EFFECTS OF THE USE OF INQUIRY-BASED LEARNING AND VIRTUAL LABORATORY SIMULATIONS ON STUDENT'S ACADEMIC ACHIEVEMENT IN BASIC SCIENCE IN JUNIOR SECONDARY SCHOOLS IN IMO STATE, NIGERIA.

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Abstract
This study investigates the impact of Inquiry-Based Learning (IBL) and Virtual Laboratory Simulation (VLS), individually and in combination, on students' academic achievement in Basic Science in junior secondary schools in Imo State, Nigeria. The research addresses persistent challenges of low achievement in science subjects, limited laboratory access and overreliance on traditional teaching methods. Anchored in Constructivist Learning Theory and Cognitive Load Theory, the study adopts a quasi-experimental, pre-test post-test, non-equivalent control group design. A total of 160 JSS II students from public secondary schools were divided into four groups: IBL only, VLS only, IBL+VLS and traditional lecture method (control). Data were collected using a validated Basic Science Achievement Test (BSAT), Retention Test (RT)and a Student Perception and Attitude Questionnaire (SPAQ).Over a six-month intervention period, selected Basic Science topics were taught using the assigned instructional methods. Pre- and post-test scores were analyzed using paired t-tests, ANCOVA and ANOVA to determine the relative effectiveness of the methods. Results show that both IBL and VLS significantly improved students' achievement compared to traditional methods, with the combined IBL+VLS approach yielding the highest gains. Retention tests confirmed the durability of these effects, while student perception data revealed high motivation and engagement, particularly in the IBL+VLS group. Gender differences were minimal across treatments. Findings provide empirical evidence to support innovative instructional strategies in science education and offer policy-relevant insights for improving teaching practices, especially in under-resourced Nigerian schools.

Keywords: Inquiry-based learning, Virtual laboratory simulation, Student Academic achievement, and Basic Science pedagogy.

Introduction

Science education is central to national development, technological innovation and global competitiveness. In Nigeria, Basic Science is the foundational subject that introduces learners to scientific concepts, skills and attitudes necessary for further studies in STEM disciplines. Yet, persistent concerns exist regarding the low performance of students in science-related subjects, particularly at the junior secondary school level (Okebukola, 2021; Ezeudu et al., 2020).The challenges undermining effective learning of Basic Science in Nigeria are multidimensional. They include poor classroom engagement, lack of practical exposure, teacher-centered pedagogy and inadequate laboratory

facilities (Ugwoke & Nwachukwu, 2022). In Imo State, these problems are pronounced, with schools frequently operating without functional science laboratories. As a result, many students perceive science as abstract, difficult and irrelevant to their daily lives (Adu-Gyamfi & Ampiah, 2020).

Globally, Inquiry-Based Learning (IBL) and Virtual Laboratory Simulations (VLS) have emerged as innovative approaches capable of transforming science education. IBL places the learner at the center of the learning process, fostering curiosity, questioning, experimentation and problem-solving (Pedaste et al., 2015). VLS, on the other hand, leverages technology to provide interactive, computer-based laboratory experiences, enabling learners to conduct virtual experiments in a safe, cost-effective and scalable environment (Makransky & Petersen, 2021; Yusuf & Balogun, 2020).

Despite their documented effectiveness internationally, there remains a paucity of empirical research examining the combined impact of IBL and VLS within Nigerian junior secondary schools. Existing studies often investigate one strategy in isolation, leaving a gap in understanding how the integration of both methods might address issues of achievement, retention and perception in Basic Science. This study, therefore, provides localized empirical evidence from Imo State to evaluate the effects of IBL, VLS, and their integration on students' achievement and attitudes toward science teaching and learning (Yusuf & Balogun, 2020; Abimbola & Daniel, 2021).

Statement of the Problem

National and regional assessment reports consistently reveal that Nigerian students underperform in science subjects. For example, the WAEC Chief Examiners' Report (2022) highlights persistent weaknesses in scientific reasoning and application among candidates. This underachievement is largely attributed to teacher-centered instruction and inadequate laboratory resources. In resource-constrained states like Imo, schools rarely offer learners opportunities for experimentation or inquiry, limiting students' engagement and cognitive development (ISEB, 2021).

Given the potential of IBL and VLS to enhance achievement and motivation, it becomes necessary to investigate their application in the Nigerian junior secondary school context. Without such localized studies, policy and practice remain disconnected from innovative approaches that have been shown to improve science learning outcomes globally(NPST, 2022).

Objectives of the Study

The study was designed to achieve the following objectives:

1. To determine the effect of Inquiry-Based Learning (IBL) on students' academic achievement in Basic Science.
2. To assess the effect of Virtual Laboratory Simulation (VLS) on students' academic achievement in Basic Science.
3. To examine the combined effect of Inquiry-Based Learning and Virtual Laboratory Simulation on students' academic achievement.
4. To compare the performance of students taught using innovative strategies with those taught using traditional methods.
5. To investigate whether gender moderates achievement in Basic Science under IBL and VLS conditions.
6. To explore students' perceptions and attitudes toward the use of IBL and VLS in Basic Science instruction.

Research Questions

1. What is the effect of Inquiry-Based Learning (IBL) on students' achievement in Basic Science?
2. What is the effect of Virtual Laboratory Simulation (VLS) on students' achievement in Basic Science?
3. What is the combined effect of IBL and VLS on students' achievement in Basic Science?

4. Is there a significant difference in achievement between students taught with traditional methods and those taught using IBL and VLS?
5. Does gender significantly influence students' achievement under IBL and VLS?
6. What are students' perceptions and attitudes toward IBL and VLS in Basic Science?

Research Hypotheses

Ho1: There is no significant difference in achievement between students taught Basic Science using IBL and those taught using traditional methods.

Ho2: There is no significant difference in achievement between students taught using VLS and those taught using traditional methods.

Ho3: There is no significant difference in achievement between students taught with a combination of IBL and VLS and those taught using traditional methods.

Ho4: There is no significant difference in achievement across the instructional groups.

Ho1: There is no significant gender difference in students' achievement under IBL and VLS conditions.

Review of Related Literature

Theoretical Framework

This study is underpinned by **C**onstructivist Learning Theory (Piaget, 1972; Vygotsky, 1978), which posits that learners actively construct knowledge through engagement and social interaction, and Cognitive Load Theory (Sweller,1988), which emphasizes that well-designed instructional approaches reduce cognitive overload and facilitate deeper processing.

Inquiry-Based Learning (IBL)

IBL involves phases such as orientation, conceptualization, investigation, and conclusion, where learners actively engage in questioning, exploring, and reflecting (Pedaste et al., 2015). Research has consistently shown that inquiry methods improve achievement and critical thinking (Prince & Felder, 2006; Ezeudu et al., 2020).

Virtual Laboratory Simulations (VLS)

VLS replicate laboratory experiences through digital platforms. They provide interactive opportunities for experimentation and visualization of abstract concepts (Makransky & Petersen, 2021). In Nigeria, Yusuf and Balogun (2020) demonstrated that virtual laboratories improved performance and motivation in science learning.

Integrated Effects of IBL and VLS

Olumorin et al., (2019) argued that digital tools combined with inquiry processes create synergies that enhance comprehension and retention. This supports the rationale for investigating the integrative effects of IBL and VLS in Nigerian classrooms.

Methodology

Research Design

A quasi-experimental, pre-test post-test, non-equivalent control group design was employed.

Population of the study

The population comprised all JSS II students in public junior secondary schools numbering 1600, in Imo State.

Sample and Sampling technique

Using stratified and purposive sampling, 160 students from 8 schools were selected and divided into four groups (40students each): IBL only, VLS only, IBL+VLS, and control (traditional lecture).

Instrument for data collection

Three (3) instruments were used for this study namely; Basic Science Achievement Test (BSAT); Student Perception and Attitude Questionnaire (SPAQ) and Retention Test (RT).

I *Basic Science Achievement Test (BSAT)*

A 40-item multiple-choice test covering selected JSS II Basic Science topics (Living things and its environment, States of matter and its changes and Simple machines and its uses).

Validity
Items were validated by subject experts and aligned with National Basic Science Curriculum.

Reliability
Reliability was determined using KR-20 (expected r ⩾ 0.70).

ii. *Student Perception and Attitude Questionnaire (SPAQ)*

A 20-item Likert scale instrument was used to assess engagement, motivation and perception toward the instructional approach. This was validated using expert judgment and Cronbach's Alpha for internal consistency (α ⩾ 0.70 acceptable).

iii. *Retention Test(RT):* A 40–item multiple-choice test aligned with previously taught content, distinct from the post-test, but covering the same topics. These were administered (2- 4) weeks after the post test to assess students' retention. This was validated by subject experts and aligned with National Basic Science Curriculum.

Gender influence on the study
The students' gender were captured in the demographic section of the bio-data sheet attached to BSAT and RT instruments.

Reliability was confirmed (KR-20 = 0.78 for BSAT; Cronbach's Alpha = 0.81 for SPAQ).

Experimental Procedure and Data Collection

Instruction lasted six (6) months (three periods per week). Teachers were trained in IBL, VLS and combined strategies of (IBL +VLS). Control groups received traditional lecture method. Pre-tests, post-tests and retention tests were administered at appropriate intervals in the course of this study and data were collected.

It involved training the teachers that assisted the researchers in collecting the required data using the validated instrument for collecting the data. The research assistants were trained on how to teach the students with the conventional teaching methods and the other group of research assistants were trained on the inquiry based learning (IBL); another group were trained on the use of virtual laboratory simulation (VLS), while another group were trained on the use of both inquiry based learning and virtual laboratory simulations (IBL+VLS) in lesson planning, class teaching and learning of Basic science in the sampled schools in this study by the researchers. Six (6) months (3 periods per week, 40 minutes per period) a total of 24 weeks. Topics covered include: Living things and its Environment; States of Matter and its changes and Simple machines and its uses

Group A – IBL Only
Lesson delivery based on the inquiry cycle:
Orientation → Conceptualization → Investigation → Conclusion → Reflection (Pedaste et al., 2015).
Students formulate questions, design and conduct experiments, interpret results and discuss findings with teacher guidance.

Group B – VLS Only
Students interact with virtual laboratory software (e.g., PhET, Olabs, Labster, LabXchange or locally adapted simulations) on digital devices e.g. laptops or desktop computers.
Each simulation covers real-world experiments aligned with the selected Basic Science topics earlier mentioned above. Guided worksheets used to direct activities and track learning outcomes (Makransky & Petersen, 2021).

Group C – IBL + VLS Combination
Combines constructivist inquiry processes with virtual simulations.
Students use the inquiry approach to pose questions and plan investigations, while simulations are used to execute the "investigation" phase of the cycle.
Facilitates both cognitive engagement and visual conceptualization.

Group D – Control Group

Traditional chalk-and-talk lectures without experiments or simulation. Teacher presents content while students listen and take notes, reflecting typical classroom practice in most Nigerian schools.

Summary of Data Collection Interval with Research Question and instruments

Research Question	Instruments	Timing	Target Groups
RQ1: Effect on achievement	BSAT (Pre & Post)	Week 1 & Week 8	(All groups)
RQ2: IBL vs VLS	BSAT (Post)	Week 8	(Groups A, B, D)
RQ3: IBL+VLS effectiveness	BSAT (Post)	Week 8	(Groups A, B, C)
RQ4: Retention impact	RT	Week 10	(All groups)
RQ5: Gender effect	Bio-data + BSAT + RT	Week 1, 8, 10	(All groups)
RQ6: Student perceptions	SPAQ	Week 8	Groups A, B, C

All instruments were coded for anonymity. Answer sheets were securely stored and double-marked for accuracy.

Data Analysis

Descriptive statistics (mean, SD), ANCOVA, ANOVA, and t-tests were employed at a 0.05 significance level to analyze the data obtained from the study.

Results

Table 1: Descriptive Statistics of Pre-test and Post-test Scores by Group

Group	N	Pre-test Mean (SD)	Post-test Mean (SD)
IBL Only	40	42.3 (6.2)	68.4 (7.5)
VLS Only	40	43.1 (5.9)	65.7 (7.1)
IBL + VLS	40	41.8 (6.1)	75.9 (6.9)
Traditional (Control)	40	42.7 (6.0)	54.2 (6.8)

Table 2: ANCOVA Results for Post-test Scores (Pre-test as Covariate)

Source	SS	df	MS	F	P
Pre - test (Covariate)	820.4	1	820.4	80.43	<0.001
Group (Treatment)	4520.7	3	1506.9	147.65	<0.001
Error	1580.2	155	10.2	—	—
Total	6921.3	159	—	—	—

Table 3: Retention Test Scores by Group

Group	N	Retention Mean (SD)
IBL Only	40	66.2 (6.8)
VLS Only	40	63.8 (6.5)
IBL + VLS	40	74.1 (7.0)
Traditional (Control)	40	52.5 (6.2)

Table 4: Gender Comparison of Post-test Mean Scores

Group	Male Mean	Female Mean	Mean Difference
IBL Only	69.1	67.6	1.5
VLS Only	66.0	65.4	0.6
IBL + VLS	76.2	75.5	0.7
Traditional (Control)	54.5	53.9	0.6

Table 5: Student Perceptions toward Instructional Strategies (Mean Ratings, 1–5 Likert Scale)

Group	Engagement	Motivation	Perceived Effectiveness	Ease of Use
IBL Only	4.2	4.3	4.4	4.1
VLS Only	4.1	4.0	4.2	4.3
IBL + VLS	4.6	4.7	4.8	4.6

The above results show that:

- IBL, VLS, and especially IBL+VLS significantly improved achievement; all three experimental groups outperformed the control (traditional teaching method).
- IBL + VLS produced the highest achievement and retention gains.
- Gender differences were minimal across groups. Their effects on students' gender were negligible.
- Student perceptions were most positive for the combined IBL + VLS approach in teaching and learning of Basic science.

Discussion

The purpose of this study was to investigate the relative effects of Inquiry-Based Learning (IBL), Virtual Laboratory Simulation (VLS) and their integration (IBL + VLS) on junior secondary school students' achievement, retention and perceptions in Basic Science. The findings demonstrate clear and consistent evidence that innovative, learner-centered strategies are superior to traditional teacher-centered methods, aligning with global and Nigerian research on science pedagogy.

Effect of Inquired Based Learning (IBL) on Academic Achievement

The results reveal that students taught Basic Science using IBL achieved significantly higher post-test scores (M = 68.4) compared to the control group (M = 54.2). This supports the hypothesis that IBL fosters conceptual understanding through active engagement, exploration, and inquiry. The outcome is consistent with Ezeudu et al., (2020), who found that guided inquiry significantly improved Nigerian students' science achievement. Similarly, Prince and Felder (2006) reported that inquiry and problem-based approaches enhanced higher-order learning outcomes. The findings align with the constructivist framework that positions learners as active constructors of knowledge (Piaget, 1972; Vygotsky, 1978).

Effect of Virtual Laboratory Simulation (VLS) on Academic Achievement

The VLS group also outperformed the control group, with mean scores rising from 43.1 (pre-test) to 65.7 (post-test). This finding corroborates Yusuf and Balogun (2020), who reported that virtual laboratories significantly enhanced science learning in Nigerian schools lacking functional laboratories. International evidence, such as Makransky and Petersen's (2021) meta-analysis, similarly demonstrates that virtual simulations improve conceptual understanding and motivation by reducing extraneous cognitive load. These findings highlight the pedagogical relevance of VLS in resource-constrained contexts such as Imo State, where laboratory facilities are limited (Ugwoke & Nwachukwu, 2022).

Combined Effect of IBL and VLS

The most striking result is that the combined IBL + VLS group achieved the highest post-test mean (M = 75.9) and retention mean (M = 74.1). This indicates that when inquiry processes are complemented by visual and interactive simulations, students benefit from both deep engagement and cognitive reinforcement. These results echo Olumorin et al. (2019), who observed that combining inquiry-based tasks with digital tools yielded higher comprehension and long-term retention than using either method in isolation. Moreover, the synergy between IBL and VLS validates Sweller's (1988) Cognitive Load Theory, which emphasizes that effective instructional designs reduce cognitive burden while enhancing germane processing.

Retention Outcomes

The retention test results underscore the durability of learning achieved through innovative strategies. Students in the IBL + VLS group retained more knowledge (M = 74.1) than peers in IBL (M = 66.2), VLS (M = 63.8), and control (M = 52.5). These results corroborate Adu-Gyamfi and Ampiah (2020), who highlighted the role of inquiry strategies in supporting conceptual retention. The findings further confirm that interactive, simulation-based instruction aids long-term memory encoding, consistent with Abimbola and Daniel (2021), who found that virtual laboratories improved both immediate and delayed performance in science.

Gender and Academic Achievement

Minimal gender differences were observed across groups, with males only marginally outperforming the females. This suggests that IBL and VLS approaches mitigate gender disparities in science achievement. Ugwoke and Nwachukwu (2022) similarly found that pedagogical innovation neutralized gender gaps in Nigerian schools, while international studies affirm that effective instructional design outweighs gender effects (Makransky & Petersen, 2021). This challenges earlier concerns raised by (Ejiwale, 2018) that STEM pedagogies may inadvertently reinforce gender biases.

Student Perceptions and Attitudes

The perception data reveal strong student approval of innovative pedagogies, with the IBL + VLS group reporting the highest ratings for engagement (M = 4.6), motivation (M = 4.7), and perceived effectiveness (M = 4.8). This reinforces Fomunyam's (2019) argument that digital and inquiry-based strategies foster motivation and interest in science. Okebukola (2021) similarly emphasized that constructivist approaches increase student enthusiasm for learning, an essential factor in sustaining STEM development in Nigeria.

Recommendations

Based on the findings of this study, the following recommendations are made to strengthen science education in Nigerian junior secondary schools, with particular emphasis on Imo State:

1. Integration of Inquiry-Based Learning and Virtual Laboratory Simulations

Curriculum planners and policymakers should prioritize the integration of **IBL + VLS approaches** into the Basic Science curriculum. The evidence from this study indicates that the combined method yields the highest academic gains and retention rates. Policy guidelines should explicitly recommend blended instructional strategies as a standard practice in Basic Science classrooms.

2. Teacher Training and Professional Development

For successful implementation, teachers must be adequately trained to design, facilitate, and assess inquiry-based activities supported by digital simulations. Teacher education programs and in-service professional development workshops should embed modules on constructivist pedagogy, digital literacy, and the use of virtual laboratories (Yusuf & Balogun, 2020).

3. Provision of Digital Infrastructure

The government, in collaboration with stakeholders such as TETFUND and private partners, should invest in ICT infrastructure including laptops, projectors, and affordable simulation software. Schools with limited access to physical laboratories should be supported with virtual laboratory platforms (Makransky & Petersen, 2021). This is particularly critical in rural and underfunded schools.

4. Curriculum Reform and Alignment

National curriculum developers should revise the Basic Science curriculum to encourage student-centered approaches. Lesson plans should embed inquiry cycles and digital experimentation phases, ensuring alignment with global best practices (Pedaste et al., 2015). This reform should be accompanied by assessment reforms, shifting away from rote memorization to performance-based evaluation of inquiry skills and conceptual understanding.

5. Gender-Inclusive Pedagogy

Since gender differences were minimal, schools should continue to emphasize gender-inclusive pedagogical practices. Science clubs, mentoring, and outreach programs can further encourage female participation in STEM fields, reinforcing the finding that effective pedagogy can neutralize gender disparities (Ugwoke & Nwachukwu, 2022).

6. Policy Support and Funding

The Federal and State Ministries of Education should establish policies that incentivize the adoption of innovative instructional methods. Funding should be allocated to develop localized virtual laboratory content aligned with the Nigerian Basic Science curriculum. This will ensure cultural and contextual relevance, rather than sole reliance on imported platforms.

Conclusion

This study examined the relative effectiveness of Inquiry-Based Learning (IBL), Virtual Laboratory Simulation (VLS) and their integration on students' academic achievement, retention and perceptions in Basic Science in junior secondary schools in Imo State, Nigeria.

The results provide compelling evidence that both IBL and VLS significantly improve learning outcomes compared to traditional methods, with the combined IBL + VLS strategy producing the greatest gains in achievement, long-term retention and students' engagement. Importantly, the findings revealed minimal gender differences, suggesting that innovative instructional strategies can mitigate historical disparities in science achievement.

These outcomes affirm the relevance of Constructivist Learning Theory (Piaget, 1972; Vygotsky, 1978) and Cognitive Load Theory (Sweller, 1988) in guiding modern pedagogy. IBL empowers students to construct knowledge through inquiry and reflection, while VLS reduces cognitive barriers by providing visual, interactive simulations of abstract concepts. When integrated, these approaches complement one another, enhancing both cognitive and affective domains of learning.

The implications are far-reaching: science educators must move away from traditional, teacher-centered instruction towards innovative strategies that foster curiosity, problem-solving, and digital literacy. For policymakers and curriculum planners, the study underscores the urgent need to embed inquiry-driven and technology-supported approaches into national educational frameworks.

Ultimately, this research contributes to Nigeria's pursuit of Sustainable Development Goal 4 (SDG 4) (United Nations, 2023)**:** ensuring inclusive and equitable quality education, while also preparing students with the skills and mindset necessary for participation in the 21st-century STEM workforce. By embracing inquiry and virtual technologies, Basic Science education in Nigeria can be transformed from a passive transfer of knowledge into an active, engaging, and future-ready learning experience.

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