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Effect of Integrating Virtual Reality Laboratory and Physical Laboratory on Male and Female Senior Secondary School Students' Achievement and Retention in Chemistry

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ABSTRACT

This study investigated the effect of integrating virtual reality laboratory and physical laboratory on the achievement and retention of male and female Senior Secondary School II (SS II) students in Chemistry. Two research questions and two null hypotheses guided the study. A quasi-experimental research design was adopted for the study, which was conducted in Ogbaru Local Government Area of Anambra State, Nigeria. The population comprised 364 SS II Chemistry students, from which a sample of 65 students was selected. The instrument used for data collection was the Chemistry Achievement Test (CAT), developed by the researchers. The instrument was validated by three experts, comprising one expert in Measurement and Evaluation and two experts in Chemistry Education, all from Nwafor Orizu College of Education, Nsugbe. A reliability coefficient of 0.74 was obtained using the Pearson Product-Moment Correlation Coefficient, indicating satisfactory reliability. Data collected were analysed using mean and standard deviation to answer the research questions, while t-test was used to test the null hypotheses at the 0.05 level of significance. The findings revealed that female students obtained higher mean achievement and retention scores than their male counterparts when taught Chemistry with the integration of virtual reality laboratory and physical laboratory. However, there was no significant difference between the mean achievement scores of male and female students. In contrast, a statistically significant difference was found between the mean retention scores of male and female students taught Chemistry through the integrated virtual reality and physical laboratory approach. Based on these findings, it was recommended, among other measures, that educational agencies and other relevant stakeholders should organize workshops and seminars to equip Chemistry teachers with the knowledge and skills required for the effective integration of virtual reality laboratories with physical laboratory instruction.

Keywords: *Virtual Reality Laboratory, Physical Laboratory, Gender, Achievement and Retention*

Introduction

Chemistry is both a theoretical and an experimental discipline. Laboratory instruction provides an important context in which students can connect abstract chemical concepts with observable phenomena and practical experiences. Through laboratory activities, learners are given opportunities to manipulate materials and equipment, observe chemical changes, collect and interpret experimental data and relate theoretical explanations to real-world observations. Laboratory work therefore extends Chemistry learning beyond the classroom by engaging students in activities that require them to think, observe, investigate and make evidence-based conclusions. Agustian et al. (2022), in a systematic review of empirical studies on Chemistry laboratory learning, identified several dimensions of learning associated with laboratory instruction, including experimental competence, disciplinary knowledge, higher-order thinking, communication, collaboration and affective development. These findings demonstrate that laboratory instruction has the potential to support learning outcomes that extend beyond the acquisition of factual Chemistry knowledge.

The educational value of laboratory instruction, however, depends considerably on how laboratory activities are designed and implemented. Laboratory work does not automatically guarantee meaningful learning merely because students are physically present in a laboratory or perform an experiment. The relationship between the experimental activity, the intended learning outcomes, students' prior knowledge, teacher guidance and opportunities for reflection is important in determining what students actually learn. Agustian and Seery (2017) emphasized the importance of appropriate preparation before laboratory activities, noting that pre-laboratory activities can introduce chemical concepts, laboratory techniques and safety considerations while helping students approach experimental work with greater confidence and preparedness. Similarly, Seery et al. (2024) argued that effective laboratory learning requires deliberate attention to laboratory design, teaching approaches, assessment, student support and the broader organization of laboratory experiences. Thus, the effectiveness of Chemistry laboratory instruction is influenced not simply by the presence of laboratory facilities but by the quality of the learning experience created around them.

Physical laboratory instruction remains particularly important because it exposes students to authentic experimental conditions that cannot be completely reproduced through theoretical instruction. In a physical laboratory, students directly handle apparatus and materials, measure quantities,

observe changes in colour, temperature, precipitate formation or gas evolution and encounter the practical uncertainties associated with real experiments. Such experiences can contribute to the development of manipulative skills, experimental competence, observation skills and an appreciation of the nature of scientific inquiry. Agustian et al. (2022) reported that laboratory learning contributes to students' ability to plan and conduct investigations, manipulate equipment, analyse experimental data and interpret evidence. Physical laboratory activities can therefore provide an important bridge between knowing Chemistry conceptually and being able to apply Chemistry through practical investigation.

Despite these potential benefits, the effective use of physical laboratories in secondary school Chemistry education can be constrained by the availability, adequacy and utilization of laboratory facilities. This issue is particularly relevant in the Nigerian context, where schools may differ substantially in the availability of functional laboratories, equipment, chemicals and other resources required for practical Chemistry instruction. Recent Nigerian evidence from public secondary schools in Ogun State indicates that the provision and utilization of laboratory facilities are relevant considerations in students' Chemistry achievement, highlighting the continuing importance of laboratory resources in the Nigerian secondary school context (Akinnawonu & Yonlonfoun, 2026). Similar concerns have been reported in investigations of laboratory facility availability and utilization in Nigerian senior secondary schools. These challenges may limit the frequency and quality of students' exposure to practical Chemistry and may consequently reduce opportunities for meaningful experimental learning.

Consequently, although physical laboratory instruction remains an essential component of Chemistry education, there is a need to examine ways of improving its effectiveness through appropriate integration with emerging technologies. The central issue is therefore not whether virtual laboratory experiences should replace physical laboratories but whether combining the strengths of both environments can provide students with richer opportunities for preparation, experimentation, reflection and reinforcement of learning. This consideration provides the basis for examining virtual reality laboratory instruction and its possible integration with physical laboratory experiences in secondary school Chemistry education.

Virtual Reality Laboratory (VRL) refers to a computer-generated laboratory environment in which learners interact with simulated laboratory equipment, materials and experimental procedures within an immersive or three-dimensional digital space. Unlike conventional computer simulations that may be viewed on a flat screen, immersive virtual reality can provide learners with a stronger sense of presence by allowing them to manipulate virtual objects and perform experimental procedures through interactive interfaces. In Chemistry education, VRLs are increasingly being explored as a means of providing students with opportunities to observe, practice and repeat laboratory procedures in an environment where the consequences of errors can be controlled. Chan et al. (2021) explained that virtual chemical laboratories encompass different technological forms, ranging from two-dimensional and three-dimensional desktop environments to immersive virtual reality systems, with the choice of technology depending on the intended learning outcomes and instructional design.

The use of VRL in Chemistry is particularly relevant because many chemical concepts and laboratory procedures involve processes that are difficult for students to observe directly or practice repeatedly in conventional laboratories. A virtual environment can represent laboratory apparatus and experimental processes in ways that allow learners to manipulate variables, observe outcomes and repeat procedures without consuming physical reagents or risking damage to equipment. For example, students can practice procedures such as titration, measurement, mixing of substances and laboratory safety routines before undertaking the corresponding experiment in a physical laboratory. Agbonifo et al. (2020) developed a virtual reality-enhanced Chemistry laboratory platform for titration in Nigeria specifically to enable students to learn the procedure virtually before proceeding to the wet laboratory. Their study involving secondary school and first-year undergraduate Chemistry students reported generally positive perceptions of the usefulness and ease of interaction with the virtual environment. Chan et al. (2021), in their systematic review of virtual chemical laboratories, reported that virtual laboratories generally produced better learning outcomes than passive instructional media. However, the authors also emphasized that the effectiveness of virtual laboratories depends considerably on instructional design and the extent to which the technology is appropriately integrated into teaching. A systematic review by Guruloo and Osman (2023) noted that the use of VR in chemistry education has increasingly focused on areas such as atomic and molecular structures, indicating the potential of immersive technologies to address aspects of Chemistry that are difficult to represent through conventional laboratory activities.

Although virtual laboratories can provide students with opportunities to practice procedures, visualize chemical processes and repeat experiments in a controlled environment, they cannot completely reproduce the sensory, manipulative and authentic experiences associated with handling real laboratory materials and equipment. Similarly, physical laboratories provide authentic practical experiences but may be constrained by limited equipment, availability of chemicals, time, safety considerations and the level of students' prior preparation. Consequently, integrating virtual reality laboratory experiences with physical laboratory instruction offers a potentially more comprehensive approach to chemistry laboratory learning. Olympiou and Zacharia (2012) demonstrated this principle experimentally by comparing physical manipulatives, virtual manipulatives and a blended combination of both. Their findings showed that students who experienced the blended approach achieved greater conceptual understanding than students who used either physical or virtual manipulatives alone.

Nevertheless, most of the existing empirical literature has focused on university students, comparisons between virtual and physical laboratories or the general effectiveness of virtual laboratory environments. There remains a need for empirical evidence concerning the effect of a deliberately integrated VR and physical laboratory approach on secondary school Chemistry students' achievement and retention**,** particularly when gender is considered as a potential moderating variable. This gap provides the basis for the present study.

Academic achievement is an important indicator of the extent to which students have acquired the knowledge, understanding and skills expected from a particular instructional experience. In Chemistry education, achievement extends beyond the ability to recall definitions, laws, formulae and chemical reactions. It includes students' ability to understand chemical concepts, interpret experimental observations, apply principles to unfamiliar situations and

use acquired knowledge to solve chemical problems. Consequently, Chemistry achievement can be assessed through students' performance on appropriately designed achievement tests that measure the learning outcomes associated with the content and instructional experiences to which they have been exposed.

Retention refers to the ability of learners to maintain and subsequently recall or apply knowledge, skills and understanding acquired through instruction after a period has elapsed. In educational research, retention is an important indicator of meaningful learning because immediate post-instruction performance does not necessarily demonstrate that the acquired knowledge has been firmly established in long-term memory. A student may perform well immediately after instruction because the information is still relatively fresh, yet experience considerable difficulty recalling or applying the same knowledge after a period without direct instructional reinforcement. Consequently, evaluating retention alongside immediate achievement provides a more comprehensive indication of the effectiveness of an instructional strategy. Effective Chemistry instruction should consequently aim not only to improve students' immediate test performance but also to promote learning that remains accessible after the completion of a teaching episode.

Retention is also relevant to the evaluation of gender differences in technology supported Chemistry instruction. Gender is another factor that warrants consideration when examining achievement and retention in Chemistry. Male and female students may respond differently to instructional environments because of differences in prior experiences, confidence, technological familiarity, participation patterns or other contextual factors. Male and female students may enter technology enhanced learning environments with different levels of previous exposure, confidence or experience and these factors may influence how they engage with the instructional method. However, existing Nigerian evidence does not establish a consistent gender advantage in retention following virtual laboratory instruction. Jack and Shidawa (2025) found no significant difference between male and female students in the virtual laboratory group, while Anari et al. (2026) similarly reported findings that did not support a significant gender difference in the outcomes examined. These findings reinforce the need for empirical investigation rather than assumptions about which gender may benefit more from technology-enhanced laboratory instruction. These findings indicate the need to investigate gender empirically rather than treating it as a predetermined source of difference.

However, there is insufficient evidence on the effect of a deliberately integrated virtual reality laboratory and physical laboratory approach on both immediate achievement and delayed retention**,** particularly among senior secondary school Chemistry students in Anambra State, Nigeria**,** while simultaneously examining gender as a possible moderating variable**.** The present study is therefore designed to address this gap by investigating whether integrating virtual reality laboratory experiences with physical laboratory experimentation can enhance students' achievement and retention in Chemistry and whether the effects differ between male and female students.

Purpose of the Study

The purpose of this study was to determine the effect of integrating virtual reality laboratory and physical laboratory instruction on male and female senior secondary school students' achievement and retention in Chemistry in Ogbaru Local Government Area of Anambra State, Nigeria. Specifically, the study sought to:

1. Determine the difference in the mean achievement scores of male and female students taught Chemistry with integration of virtual reality laboratory and physical laboratory.
2. Determine the difference in the mean retention scores of male and female students taught Chemistry with integration of virtual reality laboratory and physical laboratory.

Research Questions

The following research questions guided the study:

1. What are the mean achievement scores of male and female senior secondary school students taught Chemistry with integration of virtual reality laboratory and physical laboratory?
2. What are the mean retention scores of male and female senior secondary school students taught Chemistry with integration of virtual reality laboratory and physical laboratory?

Research Hypotheses

The following null hypotheses were formulated and tested at the 0.05 level of significance:

H_o1: There is no significant difference in the mean achievement scores of male and female senior secondary school students taught Chemistry with integration of virtual reality laboratory and physical laboratory.

H_o2: There is no significant difference in the mean retention scores of male and female senior secondary school students taught Chemistry with integration of virtual reality laboratory and physical laboratory.

METHODOLOGY

The study adopted a quasi-experimental research design, which employed intact classes because the design does not allow for the random assignment of subjects to experimental and control groups. The population of the study comprised 364 Senior Secondary II Chemistry students in secondary schools in Ogbaru Local Government Area of Anambra State, Nigeria. From this population, a sample of 65 students was drawn from two co-educational secondary schools selected out of the ten schools in the area using a simple random sampling technique. The two sampled schools were the treatment groups. The instrument for data collection was the Chemistry Achievement Test (CAT). The test consisted of 20 objective questions on Quantitative Analysis, with each question carrying five marks. The instrument was divided into two sections: Section A collected students' biodata, while Section B contained the objective test items. The CAT was used to measure both achievement and retention. To ensure validity, the instrument was reviewed by two experts in Chemistry Education and one expert in Measurement and Evaluation. Its reliability was established using the Pearson Product Moment Correlation Coefficient, yielding an overall reliability coefficient of 0.74, which was considered satisfactory for the study. The experimental procedure was carried out in two phases. The first phase involved the training of research assistants, who were the students' regular Chemistry teachers. They received three days of training from the researchers on how to implement the lesson plans. The second phase involved teaching the students and administering the CAT. Both schools were given a pre-test before instruction. The teaching lasted four weeks, after which the test items were rearranged and administered as a post-test. Two weeks later, the same instrument, rearranged again, was given as a retention test. In total, the entire teaching and data collection lasted six weeks. Normal intact classes were maintained, and no alterations were made to the school timetable. For data analysis, mean and standard deviation were used to answer the research questions, while a t-test was employed to test the null hypotheses at the 0.05 level of significance.

RESULT

Research Question One: What are the mean achievement scores of male and female students taught Chemistry with integration of virtual reality laboratory and physical laboratory?

Table 1: *Pre-test and Post-test Mean Achievement and Standard Deviation Scores of Male and Female Students Taught Chemistry with Integration of Virtual Reality and Physical Laboratory*

Gender	Pre-test			Post-test		Mean Difference
	N	M	SD	M	SD	
Male	34	31.65	6.85	70.94	11.62	39.29
Female	31	29.16	6.30	71.10	12.42	41.94

Table 1 reveals that the pre-test and post-test achievement scores of male students taught Chemistry with integration of virtual reality and physical laboratory were 31.65 and 70.94 while that of the female students were 29.16 and 71.10. The mean differences for male and female students were 39.29 and 41.94 respectively, with a gender mean achievement difference of 2.65 in favor of female students.

Research Question Two: What are the mean retention scores of male and female students taught Chemistry with integration of virtual reality laboratory and physical laboratory?

Table 2: *Mean and Standard Deviation Scores on Retention of Male and Female Students Taught Chemistry with Integration of Virtual Reality and Physical Laboratory*

Gender	N	M	SD	Mean Difference
Male	34	52.24	6.75	
				0.92
Female	31	53.16	5.77	

The results presented in Table 2 presents the mean retention in Chemistry for male students taught with integration of virtual reality and physical laboratory was 52.24 and the mean retention for the female students was 53.16. The slight mean difference of 0.92 was in favour of the female students.

Hypothesis One: There is no significant difference in the mean achievement scores of male and female students taught Chemistry with integration of virtual reality laboratory and physical laboratory.

Table 3: *Independent Samples t-test Analysis on Post-test Mean Achievement Scores of Male and Female Students Taught Chemistry with Integration of Virtual Reality and Physical Laboratory*

Gender	Post-test		Do	*T*	*P*	*Remark*
	M	SD				
Male (n=34)	70.94	11.62	63	-0.05	0.74	NS
Female (n=31)	71.10	12.42				

The summary of the independent samples t-test results presented in Table 3 reveals that male and female students taught Chemistry with integration of virtual reality and physical Chemistry laboratory were not significantly different in their mean achievement scores in Chemistry, t (63) = -0.05, p=0.74. Since the p-value was greater than 0.05 level of significance, the null hypothesis was not rejected.

Hypothesis Two: There is no significant difference in the mean retention scores of male and female students taught Chemistry with integration of virtual reality laboratory and physical laboratory.

Table 4: *Independent Samples t-test Analysis on Mean Retention Scores of Male and Female Students Taught Chemistry with Integration of Virtual Reality and Physical Laboratory*

Gender	**Post-test**		**Do**	***T***	***P***	***Remark***
	M	**SD**				
Male (n=34)	52.24	6.75	63	-0.59	0.56	NS
Female (n=31)	53.16	5.77				

The independent samples t-test results presented in Table 4 shows that male and female students taught Chemistry with integration of virtual reality and physical laboratory were not significantly different in their mean retention scores in Chemistry, t (63) = -0.59, p=0.56. Since the p-value was greater than 0.05 level of significance, the null hypothesis was not rejected.

Discussion

The mean achievement score of female students taught with the integration of virtual reality laboratory and physical laboratory were slightly better than male students. The mean achievement score of male and female students taught Chemistry with the integration of virtual laboratory and physical laboratory was not significantly different.

The findings of this study showed that female students taught with the integration of virtual reality laboratory and physical laboratory achieved slightly higher than male students in Chemistry. The findings of this study also showed that there is no significant difference in the mean achievement scores of male and female students taught Chemistry with the integration of virtual reality laboratory and physical laboratory. This findings are in agreement with the finding of Jack and Shidawa (2025) who found no significant difference between male and female students in the virtual laboratory group.

The findings of this study are in contrary to the findings of Gambari et al. (2017) who found that male and female students taught Chemistry using a virtual laboratory in an individualized learning setting differed significantly in their mean achievement scores.

The mean retention score of female students taught with the integration of virtual reality laboratory and physical laboratory were slightly better than male students. The mean retention score of male and female students taught Chemistry with the integration of virtual laboratory and physical laboratory was not significantly different.

The findings of this study revealed that female students taught with virtual reality laboratory had slightly greater retention score than the male students. Also, the findings of this study revealed that there is no significant difference in the mean retention scores of male and female students taught Chemistry with the integration of virtual laboratory and physical laboratory was not significantly different. This is in conformity with the findings of Agustian and Seery (2017) whose findings revealed that female students performed slightly better than male counterparts in the acquisition and retention of practical Chemistry skills using virtual laboratory instruction.

The findings of this study are also in contrary with the findings of Reeves et al. (2021) whose study concluded that female students benefitted more from virtual laboratory than male students.

Conclusion

From the findings and its discussion, the study revealed that there is no significant difference in the mean achievement scores of male and female students taught Chemistry with the integration of virtual reality laboratory and physical laboratory. In addition, there is no significant difference in the mean retention scores of male and female students taught Chemistry with the integration of virtual reality laboratory physical laboratory.

Recommendations

Based on the findings of the study, the following recommendations were made:

1. Chemistry teachers should effectively utilize available laboratory facilities in public secondary schools to support practical Chemistry instruction.
2. Educational agencies and relevant stakeholders should organize workshops and seminars to equip Chemistry teachers with skills for effectively integrating virtual and physical laboratory instruction.
3. Chemistry teachers should adopt collaborative virtual laboratory approaches that provide male and female students with equitable opportunities to participate in practical learning activities.
4. NERDC and other relevant organizations should develop and produce quality interactive virtual laboratory materials for Chemistry and other science subjects to complement physical laboratory resources.

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