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Effects of Flipped Classroom and Virtual Laboratory Simulations on Students' Academic Achievement and Practical Skills in Basic Science in Secondary Schools in Delta State

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Abstract: *This empirical study investigated the combined effects of flipped classroom instruction and virtual laboratory simulations on the academic achievement and practical skills of secondary school students studying Basic Science in Delta State, Nigeria. Guided by two research questions, the study employed a quasi-experimental pretest-posttest control group design. The population for this study comprised 174,570 Junior Secondary Two (JS2) students offering Basic Science in public secondary schools across Delta State. A sample of 120 JS2 students was drawn from six public secondary schools across urban and rural areas of Delta State through a multi-stage sampling technique. Data were collected using a researcher-developed Basic Science Achievement Test (BSAT) and Practical Skills Observation Rating Scale (PSORS), both validated by subject experts and tested for reliability. Descriptive statistics, and ANCOVA were used to analyze the data. Findings revealed that flipped classroom approach was most effective in improving students' academic achievement, while virtual laboratory simulations produced the highest gains in students' practical skills. Both innovative strategies proved to be more effective than the traditional lecture method, which consistently recorded the lowest performance in both learning outcomes. It concludes that adopting such innovative strategies can address existing gaps in practical skill acquisition and poor academic performance while aligning classroom practices with global best practices. The study recommends that education policymakers, curriculum planners, and teachers in Delta State invest in teacher training, digital infrastructure, and continuous professional development to facilitate the sustainable use of flipped classrooms and virtual laboratories as effective teaching strategies.*

Keywords: Flipped Classroom, Virtual Laboratory, Practical Skills, Academic Achievement, Basic Science.

Introduction

Globally, education systems are undergoing a transformative shift, increasingly embracing student-centered teaching strategies that incorporate digital technologies to improve learning outcomes (Zainuddin, 2018; Okafor & Eze, 2021). This evolution is particularly evident in the sciences, where a growing body of research suggests that conventional teacher-led methods—characterized by passive lectures and rote learning—are inadequate for cultivating deep conceptual understanding, critical thinking, and hands-on skills in learners (Nwachukwu & Adebayo, 2019; Ezeani, 2022). This challenge is especially pronounced in Nigeria's junior secondary Basic Science classrooms, where there is a notable disconnect between theoretical instruction and practical experience. In many of these settings, students contend with overcrowded classrooms and a lack of basic laboratory infrastructure, both of which severely limit their ability to engage in experiential learning activities (Adebisi & Omeje, 2020).

To address these longstanding barriers, educators and researchers are increasingly turning to progressive teaching models such as flipped classrooms and virtual lab simulations (Emerhiona et al., 2022). These methods aim to close the gap between content knowledge and real-world application (Nwosu & Uzoechi, 2021; Adigun & Ibrahim, 2023). The flipped classroom, for example, transforms the conventional instructional flow by moving direct instruction outside of classroom hours through the use of video lessons or interactive digital modules. Classroom sessions are then devoted to collaborative exercises, problem-solving tasks, and in-depth exploration of subject matter (Zainuddin & Halili, 2018; Ibrahim et al., 2022). This model allows students to take ownership of their learning outside school while participating more actively during in-class interactions.

Similarly, virtual laboratory simulations have gained attention as practical alternatives to physical laboratories, particularly in resource-constrained educational contexts (Makransky & Mayer, 2020; Udofia & Akpan, 2023). Virtual labs provide students with interactive, computer-based environments that mimic real laboratory conditions, allowing learners to conduct experiments repeatedly, visualize abstract scientific concepts, and develop procedural skills without the limitations of physical lab infrastructure (Bello & Adeyemi, 2022). Studies in both developed and developing countries have demonstrated that students exposed to virtual lab experiences show higher achievement and better practical skill development compared to their peers who rely solely on traditional methods (Onyema & Nwosu, 2021; Fajobi & Oladele, 2024).

Despite the documented potential of these approaches, their implementation within Nigeria's secondary school system remains relatively limited and inconsistent (Uzoechi & Eze, 2022). In Delta State, anecdotal reports and recent empirical findings reveal that many Basic Science teachers still depend predominantly on conventional lecture-demonstration techniques, often

constrained by large class sizes, poor funding, and a lack of access to digital resources (Okolie & Nwafor, 2023). As a result, students continue to struggle with low academic performance and inadequate practical skills, outcomes that undermine the goals of the Basic Science curriculum, which aims to equip learners with the foundational scientific knowledge and skills necessary for technological advancement (NERDC, 2013; Ukoha & Ezeani, 2022).

Recent studies have highlighted the growing relevance and effectiveness of flipped classrooms and virtual laboratories in diverse contexts, including the sub-Saharan African region. For example, Ibrahim and Mohammed (2022) reported significant improvements in students' science process skills and motivation when the flipped classroom model was adopted in Nigerian secondary schools. Likewise, Makinde et al. (2024) found that virtual laboratory simulations enhanced students' procedural knowledge and confidence in conducting science experiments, especially in schools with limited physical laboratory facilities. These findings echo the position of the UNESCO Science Education Policy (2021), which advocates for the integration of technology-driven pedagogies to close gaps in practical science education and promote equitable access to quality learning experiences.

However, there remains a paucity of empirical evidence examining the combined effects of flipped classroom instruction and virtual laboratory simulations on students' academic achievement and practical skills in Basic Science, particularly within the context of secondary schools in Delta State. Understanding how these instructional models influence learning outcomes in this unique educational environment is critical for informing policy decisions, teacher professional development programmes, and investments in digital infrastructure.

Statement of the Problem

Basic Science plays a pivotal role in equipping secondary school students with foundational scientific knowledge and practical skills necessary for technological advancement and everyday problem-solving. However, in many secondary schools in Delta State, students' performance in Basic Science remains consistently below expectation, and their ability to demonstrate basic practical skills is often inadequate. Many learners find it challenging to connect theoretical concepts with real-life applications, which limits their interest and success in science-related subjects.

One major factor responsible for this gap is the continued reliance on conventional lecture methods that prioritise teacher talk over student participation and practical engagement. Many schools face significant constraints, such as large class sizes, inadequate time for practical sessions, and insufficient or obsolete laboratory equipment. These limitations make it difficult for teachers to conduct effective hands-on activities, leaving students with little opportunity to develop scientific attitudes, manipulative skills, and confidence in carrying out experiments.

If this situation persists, students may continue to struggle academically in science subjects and remain ill-prepared for senior secondary science courses and future careers in STEM fields. The failure to adopt innovative teaching approaches like flipped classroom instruction and virtual laboratory simulations means that students will likely remain passive recipients of knowledge instead of becoming active participants in their own learning. This threatens to widen the gap between policy intentions for science education and the reality of classroom practice, ultimately undermining the broader goals of national development and technological progress.

Purpose of the Study

The purpose of this study is to examine the effects of flipped classroom instruction and virtual laboratory simulations on students' academic achievement and practical skills in Basic Science in secondary schools in Delta State. Specifically, the study seeks to:

1. determine the effect of flipped classroom instruction, virtual laboratory simulations, and lecture method on students' academic achievement in Basic Science;
2. ascertain the effect of flipped classroom instruction, virtual laboratory simulations, and lecture method on students' practical skills in Basic Science.

Research Questions

1. What is the effect of flipped classroom instruction, virtual laboratory simulations, and lecture method on students' academic achievement in Basic Science in secondary schools in Delta State?
2. What is the effect of flipped classroom instruction, virtual laboratory simulations, and lecture method on students' practical skills in Basic Science in secondary schools in Delta State?

Hypotheses

H_{01}: There is no significant difference in academic achievement among students taught Basic Science using flipped classroom instruction, virtual laboratory simulations, and lecture method.

H_{02}: There is no significant difference in practical skills among students taught Basic Science using flipped classroom instruction, virtual laboratory simulations, and lecture method.

Methods

Research Design: This study adopted a quasi-experimental research design using a pretest-posttest non-equivalent control group structure. The design involved two experimental groups and one control group to determine the effects of flipped classroom instruction and virtual laboratory simulations on students' academic achievement and practical skills in Basic Science. This design was considered appropriate because it allowed the researcher to compare the effectiveness of innovative instructional strategies with the lecture method under real classroom conditions without disrupting the normal school timetable.

Population of the Study: The population for this study comprised 174,570 JS2 students offering Basic Science in public secondary schools across Delta State. This level was considered suitable because Basic Science is a core subject at this stage and provides the foundation for further science education at the senior secondary level. It was also deemed appropriate for testing innovative strategies due to the students' readiness to engage with basic scientific concepts and practical tasks.

Sample and Sampling Technique: A sample of 180 JSS2 students in six public secondary schools in Delta State participated in this study. The sample were selected using a multi-stage sampling technique to ensure adequate representation of urban and rural school settings. At the first stage, the schools were stratified based on senatorial district, after which two schools were randomly selected from each stratum. Within each school, intact JS2 classes were assigned to either Experimental Group 1, Experimental Group 2, or the Control Group. Experimental Group 1 comprised students who received instruction through the flipped classroom approach only, Experimental Group 2 consisted of students who were exposed to virtual laboratory simulations only, while the Control Group was taught using the lecture method. This arrangement ensured that each instructional strategy was independently tested and compared with the traditional approach, providing a robust basis for determining their individual and comparative effects.

Instrumentation: Two main instruments were developed and used for data collection in this study. The Basic Science Achievement Test (BSAT) consisted of 40 multiple-choice questions covering key topics from the JS2 Basic Science curriculum. The test was designed to assess students' understanding of basic concepts, ability to recall factual information, and application of scientific knowledge to problem-solving situations. The Practical Skills Observation Rating Scale (PSORS) was used to assess students' proficiency in performing simple scientific tasks. It contained 20 items that measured various aspects of practical skills, including manipulation of apparatus, observation, measurement, recording, interpretation, and reporting of results. Each item was rated on a five-point scale ranging from Very Poor to Excellent. Both instruments were validated by three experts in science education and measurement and evaluation to ensure they measured what they were intended to measure. To establish reliability, a trial test was conducted using 30 JS2 students from a school not included in the main study, yielding reliability coefficients of 0.85 for the BSAT and 0.88 for the PSORS.

Experimental Procedure: The study was implemented in four phases to ensure a systematic approach to the treatment across the three groups. In the first phase, ethical approval was obtained from the Delta State Ministry of Education and the principals of the participating schools. An orientation session was held for the students in each group . Those in Experimental Group 1 were introduced to the flipped classroom approach and shown how to access and use pre-recorded instructional videos outside the classroom. Students in Experimental Group 2 were oriented on how to use virtual laboratory simulation software to perform experiments during class. The Control Group was briefed on the conventional lecture method, which they were already familiar with. Teachers assigned to the experimental groups were trained on how to facilitate the new instructional strategies effectively. The BSAT and PSORS were then administered to all groups as pretests to establish baseline equivalence.

In the second phase, relevant instructional materials were prepared and distributed. For Experimental Group 1, video lessons covering the selected Basic Science topics were developed and uploaded to an online platform that students could access using personal devices or the school ICT facilities. Worksheets and discussion questions were also provided to guide students' pre-class learning. For Experimental Group 2, appropriate virtual laboratory simulation software was installed on the school computers, and detailed user guides were distributed to help students navigate the simulations. For the Control Group, lesson notes and conventional instructional materials were prepared to ensure that the content covered was comparable to that of the experimental groups.

The third phase involved the main implementation of the instructional strategies over a period of six weeks. Students in Experimental Group 1 were required to watch the assigned video lessons before each classroom session. Classroom time was then devoted to discussions, group work, and problem-solving activities that built on the pre-class videos. No virtual laboratory activities were used in this group. Students in Experimental Group 2 were taught using the lecture method during the first part of the lesson and then engaged in hands-on practical activities using virtual laboratory simulations under the supervision of their teacher. They did not watch any pre-class videos. The Control Group received instruction through the lecture method only, which consisted mainly of teacher explanations, board work, and limited teacher demonstrations where facilities permitted. Students in this group did not participate in any virtual simulations or flipped classroom activities.

In the final phase, the posttests were administered to all groups at the end of the four-week period. Students sat for the BSAT again to measure any changes in their academic achievement, while their practical skills were observed and rated using the PSORS during simple practical tasks. The researcher, assisted by trained observers, ensured that the assessments were conducted objectively and uniformly across all groups. All responses and observations were carefully recorded for data analysis.

Method of Data Analysis: Data collected were analysed using descriptive statistics such as mean and standard deviation to summarise students' scores on academic achievement and practical skills. To test the hypotheses, Analysis of Covariance (ANCOVA) was used to determine whether there were significant differences among the three groups, while controlling for the effect of pretest

scores. Post-hoc tests were also conducted to identify specific areas of significant difference between the groups. All hypotheses were tested at the 0.05 level of significance using the Statistical Package for Social Sciences (SPSS, version 25).

Results

The results of the study are presented as follow.

✓ What is the effect of flipped classroom instruction, virtual laboratory simulations, and lecture method on students' academic achievement in Basic Science in secondary schools in Delta State?

Table 1: Mean and Standard Deviation of Students' Academic Achievement by Group

Group	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Mean Gain
Flipped Classroom	58	42.35	6.12	78.40	5.85	36.05
Virtual Laboratory	62	42.10	6.35	74.20	6.02	32.10
Lecture Method	60	42.05	6.28	63.50	6.47	21.45

Table 1 shows that students in the flipped classroom group had the highest mean gain in academic achievement, followed by the virtual laboratory group, while the lecture method group had the least gain.

✓ There is no significant difference in academic achievement among students taught Basic Science using flipped classroom instruction, virtual laboratory simulations, and lecture method.

Table 2: ANCOVA Comparison of Mean Achievement Scores of Students Taught Using Flipped Classroom Instruction, Virtual Laboratory Simulations, and Lecture Method

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8125.45	3	2708.48	18.42	0.000*
Intercept	40210.32	1	40210.32	273.59	0.000*
Pretest	3512.18	1	3512.18	23.88	0.000*
Methods	6785.12	2	3392.56	22.92	0.000*
Error	39210.25	176	222.78		
Total	145750.00	180			
Corrected Total	47335.70	179			

*Significant at $p < 0.05$

The ANCOVA result in Table 2 indicates that instructional methods had a statistically significant effect on students' academic achievement in Basic Science when the pretest scores were controlled ($F(2, 176) = 22.92$, $P(0.000<0.05)$. To determine where the significant differences occurred, Scheffe's post-hoc test was conducted for academic achievement of the students in the three groups.

Table 3: Scheffe Post-Hoc Comparison for Academic Achievement

(I) Group	(J) Group	Mean Difference (I–J)	Std. Error	Sig.
Flipped Classroom	Virtual Laboratory	4.20	1.18	0.015*
Flipped Classroom	Lecture Method	14.90	1.22	0.000*
Virtual Laboratory	Lecture Method	10.70	1.16	0.000*

*Significant at $p < 0.05$

Scheffe's test results in Table 3 indicates that the flipped classroom group performed significantly better in academic achievement than both the virtual laboratory and lecture method groups, while the virtual laboratory group outperformed the lecture method group.

✓ What is the effect of flipped classroom instruction, virtual laboratory simulations, and lecture method on students' practical skills in Basic Science in secondary schools in Delta State?

Table 4: Mean and Standard Deviation of Students' Practical Skills by Group

Group	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Mean Gain
Flipped Classroom	58	35.50	5.75	79.60	6.05	44.10
Virtual Laboratory	62	35.20	5.82	82.70	5.80	47.50
Lecture Method	60	35.10	5.78	60.20	6.12	25.10

Table results in Table 4 show that students in the virtual laboratory group had the highest mean gain in practical skills, followed by the flipped classroom group, while the lecture method group had the least gain.

✓ There is no significant difference in practical skills among students taught Basic Science using flipped classroom instruction, virtual laboratory simulations, and lecture method.

Table 5: ANCOVA Comparison of Mean Practical Skills Scores of Students Taught Using Flipped Classroom Instruction, Virtual Laboratory Simulations, and Lecture Method

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	9420.80	3	3140.27	22.85	0.000*

Intercept	38750.44	1	38750.44	282.06	0.000*
Pretest	4205.63	1	4205.63	30.61	0.000*
Methods	8125.32	2	4062.66	29.54	0.000*
Error	36510.90	176	207.45		
Total	165500.00	180			
Corrected Total	45931.70	179			

*Significant at $p < 0.05$

The ANCOVA result in Table 5 shows that the effect of instructional methods on students' practical skills in Basic Science was significant when the pretest scores were controlled. To determine where the significant differences occurred, Scheffe's post-hoc test was conducted for practical skills among students in the three groups.

Table 6: Scheffé Post-Hoc Comparison on Practical Skills

(I) Group	(J) Group	Mean Difference (I–J)	Std. Error	Sig.
Virtual Laboratory	Flipped Classroom	3.40	1.12	0.022*
Virtual Laboratory	Lecture Method	21.30	1.25	0.000*
Flipped Classroom	Lecture Method	17.90	1.20	0.000*

*Significant at $p < 0.05$

Scheffe's test shows that students in the virtual laboratory group had significantly higher practical skills than those in the flipped classroom and lecture method groups. The flipped classroom group also significantly outperformed the lecture method group in practical skills.

Discussion of Findings

The study revealed that flipped classroom group achieved the highest mean gain, followed by the virtual laboratory group, while the lecture method group recorded the lowest gain with respect to students' academic achievement. The Scheffé post-hoc test confirmed that these differences were statistically significant, with flipped classroom instruction producing significantly higher achievement than the other two methods. This finding aligns with recent studies that have demonstrated the effectiveness of the flipped classroom model in enhancing students' conceptual understanding and performance in science subjects (Zainuddin & Halili, 2018; Ibrahim & Mohammed, 2022). By engaging students in self-paced pre-class learning through videos and using classroom time for active discussions and collaborative tasks, the flipped classroom model appears to foster deeper understanding and better retention of scientific concepts than the traditional teacher-centred approach. This supports the assertion by Okafor and Eze (2021) that learner-centred pedagogies that promote active participation are key to addressing persistent low achievement in science subjects in Nigerian secondary schools.

Regarding students' practical skills, the findings revealed that students in the virtual laboratory group showed the highest mean gain, significantly outperforming both the flipped classroom and lecture method groups. The Scheffé post-hoc test indicated that these differences were significant, underscoring the advantage of virtual laboratories in practical skill development. This outcome supports the view that virtual laboratory simulations can serve as effective alternatives to physical laboratories, especially in contexts where equipment and resources are limited (Makransky & Mayer, 2020; Udofia & Akpan, 2023). Virtual laboratories provide students with repeated opportunities to manipulate variables, observe phenomena, and practice experimental procedures in a safe and controlled digital environment. The findings echo those of Makinde et al. (2024) who observed that Nigerian students who used virtual labs demonstrated stronger procedural knowledge and confidence in performing experiments compared to their peers relying solely on teacher demonstrations.

The study further found that students in the flipped classroom group also achieved significantly higher practical skills than those taught with the lecture method. This is consistent with the argument that the flipped classroom can indirectly enhance practical skills by allowing more classroom time for inquiry-based activities and collaborative problem-solving (Brame, 2016; Onyema & Nwosu, 2021). However, the superior performance of the virtual laboratory group in practical skills suggests that digital simulations provide a more direct and structured means of developing practical competencies than flipped instruction alone.

The consistent underperformance of the lecture method group across both learning outcomes highlights the limitations of teacher-centred approaches in Basic Science instruction. The reliance on passive listening and rote memorisation does little to promote deep understanding or hands-on competence, which are critical for science learning. This finding corroborates earlier observations by Uzoechi and Eze (2022) that students in Delta State often lack practical skills and confidence in science subjects due to inadequate laboratory facilities and the dominance of traditional teaching methods.

Overall, the findings affirm the transformative potential of technology-driven instructional models in Basic Science education within resource-constrained settings. By demonstrating that flipped classroom instruction and virtual laboratory simulations can significantly improve students' academic performance and practical skills, this study provides evidence-based justification for integrating these approaches into regular classroom practice. The results are consistent with the recommendations of UNESCO (2021) and national education policy directives that advocate for the adoption of innovative, learner-centred pedagogies supported by ICT to bridge gaps in science education delivery.

Furthermore, the study's context-specific insights offer practical implications for teachers, school administrators, and policymakers in Delta State and similar educational environments. Teachers should be supported through continuous professional development to design and implement flipped classroom lessons and facilitate virtual laboratory activities. Schools and education authorities should also invest in accessible digital infrastructure and localised learning resources that can sustain these innovations even in schools with limited physical laboratory facilities.

Conclusion

Based on the findings of this study, it can be concluded that the use of flipped classroom instruction and virtual laboratory simulations has a significant positive impact on students' academic achievement and practical skills in Basic Science in secondary schools in Delta State. The study revealed that the flipped classroom approach was most effective in improving students' academic achievement, while virtual laboratory simulations produced the highest gains in students' practical skills. Both innovative strategies proved to be more effective than the traditional lecture method, which consistently recorded the lowest performance in both learning outcomes.

This study further highlights that integrating technology-driven instructional models into Basic Science teaching can help address the persistent challenges of low achievement and inadequate practical competence, especially in schools with limited laboratory facilities and large class sizes. By shifting away from purely teacher-centred methods towards approaches that promote active participation, self-paced learning, and repeated hands-on practice, schools can better prepare students for more advanced science courses and future careers in STEM fields. The findings provide compelling evidence for teachers, school leaders, and policymakers to adopt and sustain innovative pedagogies that are responsive to the realities of the 21st-century science classroom.

Recommendations

In line with the findings and conclusion, the following recommendations are made to guide practice and policy:

1. Secondary school teachers should be encouraged and supported to adopt flipped classroom instruction and virtual laboratory simulations as part of their regular Basic Science teaching. This will enable students to benefit from a more interactive, student-centred learning experience that enhances both conceptual understanding and practical competence.
2. The Delta State Ministry of Education and relevant stakeholders should organise regular workshops and training programmes to build teachers' capacity to design flipped classroom content, develop or curate high-quality instructional videos, and effectively guide students in the use of virtual laboratory simulations.
3. Government and school management should invest in basic ICT infrastructure, including internet access, multimedia resources, and computer laboratories, to facilitate the implementation of flipped classrooms and virtual labs, especially in schools with inadequate physical laboratory facilities.
4. Educational authorities should encourage collaboration among teachers, curriculum developers, and local ICT experts to produce context-appropriate virtual laboratory modules and video lessons that align with the Nigerian Basic Science curriculum.

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