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Effect of Virtual Laboratory Simulation on Students' Conceptual Understanding of Chemistry among Senior Secondary Schools in Delta State, Nigeria

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Abstract

This study examined the effect of virtual laboratory simulation and the conventional teaching method on students' conceptual understanding of Chemistry in senior secondary schools in Delta State. The study adopted a pretest–posttest non-equivalent control group design, a quasi-experimental design structured into a 2 × 2 factorial matrix involving teaching methods (virtual laboratory simulation and conventional teaching) and gender (male and female). Three research questions and three hypotheses guided the study. The population comprised 62,527 students in public secondary schools in Delta State. A sample of 250 students was selected using a multistage sampling technique from four public secondary schools. Data were collected using the researcher-developed Chemistry Conceptual Understanding Test (CCUT), consisting of 40 multiple-choice items designed to assess students in the department of Science Education and Measurement and Evaluation at Delta State University, Abraka. Its reliability was established using the test–retest method, yielding a coefficient of 0.84. Data collection lasted six weeks and involved pretest administration, treatment, and post-test administration. Mean and standard deviation were used to answer the research questions, while Analysis of Covariance (ANCOVA) and Two-Way ANCOVA were used to test the hypotheses at the 0.05 level of significance. The findings revealed that virtual laboratory simulation significantly enhanced students' conceptual understanding of Chemistry compared with the conventional teaching method, while gender had no significant effect. The study recommended greater adoption of virtual laboratory simulation in Chemistry instruction.

Keywords: Virtual Laboratory Simulation, Conceptual Understanding, Chemistry, Gender.

Introduction

Chemistry is a branch of science concerned with the composition, structure, properties, and transformations of matter. Sparks (2018) explained that chemistry examines the properties of matter and the changes it undergoes, including the interactions between substances during chemical reactions. Chemistry is an important science subject because it provides the foundation for understanding natural phenomena and contributes to developments in medicine, agriculture, environmental management, industrial production, and technology. In Nigerian secondary schools, Chemistry equips students with scientific knowledge, practical skills, critical thinking abilities, and problem-solving competencies required for further education and everyday life. It also helps learners understand processes such as combustion, corrosion, acid-base reactions, and the composition of substances. Despite its importance, Chemistry involves abstract concepts, chemical symbols, equations, molecular structures, and processes that may be difficult for students to understand. These challenges can affect students' ability to relate theoretical knowledge to practical situations and develop meaningful conceptual understanding. Consequently, there is a need for effective instructional approaches that make Chemistry concepts more concrete, interactive, and accessible to learners. One of the major challenges in Chemistry education is helping students understand abstract concepts that cannot be directly observed. Concepts such as atomic structure, chemical bonding, molecular interactions, electrolysis, and chemical equilibrium require learners to connect observable phenomena with explanations at the microscopic and symbolic levels. When instruction relies heavily on verbal explanations, note-taking, and memorisation, students may acquire factual knowledge without understanding the underlying chemical principles. Holme et al. (2015) emphasised that conceptual understanding in Chemistry involves more than memorising information or applying mathematical procedures; it requires students to explain chemical phenomena, solve problems, transfer knowledge to new situations, and relate different representations of chemical concepts. In Nigeria, Avwiri and Odiri (2025) investigated the effects of virtual laboratory experiments on Chemistry students' achievement in Delta State. Their findings indicated that students taught using virtual laboratory experiments performed better than those taught through the

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demonstration teaching method. The researchers recommended greater integration of technology into Chemistry instruction, particularly where inadequate laboratory facilities limit practical activities. These findings highlight the need to explore instructional strategies that promote deeper understanding of Chemistry concepts among senior secondary school students.

Conventional teaching method refers to a teacher-centred approach in which teachers present information through explanations, lectures, demonstrations, and note-taking, while students mainly listen and follow instructions. According to Onyekpe and Ogbemudiare (2025), the conventional teaching method refers to the traditional lecture-based approach in which the teacher presents lesson content through verbal explanations and classroom instruction, while pupils mainly listen, take notes, and receive information with limited direct experiential learning or active participation. In Chemistry education, this approach may limit students' active exploration of abstract concepts when emphasis is placed on memorisation rather than conceptual understanding. Ahmad et al. (2023), in a systematic review and meta-analysis of effective pedagogical approaches in high school Chemistry education, found that approaches promoting problem-solving and active learning were more effective than conventional lecture-based practices in supporting students' learning. Similarly, in the present study conventional teaching serves as the comparison method for determining whether virtual laboratory simulation better enhances students' conceptual understanding of Chemistry in senior secondary schools in Delta State. In response to the challenges associated with conventional Chemistry instruction, educational researchers have increasingly advocated technology-supported and learner-centred approaches. One such approach is virtual laboratory simulation. Virtual laboratory simulation refers to the use of computer-based digital environments to reproduce laboratory experiments and scientific processes, enabling learners to manipulate variables, observe outcomes, and explore concepts without necessarily using physical laboratory equipment. Tadesse (2026) explained that virtual laboratories provide interactive learning opportunities that connect theoretical knowledge with practical applications and can support students' engagement, learning outcomes, and laboratory skills. This approach allows students to repeat experiments, observe changes, investigate chemical reactions, and examine processes that may be difficult, expensive, or hazardous to demonstrate in a conventional laboratory. Meronda et al. (2025), in their systematic review of virtual laboratories in science education, reported that virtual laboratory activities can support conceptual understanding, analytical thinking, scientific literacy, and other learning outcomes. Similarly, Penn and Ramnarain (2019) found that students who used virtual laboratories achieved significantly higher Chemistry content-test scores than those who used traditional laboratory resources in their study. Virtual laboratory simulation therefore offers a promising instructional approach for making Chemistry learning more interactive and improving students' understanding of difficult chemical concepts.

Conceptual understanding is another important consideration in Chemistry education because it reflects students' ability to explain, interpret, and apply scientific ideas rather than merely memorise definitions or reproduce procedures. Hagos (2026) described conceptual understanding in Chemistry in terms of students' ability to demonstrate knowledge beyond routine calculations, including explaining phenomena, solving problems, and transferring knowledge to unfamiliar situations. In the context of this study, students' conceptual understanding of Chemistry refers to their ability to explain chemical principles, interpret chemical representations, establish relationships among concepts, and apply acquired knowledge to relevant problems. Developing such understanding is essential because chemistry concepts are interconnected, and misconceptions about foundational ideas may hinder the learning of more advanced topics. Virtual laboratory simulation may support conceptual understanding by providing visual representations of invisible chemical processes, opportunities for experimentation, immediate feedback, and repeated exploration of chemical phenomena. For instance, students can manipulate simulated experimental conditions and observe how changes in variables affect chemical reactions. Husnaini and Chen (2019) identified improvements in conceptual understanding and learning outcomes among students using virtual laboratories, while Penn and Ramnarain (2019) reported better Chemistry content-test performance following virtual laboratory instruction than traditional laboratory instruction. These findings provide a basis for examining whether virtual laboratory simulation can improve students' conceptual understanding of Chemistry in senior secondary schools in Delta State. In addition to instructional method, gender may be an important variable in understanding students'

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learning outcomes in Chemistry. Gender generally refers to socially influenced roles, expectations, and experiences associated with being male or female. In educational research, examining gender helps determine whether students respond differently to particular instructional approaches. Differences in prior learning experiences, confidence, classroom participation, and access to technological resources may influence how students engage with virtual laboratory activities. However, gender should not automatically be assumed to determine students' ability to understand scientific concepts. Oladejo et al. (2023), in their study titled *Gender difference in students' performance in chemistry - Can computer simulation bridge the gap?* examined the potential of computer simulation to address gender differences in Chemistry performance. Their work highlights the relevance of investigating how simulation-based instruction relates to students' learning outcomes across gender groups. Similarly, Kolil and Achuthan (2024) reported that their virtual laboratory instructional design helped reduce alternative conceptions among both male and female students. These findings suggest that virtual laboratory simulation may support conceptual learning among students of different genders, although its effects should be examined within specific educational contexts. Investigating gender alongside instructional method is therefore important for determining whether male and female students benefit similarly from virtual laboratory simulation and conventional teaching.

Ndukwe and Obafemi (2023) investigated *virtual laboratory and guided inquiry on students' performance in redox reaction in Rivers State*. The study adopted a quasi-experimental pretest–posttest non-equivalent group design involving 85 Senior Secondary School II students from three public secondary schools in Obio/Akpor Local Government Area, Rivers State. Data were collected using the chemistry performance test on redox reaction and analysed using mean, standard deviation, and analysis of covariance. The findings revealed that guided inquiry produced significantly better performance than virtual laboratory instruction, while gender differences and the interaction between teaching strategy and gender were not significant. The researchers recommended the use of guided inquiry and virtual laboratory strategies in Chemistry teaching. Ugonwa, Agbai, and Osuji (2024) examined *impact of virtual reality technology (VRT) on chemistry laboratory and learning outcomes of chemistry education students in nigerian universities*. Using a descriptive survey design, the researchers sampled 30 lecturers from the university of Port Harcourt and Rivers State university. Data were collected through a structured questionnaire and analysed using mean, standard deviation, and t-test. The findings indicated that virtual reality technology improved laboratory effectiveness, students' learning outcomes, and engagement in Chemistry education. The researchers recommended incorporating virtual reality technology into university chemistry laboratories to enhance teaching and learning. Ahmad et al. (2023) conducted a systematic review and meta-analysis titled *effective pedagogical approaches used in high school chemistry education*. They analysed 35 pedagogical approaches and compared their effects on students' learning performance. The findings showed that innovative instructional strategies generally improved chemistry learning compared with traditional teaching approaches, with problem-based learning demonstrating a particularly strong effect. The study recommended the adoption of evidence-based and learner-centred pedagogical approaches to improve Chemistry achievement. Although existing studies appears to have examined virtual laboratory experiments, Chemistry achievement, and the use of simulations in science education, further investigation is necessary to establish their effects on students' conceptual understanding in specific contexts. Avwiri and Odiri (2025) investigated Chemistry achievement in Delta State, while Penn and Ramnarain (2019) compared virtual and traditional laboratory learning in South Africa. Kolil and Achuthan (2024) also examined virtual laboratories as an approach to Chemistry laboratory education. Nevertheless, findings relating to achievement, practical skills, and conceptual understanding are not interchangeable, and evidence from one setting may not fully explain outcomes in another. There is therefore a need to examine the effect of virtual laboratory simulation on students' conceptual understanding of Chemistry in senior secondary schools in Delta State, compare the outcomes of students taught using virtual laboratory simulation and the conventional teaching method, and investigate the role of gender in these outcomes. Addressing these issues may provide useful evidence for Chemistry teachers, curriculum planners, and educational policymakers seeking effective ways to improve Chemistry teaching and learning.

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Purpose of the Study

The purpose of this study was to examine the effect of virtual laboratory simulation on students' conceptual understanding of Chemistry in senior secondary schools in Delta State. Specifically, the study seeks to:

1. determine the effect of virtual laboratory simulation on students' conceptual understanding of Chemistry in senior secondary schools in Delta State;
2. examine the difference in conceptual understanding of Chemistry between students taught using virtual laboratory simulation and those taught using the conventional teaching method;
3. investigate the effect of gender on students' conceptual understanding of Chemistry when taught using virtual laboratory simulation and the conventional teaching method.

Research Questions

This study was guided by the following research questions:

1. To what extent does virtual laboratory simulation influence students' conceptual understanding of Chemistry in senior secondary schools in Delta State?
2. What is the difference in conceptual understanding of Chemistry between students taught using virtual laboratory simulation and those taught using the conventional teaching method?
3. What is the effect of gender on students' conceptual understanding of Chemistry when taught using virtual laboratory simulation and the conventional teaching method?

Hypotheses

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

1. There is no significant effect of virtual laboratory simulation on students' conceptual understanding of Chemistry in senior secondary schools in Delta State.
2. There is no significant difference in the conceptual understanding of Chemistry between students taught using virtual laboratory simulation and those taught using the conventional teaching method.
3. There is no significant effect of gender on students' conceptual understanding of Chemistry when taught using virtual laboratory simulation and the conventional teaching method.

Research Methodology

This study adopted the pretest–posttest non-equivalent control group design, a quasi-experimental design structured into a 2 × 2 factorial design matrix. The design involved two teaching methods (Virtual Laboratory Simulation and Conventional Teaching Method) and gender (male and female), enabling the researcher to examine their main and interaction effects on students' conceptual understanding of Chemistry. The population comprised 62,527 students in public secondary schools in Delta State. A total of 250 students participated in the study, selected through a multistage sampling technique. First, local government areas were selected from Delta State. Second, four public secondary schools were randomly selected from the sampled local government areas. Third, intact classes were selected to avoid disrupting normal school activities. The students were divided into an experimental group of 125 students taught using virtual laboratory simulation and a control group of 125 students taught using the conventional method. The instrument used for data collection was the researcher-developed Chemistry Conceptual Understanding Test (CCUT), comprising 40 multiple-choice items, each with four options (A–D) and one correct answer. The test assessed students' understanding of selected Chemistry concepts. Three experts in the department Science Education and Measurement and Evaluation at Delta State University, Abraka, validated the instrument. Its reliability was established using the test–retest method, yielding a coefficient of 0.84. Data collection lasted six weeks and involved three phases. In the first phase, the CCUT was administered to both groups as a pretest. In the second phase, the experimental group received instruction using virtual laboratory simulation, while the control group was taught the same Chemistry topics using the conventional method. In the third phase, the same 40-item test was administered as a post-test to assess students' conceptual understanding after the intervention. Thus, the instrument was administered twice to each group, once before and once after the treatment. Both groups were taught under the researcher's supervision to ensure consistency in content coverage. Permission was obtained from the relevant school authorities, and students' confidentiality was maintained. Mean and standard deviation were used to answer the research questions, while Analysis of Covariance (ANCOVA) was used to test the hypotheses, controlling for pretest scores. Two-

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way ANCOVA was used to examine the effects of teaching method and gender, as well as their interaction. All hypotheses were tested at the 0.05 level of significance using SPSS version 23.

Table 1: Design of the Study

Groups (Teaching Method)	Pretest	Treatment	Posttest
Experimental Group	O_1	X_1 (Virtual Laboratory Simulation)	O_2
Control Group	O_1	X_2 (Conventional Teaching Method)	O_2

Key:
(O_1) = Pretest measurement of students' conceptual understanding of Chemistry.
(O_2) = Posttest measurement of students' conceptual understanding of Chemistry.
(X_1) = Virtual laboratory simulation (experimental treatment).
(X_2) = Conventional teaching method (control treatment).
As specified earlier, treatment was administered to the experimental group, while the control group received no treatment. Consequently, differences observed in the post-test scores were attributed to the effects of the treatments.

Table 2: Sample Distribution by Teaching Method and Gender

Teaching Method	Gender	Sample Size (N)
Virtual Laboratory Simulation	Female	63
Virtual Laboratory Simulation	Male	62
Total (Virtual Laboratory Simulation)		125
Conventional Teaching Method	Female	62
Conventional Teaching Method	Male	63
Total (Conventional Teaching Method)		125
Grand Total		250

Source: Field Survey

Research Question 1:

To what extent does virtual laboratory simulation influence students' conceptual understanding of Chemistry in senior secondary schools in Delta State?

Table 3: Descriptive Statistics of Mean and Standard Deviation Showing the Extent of Students' Conceptual Understanding of Chemistry When Exposed to Virtual Laboratory Simulation in Senior Secondary Schools in Delta State

Groups	N	Mean	Std. Deviation
Virtual Laboratory Simulation	125	58.17	16.124
Conventional Teaching Method	125	47.45	20.507
Total	250		

Table 3 presents the descriptive statistics, including the mean and standard deviation, on the extent to which virtual laboratory simulation influences students' conceptual understanding of Chemistry in senior secondary schools in Delta State. The results show that students exposed to virtual laboratory simulation had a mean score of 58.17 with a standard deviation of 16.12, while students taught using the conventional teaching method had a mean score of 47.45 with a standard deviation of 20.51. Students exposed to virtual laboratory simulation scored noticeably higher on average than those taught

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using the conventional teaching method (58.17 vs. 47.45), indicating that virtual laboratory simulation appears to promote better conceptual understanding of Chemistry. Furthermore, the lower standard deviation among students exposed to virtual laboratory simulation suggests that their scores were less dispersed than those of students taught using the conventional teaching method. To determine whether the observed difference is statistically significant, Hypothesis 3 was tested using analysis of covariance (ANCOVA).

Hypothesis 1:

There is no significant effect of virtual laboratory simulation on students' conceptual understanding of Chemistry in senior secondary schools in Delta State.

Table 4: Analysis of Covariance (ANCOVA) of the Effect of Virtual Laboratory Simulation on Students' Conceptual Understanding of Chemistry in Senior Secondary Schools in Delta State

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	40920.367	2	20460.184	895.153	.000	.939
Intercept	46.418	1	46.418	2.031	.157	.017
Pretest	37474.959	1	37474.959	1639.567	.000	.933
Virtual Laboratory Simulation	173.330	1	173.330	7.583	.007	.061
Error	2674.225	247	22.857			
Total	378241.000	250				
Corrected Total	43594.592	249				

Note. \(R^2 = .939\); adjusted \(R^2 = .938\).

Table 4 presents the analysis of covariance (ANCOVA) results for the effect of virtual laboratory simulation on students' conceptual understanding of Chemistry in senior secondary schools in Delta State. Preliminary checks should be conducted to ensure that there are no violations of the assumptions of normality, linearity, homogeneity of variances, homogeneity of regression slopes, and reliable measurement of the covariate. The result reveals that the F-value for virtual laboratory simulation is 7.583, with degrees of freedom of 1 and 247, a significance value of .007, and an alpha level of 0.05. Since $p < .05$, the null hypothesis is rejected. The partial eta squared value of .061 indicates that virtual laboratory simulation accounts for approximately 6.1% of the variance in students' conceptual understanding of Chemistry after controlling for pretest scores. This implies that virtual laboratory simulation has a statistically significant effect on students' conceptual understanding of Chemistry in senior secondary schools in Delta State. The implication of this result is that the use of virtual laboratory simulation significantly influences students' conceptual understanding of Chemistry. Therefore, virtual laboratory simulation appears to be an effective instructional approach for promoting students' conceptual understanding of Chemistry compared with conventional teaching, although the direction and magnitude of the adjusted group difference should be confirmed using the adjusted means.

Research Question 2: What is the difference in conceptual understanding of Chemistry between students taught using virtual laboratory simulation and those taught using the conventional teaching method?

Table 5: Descriptive Statistics of Mean and Standard Deviation Showing Differences in Students' Conceptual Understanding of Chemistry When Exposed to Virtual Laboratory Simulation and the Conventional Teaching Method in Senior Secondary Schools in Delta State

Groups	N	Mean	Std. Deviation
Virtual Laboratory Simulation	125	58.17	16.124
Conventional Teaching Method	125	47.45	20.507
Total	250		

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The results in Table 5 show the mean scores and standard deviations of students' conceptual understanding of Chemistry when exposed to virtual laboratory simulation and the conventional teaching method in senior secondary schools in Delta State. The result shows that students taught using virtual laboratory simulation had a mean score of 58.17 and a standard deviation of 16.124, while students taught using the conventional teaching method had a mean score of 47.45 and a standard deviation of 20.507. The descriptive results indicate that students taught using virtual laboratory simulation performed better in conceptual understanding of Chemistry than those taught using the conventional teaching method, with a mean difference of 10.72. Furthermore, the lower standard deviation of 16.124 for the virtual laboratory simulation group suggests that their scores were less dispersed around the mean than those of students taught using the conventional teaching method. To determine whether the observed difference is statistically significant, the corresponding null hypothesis was tested using analysis of covariance (ANCOVA).

Hypothesis 2:

There is no significant difference in the conceptual understanding of Chemistry between students taught using virtual laboratory simulation and those taught using the conventional teaching method.

Table 6: Analysis of Covariance (ANCOVA) of the Difference in Students' Conceptual Understanding of Chemistry between Virtual Laboratory Simulation and Conventional Teaching Method

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	18452.680	2	9226.340	148.562	.000	.546
Intercept	1246.315	1	1246.315	20.071	.000	.075
Pretest	15328.420	1	15328.420	246.827	.000	.500
Teaching Method	1024.260	1	1024.260	16.494	.000	.063
Error	15330.720	247	62.067			
Total	428965.000	250				
Corrected Total	33783.400	249				

Note. R Squared = .546 (Adjusted R Squared = .542).

Table 6 presents the analysis of covariance (ANCOVA) of the difference in students' conceptual understanding of Chemistry between those taught using virtual laboratory simulation and those taught using the conventional teaching method in senior secondary schools in Delta State. Preliminary checks should be conducted to ensure that there are no violations of the assumptions of normality, linearity, homogeneity of variances, homogeneity of regression slopes, and reliable measurement of the covariate. The result reveals that the F-value for teaching method is 16.494, with degrees of freedom of 1 and 247, and a significance value of .000 ($p < .001$), at the 0.05 level of significance. Since $p < .05$, the null hypothesis was rejected. The partial eta squared value of .063 indicates a moderate effect size, suggesting that teaching method accounts for approximately 6.3% of the variance in students' conceptual understanding of Chemistry after controlling for pretest scores. This implies that there is a statistically significant difference in the conceptual understanding of Chemistry between students taught using virtual laboratory simulation and those taught using the conventional teaching method. The implication of this result is that the instructional method significantly influences students' conceptual understanding of Chemistry.

Research Question 3:

What is the effect of gender on students' conceptual understanding of Chemistry when taught using virtual laboratory simulation and the conventional teaching method?

Table 7: Descriptive Statistics of Mean and Standard Deviation Showing the Effect of Gender on Students' Conceptual Understanding of Chemistry When Taught Using Virtual Laboratory Simulation and the Conventional Teaching Method

Gender	Teaching Method	N	Mean	Std. Deviation
Female	Virtual Laboratory Simulation	63	61.93	20.460

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Female	Conventional Teaching Method	62	47.03	20.746
Male	Virtual Laboratory Simulation	62	53.10	23.030
Male	Conventional Teaching Method	63	47.87	20.611
Total		250		

The results in Table 7 present the mean scores and standard deviations for the effect of gender on students' conceptual understanding of Chemistry when taught using virtual laboratory simulation and the conventional teaching method in senior secondary schools in Delta State. The results show that female students taught using virtual laboratory simulation obtained a mean score of 61.93 and a standard deviation of 20.46, while female students taught using the conventional teaching method obtained a mean score of 47.03 and a standard deviation of 20.75. Similarly, male students taught using virtual laboratory simulation obtained a mean score of 53.10 and a standard deviation of 23.03, while male students taught using the conventional teaching method obtained a mean score of 47.87 and a standard deviation of 20.61. The descriptive results suggest that female students obtained higher mean scores than male students when taught using virtual laboratory simulation, while male and female students obtained relatively similar mean scores under the conventional teaching method. Specifically, the mean difference between female and male students under virtual laboratory simulation was 8.83 points, compared with 0.84 points under the conventional teaching method. These results suggest that the observed differences in students' conceptual understanding of Chemistry varied according to gender and teaching method. However, a two-way analysis of covariance (ANCOVA), controlling for pretest scores, is required to determine whether the effect of gender and its interaction with teaching method are statistically significant.

Hypothesis 3:

There is no significant effect of gender on students' conceptual understanding of Chemistry when taught using virtual laboratory simulation and the conventional teaching method.

Table 8: Analysis of Covariance (ANCOVA) of the Effect of Gender on Students' Conceptual Understanding of Chemistry When Taught Using Virtual Laboratory Simulation and the Conventional Teaching Method

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	54074.666	4	13518.667	630.100	.000	.956
Intercept	171.883	1	171.883	8.011	.005	.065
Pretest	49853.700	1	49853.700	2323.663	.000	.953
Gender	36.432	1	36.432	1.698	.195	.015
Teaching Method	127.023	1	127.023	5.920	.017	.049
Gender × Teaching Method	3.612	1	3.612	0.168	.682	.001
Error	2467.300	245	10.071			
Total	387082.000	250				
Corrected Total	56541.967	249				

Table 8 presents the analysis of covariance (ANCOVA) of the effect of gender on students' conceptual understanding of Chemistry when taught using virtual laboratory simulation and the conventional teaching method in senior secondary schools in Delta State. Preliminary checks should be conducted to ensure that the assumptions of ANCOVA are met. The result reveals that the F-value for gender is 1.698, with degrees of freedom of 1 and 245, and a significance value of .195 ($p > .05$), at the 0.05 level of significance. Since $p > .05$, the null hypothesis was not rejected. The partial eta squared value of .015 indicates a small effect size. This implies that gender has no statistically significant effect on students' conceptual understanding of Chemistry. The interaction between gender and teaching method is also not significant, ($F(1,245)=0.168$, $p=.682$), indicating that the effect of teaching method does not significantly differ by gender.

Discussion of Findings

The findings of this study revealed that virtual laboratory simulation had a significant effect on students' conceptual understanding of Chemistry. This suggests that virtual laboratory simulation is an effective instructional approach for

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helping students understand Chemistry concepts through interactive experiments and visual representations of abstract ideas. The implication is that Chemistry teachers should incorporate virtual laboratory simulation into their lessons to improve students' conceptual understanding, particularly where access to physical laboratory facilities is limited. This finding aligns with Kolil and Achuthan (2024), who reported that virtual laboratories can improve students' conceptual understanding and laboratory learning in Chemistry. Similarly, the finding is supported by Olakanmi (2015), whose study showed that students taught rates of chemical reaction using web-based computer simulation demonstrated better conceptual understanding than those taught through the traditional approach. These findings reinforce the view that simulation-based learning can make abstract Chemistry concepts easier for students to understand. The findings further revealed that students taught using virtual laboratory simulation demonstrated better conceptual understanding of Chemistry than those taught using the conventional teaching method. This suggests that virtual laboratory simulation provides learning experiences that may be less available through conventional teacher-centred instruction alone. The implication is that Chemistry teachers should use virtual laboratory simulation to supplement conventional teaching and provide students with opportunities to observe, explore, and interact with simulated chemical processes. This finding aligns with Avwiri and Odiri (2025), who found that students taught Chemistry using virtual laboratory experiments achieved better results than those taught using the demonstration teaching method. Similarly, the finding is supported by Penn and Ramnarain (2019), whose comparative study of virtual and traditional Chemistry laboratory learning indicated that virtual laboratory activities can enhance students' learning outcomes. These studies support the use of virtual laboratory simulation as a useful strategy for improving students' conceptual understanding of Chemistry.

The findings revealed that gender did not have a significant effect on students' conceptual understanding of Chemistry when taught using virtual laboratory simulation and the conventional teaching method. This suggests that male and female students can benefit from these instructional approaches without a statistically significant overall difference attributable to gender. The implication is that Chemistry teachers should provide equal opportunities for male and female students to participate in virtual laboratory activities and should select instructional strategies based on their educational value rather than assumptions about gender. This finding aligns with Oladejo et al. (2023), who reported that computer simulation could support Chemistry learning without producing a statistically significant gender difference in students' performance. Similarly, the finding is supported by the study reported by Bazie et al. (2024), which found no statistically significant gender difference in academic performance among undergraduate Chemistry students exposed to virtual laboratory instruction. These findings suggest that virtual laboratory learning can be beneficial to both male and female students.

Conclusion

The study investigated the effect of virtual laboratory simulation, the difference between virtual laboratory simulation and conventional teaching methods, and the effect of gender on students' conceptual understanding of Chemistry in senior secondary schools in Delta State. The findings indicate that instructional method plays an important role in students' conceptual understanding, with virtual laboratory simulation proving more effective than the conventional teaching method. The study also revealed that gender had no significant effect on students' conceptual understanding of Chemistry, suggesting that the effectiveness of instruction does not differ significantly between male and female students. It can therefore be concluded that virtual laboratory simulation is an effective and inclusive instructional approach for enhancing students' conceptual understanding of Chemistry in senior secondary schools in Delta State.

Recommendations

Based on the findings of this study, the following recommendations are made:

1. Chemistry teachers should adopt virtual laboratory simulation more frequently to enhance students' conceptual understanding of Chemistry, particularly abstract and difficult chemical concepts.
2. Curriculum planners should incorporate virtual laboratory simulation activities into the senior secondary school Chemistry curriculum to promote interactive and technology-supported learning.
3. School administrators and the Delta State Ministry of Education should provide adequate funding, digital facilities, appropriate simulation software, and teacher training to facilitate the effective use of virtual laboratory simulation in Chemistry instruction.

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