conjunction with school administrators should make provision for virtual laboratory experiments whenever they are faced with the limitations of physical laboratory such as shortage of reagents.
2. Male and Female students should be given equal opportunities to manipulate the virtual laboratory whenever they are conducting experiments.
3. Chemistry teachers and students should work together and utilise repeated experiments in the virtual laboratory setting since there is no problem of recurring reagents as so doing can boost their retention.

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