Effect of Virtual Laboratory on Students' Academic Achievement in Chemistry in Secondary Schools in Yenagoa, Bayelsa State

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Abstract
The research evaluated the effects of virtual laboratory on students' academic achievement in chemistry in Yenagoa, Bayelsa State. The pre-test and post-test control group quasi-experimental design was used in the investigation. All SSII chemistry students in Bayelsa State's Yenagoa metropolis made up the study's population. Purposive sampling was used to choose 105 students to take part in the research. A whole class from two schools was used, with the experimental and control groups being randomly allocated. The modified lecture technique and the virtual chemistry laboratory were the teaching methods employed. Five weeks were dedicated to the research. The Chemistry Achievement Test (CAT), which consisted of 20 multiple-choice questions and had a reliability of 0.88 using Kuder-Richardson Formula 21 (KR-21), was one of the study's instruments, along with two instructional guides. The study questions were answered using the mean and standard deviation, and the null hypotheses were tested using ANCOVA at 0.05 level of significance. According to the study's results, students who were taught chemistry using the virtual laboratory outperformed those who were taught using the modified lecture technique. Gender had no discernible impact on the academic achievement of the students. It was suggested that innovative resources like virtual laboratory be used to teach chemistry.

Keywords: Virtual laboratory, Modified Lecture method, Gender, Academic achievement, Chemistry,

Introduction

Chemistry education in secondary schools is a cornerstone for nurturing scientific literacy and critical thinking skills among students. The acquisition of fundamental knowledge in chemistry not only contributes to academic success but also lays the groundwork for various scientific pursuits and careers (Johnstone, 1997).

Chemistry is a practical-based subject. This practical nature means that hands-on experience is crucial for a thorough understanding (Fuangswasdi et al., 2022; Iyamuremye et al., 2023). However, the commonly used lecture method in teaching chemistry falls short in this regard, as it primarily delivers theoretical knowledge without allowing students to engage directly with the materials and processes they are learning.

Laboratory practical activities in chemistry are essential because they provide experiential learning opportunities, enabling students to observe reactions, develop specific practical skills and reasoning, and develop problem-solving skills that are vital for a comprehensive understanding of the subject (Agustian, 2020). The direct engagement available through practical laboratory activities can help students solidify their knowledge and make abstract concepts more concrete, understandable, and rooted in the real world.

Laboratory activities also support the development of observational skills, as well as other useful scientific skills (Gebrehiwot, 2017). Experimentation in the chemistry laboratory, particularly finding solutions and recording findings, also fosters creativity and genuine interest in science and chemistry, paving the pathway for real-world scientific engagements (The Royal Society of Chemistry, 2021). Thus, laboratory practical activities not only support the development of comprehensive knowledge and understanding of chemistry and other scientific fields but also equip students with essential skills that are applicable in varying scientific and professional contexts.

However, the adoption of practical activities in chemistry education in secondary school is confronted by a series of challenges. Particularly across educational landscapes, including regions like Yenagoa Local Government Area in Bayelsa State, the traditional model of hands-on experimentation is impeded by resource limitations or constraints (Hofstein & Lunetta, 2017). These constraints encompass an insufficiency of laboratory equipment, inadequate funding for practical experiments and an insufficiency of qualified personnel to guide students through these experiments effectively, among others. Consequently, students often miss out on crucial hands-on experiences, hindering their ability to comprehend and apply theoretical concepts to practical scenarios.

The use of virtual laboratory rises as a potential tool to address these challenges and limitations without compromising on the need for hands-on practical learning in chemistry. Virtual laboratory refers to computer simulations and interactive software that are used to stimulate real-world laboratory environments (Daineko et al., 2016; Hernández-de-Menéndez et al., 2019). They enable students to gain access to laboratory experiments and resources in a digital space without the constraints posed by physical laboratories and resources (Cheng & Chou, 2019). Virtual laboratory provide a more cost-effective and accessible means for students to engage in the necessary chemistry practical activities, particularly in the absence or insufficiency of physical resources.

The virtual laboratory also proves useful in scenarios where carrying out activities with physical/real-world materials and substances might prove too risky (Herga et al., 2016; Viitaharju et al., 2021). Handling hazardous chemicals, operating complex materials or machinery, and conducting some experiments opens a plethora of safety concerns for the students and instructors, such that those kinds of practical experiments are usually skipped, especially at the secondary school level. The presence of a virtual laboratory can mitigate this issue as it provides a simulation of the practical experience without any of the associated risks. The safe digital environment for chemistry practicals provided by virtual labs helps students explore a wide range of experiments that would have otherwise been avoided, restricted or required extensive safety measures in a physical lab.

Virtual labs are also particularly useful for enabling students to build confidence and competence in their skills before transitioning to a real-world laboratory setting (Kolil & Achuthan, 2024; Luse & Rursch, 2021). They can serve as a preliminary introduction to laboratory procedures, equipping students with a broad understanding and skills that will prove useful and transferable to real-world laboratory experience.

Thus, virtual laboratory platforms provide a cost-effective, scalable, and accessible means for students to immerse themselves in practical chemistry experiments, irrespective of the limitations posed by physical resources. Eilks and Hofstein (2017) state that, these digital tools offer a dynamic learning environment that promotes active student participation, critical thinking, and exploration of scientific concepts in a riskfree setting. Furthermore, they facilitate repeated trials and observations, allowing students to grasp abstract concepts through concrete experiences, thereby potentially enhancing comprehension and retention of complex chemical principles.

Numerous studies have underscored the efficacy of virtual laboratories in augmenting science education. Research findings across diverse educational settings have reported positive outcomes, including heightened student engagement, improved understanding of scientific concepts, and enhanced academic performance in chemistry (Mzoughi et al., 2020; Al-Rawi et al., 2018).

Considering the potential advantages of virtual laboratories, understanding how the integration of virtual laboratory into chemistry teaching influences students' learning outcomes, academic performance, and comprehension of chemistry concepts is crucial. However, this area remains largely underexplored.

One factor that can affect students' learning outcomes in chemistry, irrespective of the instructional technique used, is the gender of students. The gender effects can be linked to societal stereotypes and expectations, which have major implications on day to day lives of individuals, including how they define themselves and how they are treated (Ellemers, 2018). These stereotypes are still prevalent in educational contexts, with some specific fields deemed more suited to the abilities of one gender over the other. For example, Oladejo et al. (2021) state that it is generally believed that male students are more suited and capable of learning science subjects like chemistry. These stereotypes can affect their learning outcomes as they can, amongst others, lead to differences in encouragement, support, and opportunities provided by teachers and parents to pursue and excel in specific fields. Consequently, this will likely affect the student's confidence and interest.

Also notable is the potential difference in how male and female students interact with and respond to technology, which is relevant in this context as the virtual laboratory is an exclusively technological tool. Aytekin and Isiksal-Bostan (2018) state that gender influences students' attitudes and engagement with technology in a classroom, and this can, in turn, affect their learning outcomes in a technology-enhanced classroom. Thus, this study also considers whether virtual laboratories are equally effective for both male and female students or if there are disparities that need to be addressed to ensure equitable learning opportunities.

The adoption of the virtual laboratory to teach chemistry aligns with the principles of experiential learning theory. The theory proposed by David Kolb states that knowledge is created through the transformation of experience (Gencel et al., 2021). The theory emphasizes that learning is most effective when it involves a process of experiencing, reflecting, thinking, and acting. Learners engage in a cyclical process where they actively participate in an experience, reflect on what happened, conceptualise and form abstract ideas, and then experiment with these ideas in new situations (Falloon, 2019; Yusof et al., 2020). In the context of using virtual laboratories, the labs provide an interactive platform that engages students in practical activities or experiences, and by allowing students to conduct virtual experiments, observe outcomes, and reflect on their findings, virtual labs facilitate the experiential learning cycle.

Statement of the Problem

Chemistry is one of the most important fields in the world today. Being a practical-oriented field, it is essential that chemistry teaching and learning activities adequately incorporate practical laboratory activities. There needs to be more than just traditional classroom instruction to ensure meaningful chemistry learning, and the absence of such is a major contributory factor to trends of underachievement in the chemistry subject. However, laboratory chemistry instruction faces a plethora of limitations, particularly the unavailability of sufficient laboratory apparatus and resources. This issue can, however, be potentially addressed with the use of a virtual laboratory. Despite the potential of the virtual laboratory, it has yet to be reasonably established or explored in the context of chemistry education, particularly in Bayelsa state. Consequently, this study explored the effects of the virtual laboratory on the academic achievement of chemistry students in secondary schools.

Research Questions

iii. What is the mean achievement score of students in chemistry when taught with virtual laboratory and those taught with modified lecture strategy?
iv. What is the mean achievement score of male and female students in chemistry when taught with virtual laboratory and those taught with modified lecture strategy?

Null Hypotheses

1. There is no significant difference in the mean achievement score of students in chemistry when taught with virtual laboratory and those taught with modified lecture strategy.
2. There is no significant difference in the mean achievement score of male and female students in chemistry when taught with virtual laboratory and those taught with modified lecture strategy.

Methodology

This study adopted the pre-test post-test control group quasi-experimental design. The study's population consisted of all SSII chemistry students of senior secondary schools located in Yenagoa Metropolis, in Local Government Area, Bayelsa State. Two schools were purposively selected as samples based on the following criteria; Chemistry teachers at the schools must be professionally qualified and must have been teaching chemistry for a minimum of four years; the teachers of the selected schools must be willing to be involved in the experiment; the schools must be public secondary schools. One intact class from each of the schools was used as the experimental and control group. Three instruments were used for data collection, which are "Instructional Guide on Virtual Laboratory Instructional Strategy (IGVLIS), Instructional Guide on the Modified Lecture Instructional Strategy (IGMLIS), and Chemistry Achievement Test (CAT)". The instructional guides were used to teach the students during the treatment period, while the CAT was used to measure the students' chemistry achievement. Experts validated the instruments, and the CAT had a reliability of 0.88 using Kuder-Richardson Formula 21.

Teachers were trained to use the instructional guides during the first week of data collection, and a pre-test was administered during the second week, after which was the commencement of treatment on the students using the instructional guides lasted two weeks. The post-test was then administered to the students after treatment. The research questions were answered using mean and standard deviation while the hypotheses were tested using Analysis of Covariance (ANCOVA).

Results

Research Question One: "What is the mean achievement score of students in chemistry when taught with virtual laboratory and those taught with modified lecture strategy?"

Table 1: Summary of Mean and Standard Deviation of Students' Pre-test and Post-test Scores showing the Effects of Instructional Strategies on Students ' Achievement in Chemistry

Instructional Strategies	N	Pre-test Scores Mean	STD	Post-test Scores Mean	STD	Mean Gain
Virtual Laboratory	55	32.0	6.28	60.36	7.06	28.36
Modified Lecture	50	30.80	7.65	48.0	9.42	17.2
Total	105	31.43	6.96	54.48	10.31	23.05

According to Table 1, students who were taught using the virtual laboratory had a higher post-test mean score (M = 60.36, SD = 7.06) than those who were taught using the modified lecture approach (M = 48, SD = 9.42). The table also demonstrated that students taught using the modified lecture technique had a lower mean gain score (17.2) than students taught using the virtual laboratory (28.36). To determine if the difference was significant, the ANCOVA was used.

Research Question Two: What is the mean achievement score of male and female students in chemistry when taught with virtual chemistry laboratory and those taught with modified lecture strategy?

Table 2: Summary of Mean and Standard Deviation of Pre-test and Post-test Scores Showing the Effects of Instructional Strategies on Male and Female Students' Achievement in Chemistry

Instructional Strategies	Gender	N	Pre-test Scores Mean	STD	Post-test Scores Mean	STD	Mean Gain
Virtual Laboratory	**Male**	24	32.50	5.90	58.75	7.40	26.25
	Female	31	31.61	6.64	61.61	6.64	30
	Total	55	32.0	6.28	60.36	7.06	28.36
Modified Lecture	**Male**	23	28.91	6.90	47.17	9.74	18.26
	Female	27	32.41	8.01	48.70	9.26	16.29
	Total	50	30.80	7.65	48.0	50	17.2
Total	**Male**	47	30.74	6.59	53.08	10.35	22.34
	Female	58	31.98	7.25	55.60	10.22	23.62
	Total	105	31.43	6.96	54.48	10.31	23.05

Table 2 revealed that, among students instructed in the virtual laboratory, female students' post-test mean score (M = 61.51, SD = 6.64) is higher than male students' (M = 58.75, SD = 7.40). In a similar vein, among students instructed using the modified lecture approach, female students' post-test mean score (M = 48.70, SD = 9.25) is higher than male students' (M = 47.17, SD = 9.74). Female students had a higher mean score on the post-test overall (M = 55.60, SD = 10.22) than male students (M = 53.08, SD = 10.35). According to the table, female students had a higher overall mean gain score (23.62) than male students (22.34). To ascertain if the observed difference was significant, the ANCOVA was thus used.

Null Hypothesis One: There is no statistically significant difference in the mean achievement score of students in chemistry when taught with virtual chemistry laboratory and those taught with modified lecture strategy.

Table 3: One-way Analysis of Covariance of the Post-test Scores of Students Taught Chemistry through the Virtual Laboratory and the Modified Lecture Method

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4134.736[a]	2	2067.368	30.510	.000	.374
Intercept	16986.134	1	16986.134	250.683	.000	.711
Pre-test	131.273	1	131.273	1.937	.167	.019
InstructionalStrategies	4099.467	1	4099.467	60.500	.000*	.372
Error	6911.455	102	67.759			
Total	322650.000	105				
Corrected Total	11046.190	104				

a. R Squared = .374 (Adjusted R Squared = .362), *Sig at p = 0.05 alpha level

The result in Table 3 showed that there is a significant main effect of instructional strategies on students' achievement in chemistry, $F(1, 102) = 60.500$, $p < 0.05$, partial eta squared = .372. This gives an effect size of 37.2%. Thus, the null hypothesis, which states that, there is no statistically significant difference in the mean achievement score of students in chemistry when taught with virtual chemistry laboratory and those taught with modified lecture strategy, was rejected.

Null Hypothesis Two: There is no statistically significant difference in the mean achievement score of male and female students in chemistry when taught with virtual chemistry laboratory and those taught with modified lecture strategy.

Table 4: Two-way Analysis of Covariance of the Post-test Scores of Male and Female Students taught Chemistry through the Virtual Laboratory and the Modified Lecture Method

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4290.025[a]	4	1072.506	15.874	.000	.388
Intercept	16632.080	1	16632.080	246.176	.000	.711
Pre-test	146.624	1	146.624	2.170	.144	.021
InstructionalStrategies	3995.945	1	3995.945	59.145	.000	.372
Gender	150.729	1	150.729	2.231	.138	.022
InstructionalStrategies * Gender	2.052	1	2.052	.030	.862*	.000
Error	6756.165	100	67.562			
Total	322650.000	105				
Corrected Total	11046.190	104				

a. R Squared = .388 (Adjusted R Squared = .364), *Sig at p < 0.05 alpha level

Table 4 shows that there is no significant interaction effect of gender on students' achievement in chemistry, $F(1, 100) = .30$, $p = .862$. Thus, the null hypothesis, which states that, there is no statistically significant difference in the mean achievement score of male and female students in chemistry when taught with virtual chemistry laboratory and those taught with modified lecture strategy, was upheld.

Discussion of Findings

The study's findings showed that students taught with virtual laboratories have significantly better mean achievement in chemistry than students taught with the modified lecture strategy.

This finding agrees with those of Famuwagun and Mohammed (2020) and Tuysuz (2015), who investigated the effects of Virtual Laboratories on secondary school students' performance in chemistry and reported that students exposed to chemistry through virtual laboratories performed significantly better than their counterparts who were exposed to the conventional method of teaching chemistry.

The finding also agrees with that of Asareet al., (2022), who examined the effect of Virtual Laboratory (VL) on student teachers' achievement in Integrated Science in a tertiary institution and reported that students' performance improved in Integrated Science through virtual laboratory.

The findings of the study also showed that there is no statistically significant difference in the mean achievement score of male and female students in chemistry when taught with virtual chemistry laboratory and those taught with modified lecture strategy.

Conclusion

Based on this study's findings, it can be concluded that a virtual chemistry laboratory is more effective for teaching chemistry concepts than conventional methods (modified lecture strategy). As such, its adoption will lead to better learning outcomes in chemistry. Students' achievement in chemistry is not mediated by their gender. Thus, female students can perform just as well as male students in chemistry and vice versa.

Recommendations

1. Steps should be taken to incorporate innovative tools like virtual chemistry laboratories into curricula and classroom instructional processes to enhance student learning experiences.
2. Training should be provided for teachers to use virtual tools and integrate technology into teaching practices effectively.
3. Pre-service teacher training programs should also prepare prospective teachers to effectively implement innovative digital strategies and tools, such as virtual laboratories.
4. Educational and governmental entities should proactively ensure the availability of essential digital devices required to facilitate the implementation of instructional strategies like the virtual chemistry laboratory.

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