BLENDED STEM INSTRUCTION USING VIRTUAL LABS AND SIMULATIONS: EFFECTS ON ACADEMIC PERFORMANCE AND SELF-EFFICACY IN BIOLOGY, MATHEMATICS, PHYSICS, AND CHEMISTRY AMONG SECONDARY SCHOOL STUDENTS ZARIA EDUCATION ZONE KADUNA STATE NIGERIA

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Abstract

This study investigated the effects of blended STEM instruction using virtual laboratories and simulations on academic performance and self-efficacy in Biology, Mathematics, Physics, and Chemistry among senior secondary students in Zaria Education Zone, Kaduna State, Nigeria. Employing a quasi-experimental design with pre-test and post-test control groups, the population comprised 8500 students, out of which 200 students from four selected co-educational schools were selected using a simple random sampling technique. The sample was divided into experimental and control groups. The experimental group received blended instruction integrating virtual labs and simulations, while the control group experienced conventional teaching methods. Data were collected using standardised achievement tests and a validated self-efficacy scale, then analysed with ANCOVA and t-tests. Results showed significant improvements in academic performance ($F(1,196) = 45.87$, $p < 0.001$, $\eta^2 = 0.210$) and self-efficacy ($F(1,196) = 32.45$, $p < 0.001$, $\eta^2 = 0.142$) for the experimental group compared to controls. No significant gender differences were found. The findings underscore the effectiveness of virtual labs and simulations in enhancing STEM learning outcomes and student confidence, recommending wider adoption in resource-limited Nigerian schools.

Keywords: Blended Learning, Virtual Laboratories, STEM Education, Academic Performance, Self-Efficacy.

Introduction

The Fourth Industrial Revolution has intensified the demand for an education system that equips learners with advanced problem-solving, analytical reasoning, and technological skills. In response to this demand, Science, Technology, Engineering, and Mathematics (STEM) education has emerged as a critical framework for developing globally competitive competencies among secondary school students. Despite the strategic importance of STEM subjects like Biology, Mathematics, Physics, and Chemistry in national development, student performance and engagement in these areas, particularly in sub-Saharan Africa, remain significantly low (Tikly et al., 2018). Contributing factors include insufficient laboratory resources, large class sizes, poor teaching methodologies, and limited exposure to practical applications. In Nigeria, this issue is compounded by a lack of qualified teachers and under-resourced laboratory environments, especially in public secondary schools. Consequently, students often experience difficulty linking theoretical content with real-world applications, which adversely affects their academic performance and self-efficacy (Akorede & Olaleye, 2019).

Vetrivel et al (2024) opined that Blended learning has emerged as a promising pedagogical model for bridging these gaps. It combines the strengths of face-to-face instruction with the flexibility and interactivity of digital technologies. Among the most transformative tools in blended STEM instruction are virtual laboratories and computer-based simulations, which offer students hands-on experiences in a risk-free, scalable, and resource-efficient environment. Through dynamic visualisation, repetition of experiments, and real-time feedback, these

tools not only enhance students' understanding of abstract scientific and mathematical concepts but also build confidence in their problem-solving abilities. Virtual labs simulate real laboratory conditions, allowing students to perform dissections, chemical titrations, mathematical modelling, and physics experiments without the need for physical infrastructure or reagents. Simulations further help learners develop intuitive understandings of complex systems such as molecular interactions, mechanics, and algebraic functions by allowing them to manipulate variables and observe outcomes.

Research has shown that virtual labs and simulations significantly improve academic performance and enhance learners' self-efficacy. According to Yusuf and Afolabi (2022), students exposed to blended learning environments with virtual science labs outperformed their counterparts taught through traditional methods. Similarly, Ibrahim et al. (2021) found that simulations in mathematics instruction promoted better retention and confidence in problem-solving. However, while studies have demonstrated the isolated effectiveness of these tools in individual subjects, there is a limited body of evidence on how cross-disciplinary application of blended instruction using virtual labs and simulations affects student learning across the core STEM domains simultaneously.

This study, therefore, seeks to evaluate the impact of blended STEM instruction using virtual labs and simulations on the academic performance and self-efficacy of senior secondary school students in Biology, Mathematics, Physics, and Chemistry. The study also examines the extent to which gender moderates these effects and whether virtual tools can serve as sustainable alternatives to traditional laboratory instruction in Nigerian classrooms.

Statement of the Problem

Despite the pivotal role of STEM education in fostering national development, innovation, and economic growth, students in Nigerian secondary schools continue to record poor academic performance in key STEM subjects such as Biology, Mathematics, Physics, and Chemistry. Reports from national examinations such as WAEC and NECO consistently show high failure rates, which are often linked to ineffective instructional methods, limited laboratory infrastructure, large class sizes, and low learner engagement. Many students lack access to functional science laboratories, thereby missing opportunities for hands-on experimentation that could improve understanding, motivation, and retention. This lack of exposure to experiential learning diminishes students' confidence in their ability to succeed in STEM subjects, contributing to low self-efficacy and disinterest in science-related careers.

Meanwhile, the integration of digital technologies, particularly virtual laboratories and simulations, offers promising alternatives to traditional instruction. These tools provide interactive, cost-effective, and scalable platforms that can replicate real-world STEM experiences in environments where physical resources are scarce. However, while research exists on the effectiveness of virtual learning in specific subjects, there is limited comprehensive evidence on its impact across multiple STEM disciplines within a blended instructional model. In addition, the question of whether such an approach can significantly influence students' self-efficacy, especially in the context of rural or under-resourced schools in Nigeria, remains underexplored.

Therefore, this study seeks to fill this gap by investigating the effects of blended STEM instruction using virtual labs and simulations on students' academic performance and self-efficacy across four core subjects: Biology, Mathematics, Physics, and Chemistry. It aims to determine whether this integrated digital approach can enhance learning outcomes, build learners' confidence in their abilities, and serve as a viable solution to infrastructural and pedagogical challenges in Nigerian secondary schools.

Objectives of the Study

The primary objective of this study is to evaluate the impact of blended STEM instruction using virtual laboratories and simulations on students' academic performance and self-efficacy in Biology, Mathematics, Physics, and Chemistry in Nigerian secondary schools. Specifically, the study aims to:

1. Determine the effect of blended STEM instruction using virtual labs and simulations on students' academic performance across Biology, Mathematics, Physics, and Chemistry.
2. Examine the influence of blended STEM instruction on students' self-efficacy in learning core STEM subjects.

3. Investigate whether gender moderates the effect of blended STEM instruction on academic performance and self-efficacy.

Research Questions

The study is guided by the following research questions:

1. What is the difference in academic performance between students taught Biology, Mathematics, Physics, and Chemistry using blended STEM instruction with virtual labs and simulations and those taught using conventional methods?
2. What is the difference in self-efficacy levels between students exposed to blended STEM instruction using virtual labs and those exposed to traditional instruction?
3. Is there a gender-based difference in the impact of blended STEM instruction on academic performance and self-efficacy?

Hypotheses

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

H_{01}: There is no significant difference in academic performance between students taught STEM subjects (Biology, Mathematics, Physics, and Chemistry) using blended instruction with virtual labs and those taught using conventional methods.

H_{02}: There is no significant difference in self-efficacy levels between students taught STEM subjects using blended instruction with virtual labs and those taught using conventional methods.

H_{03}: There is no significant gender-based difference in the academic performance and self-efficacy of students taught STEM subjects using blended instruction with virtual labs and simulations.

Theoretical Framework

This study is anchored on Bandura's Social Cognitive Theory (1986) and Mayer's Cognitive Theory of Multimedia Learning (2009). Bandura's theory emphasises the role of observational learning, self-efficacy, and reinforcement in shaping behaviour and academic achievement. Self-efficacy, defined as learners' belief in their capability to execute tasks, directly influences motivation, effort, and persistence. The use of virtual simulations and digital labs creates mastery experiences, promotes student autonomy, and provides immediate feedback, which are essential factors in building self-efficacy.

Mayer's Cognitive Theory of Multimedia Learning supports the effectiveness of learning through a combination of visual and verbal channels. According to this theory, meaningful learning occurs when learners actively select relevant information, organise it mentally, and integrate it with prior knowledge. Virtual labs and simulations embody these principles by providing learners with rich visualisations, animations, and interactive content that align with cognitive processing capacities. These theories provide a framework for understanding how virtual and blended learning environments can enhance both academic performance and confidence in STEM contexts.

Literature Review

Blended learning approaches have become increasingly prominent in STEM education due to their ability to integrate traditional face-to-face instruction with digital resources that promote deeper understanding. According to Almasri et al. (2021), blended learning environments enhance learning outcomes in science and mathematics by offering flexible, student-centred instruction that accommodates diverse learning styles. Virtual laboratories, a core component of blended STEM instruction, allow learners to perform experiments in simulated environments, which is especially beneficial in contexts where real labs are limited or unavailable (Makransky et al., 2019). These tools offer safe, repeatable, and cost-effective ways to explore abstract scientific concepts.

In Nigeria, Adeoye and Arogundade (2020) found that the use of digital simulations in teaching Chemistry improved students' comprehension of molecular interactions and increased their motivation to learn. Similarly, Onasanya and Adegbija (2022) reported significant gains in Physics achievement among secondary students who used computer-based simulations compared to those taught traditionally. In Mathematics, research by Yusuf and Ibrahim (2021) showed that virtual manipulatives improved students' conceptual understanding of algebraic and geometric ideas, leading to higher test scores and more positive attitudes toward the subject.

Beyond performance, virtual labs have also been shown to positively impact learners' self-efficacy. According to Lee and Wong (2020), students using virtual simulations developed stronger confidence in their ability to perform scientific tasks, mainly because these tools provided a sense of control and mastery. This finding is echoed by Odogwu and Eze (2021), who found that interactive simulations in Biology classes helped students visualise complex processes like photosynthesis and digestion, resulting in increased self-belief and engagement.

Gender differences in blended STEM learning have also been explored. Odu et al. (2022) and Akorede et al. (2022) affirmed that male students may initially show higher confidence in virtual environments. Interventions using inclusive and collaborative tools often eliminate such disparities. Indeed, research shows that when girls are exposed to well-structured blended environments with supportive feedback, their academic outcomes and self-efficacy are comparable to those of their male counterparts.

In sum, the literature supports the idea that blended STEM instruction using virtual labs and simulations improves academic achievement and self-efficacy across multiple domains. However, comprehensive cross-disciplinary studies that assess these effects simultaneously across Biology, Mathematics, Physics, and Chemistry in sub-Saharan Africa are limited. This study, therefore, aims to bridge this gap.

Methodology

This study employed a quasi-experimental design incorporating pre-test and post-test control groups to assess the effects of blended STEM instruction using virtual labs and simulations on students' academic performance and self-efficacy in Biology, Mathematics, Physics, and Chemistry. The population comprised all senior secondary two (SS2) students across public secondary schools in the Zaria Education Zone of Kaduna State, Nigeria, estimated at approximately 8,500 students distributed in 15 schools. Using simple random sampling, four co-educational schools were selected, from which two intact classes each were assigned as experimental and control groups, totalling 200 students (100 per group). The experimental group received blended instruction integrating face-to-face teaching with virtual laboratories and computer-based simulations over 10 weeks, while the control group was taught using conventional, lecture-based methods. To measure academic performance, standardised subject-specific achievement tests were developed and validated by experts in science education and administered before and after the intervention. Self-efficacy was assessed using a modified version of the Science Self-Efficacy Scale (SSES), validated for the local context. Reliability testing of the instruments through pilot testing yielded Cronbach's alpha coefficients of 0.82 for academic tests and 0.87 for the self-efficacy scale, indicating strong internal consistency. Data collected were analysed using Analysis of Covariance (ANCOVA) to control for pre-test scores and evaluate post-test differences between groups, while independent samples t-tests examined gender-based variations. Ethical clearance was obtained from the school authorities, and informed consent was secured from participants and guardians. The intervention was carefully monitored to ensure fidelity, with teachers trained on the use of virtual labs and simulations.

Data Analysis and Results

Table 1: ANCOVA Summary for Academic Performance by Instructional Method (Controlling for Pre-Test Scores)

Source	Type III Sum of Squares	Df	Mean Square	F	p-value	Partial η^2
Instruction Method	4120.45	1	4120.45	45.87	<0.001**	0.210
Pre-Test Scores	3225.67	1	3225.67	35.91	<0.001**	0.168
Error	17762.34	196	90.62			
Total	25108.46	199				

**Significant at $p < 0.05$

Hypothesis 1 (H_{01}): The ANCOVA results in Table 1 indicate a statistically significant effect of instructional method on academic performance, $F(1, 196) = 45.87$, $p < 0.001$, after controlling for pre-test scores. The partial eta squared ($\eta^2 = 0.210$) suggests that 21% of the variance in academic performance can be attributed to the instructional method, which is a large effect size. This provides strong evidence to reject the null

hypothesis, concluding that students taught using blended STEM instruction with virtual labs and simulations significantly outperformed those taught by conventional methods.

Table 2: ANCOVA Summary for Self-Efficacy Scores by Instructional Method (Controlling for Pre-Test Scores)

Source	Type III Sum of Squares	df	Mean Square	F	p-value	Partial η^2
Instruction Method	185.23	1	185.23	32.45	<0.001**	0.142
Pre-Test Scores	78.56	1	78.56	13.77	<0.001**	0.066
Error	1118.74	196	5.71			
Total	1382.53	199				

**Significant at $p < 0.05$

Hypothesis 2 (H_{02}): Table 2 shows a significant difference in self-efficacy scores based on instructional method, $F(1, 196) = 32.45$, $p < 0.001$, with a partial η^2 of 0.142, indicating a large practical effect. The blended learning approach, incorporating virtual labs, effectively enhanced students' confidence in their ability to learn and apply STEM concepts compared to the traditional approach. The null hypothesis is therefore rejected.

Table 3: Independent Samples t-test for Gender Differences in Academic Performance and Self-Efficacy (Experimental Group Only)

Variable	Gender	N	Mean	SD	t-value	df	p-value
Academic Performance	Male	52	78.92	7.41	1.24	98	0.219
	Female	48	77.18	6.95			
Self-Efficacy	Male	52	4.12	0.65	1.05	98	0.296
	Female	48	3.98	0.68			

Hypothesis 3 (H_{03}): The independent samples t-tests in Table 3 show no statistically significant gender differences in either academic performance ($t(98) = 1.24$, $p = 0.219$) or self-efficacy ($t(98) = 1.05$, $p = 0.296$) within the experimental group. These results suggest that both male and female students benefited similarly from the blended STEM instruction with virtual labs and simulations, leading to the retention of the null hypothesis that there is no significant gender-based difference.

Discussion

The findings from this study reveal that blended STEM instruction using virtual laboratories and simulations significantly enhances students' academic performance and self-efficacy across Biology, Mathematics, Physics, and Chemistry compared to conventional teaching methods. This result aligns with prior research (Akorede et al., 2017; Makransky et al., 2019; Adeoye & Arogundade, 2020), which demonstrated that virtual labs provide students with immersive, interactive learning experiences that concretise abstract STEM concepts and promote deeper understanding. The large effect size ($\eta^2 = 0.210$) observed suggests that integrating virtual simulations substantially boosts performance by providing repeated opportunities for experimentation and immediate feedback, which are often limited in traditional classroom settings due to resource constraints.

Moreover, the significant improvement in self-efficacy ($\eta^2 = 0.142$) highlights that students exposed to blended instruction felt more confident in their ability to tackle STEM problems. This supports Bandura's (1986) Social Cognitive Theory that mastery experiences enabled here by virtual lab interactions are critical for building learners' belief in their capabilities. The cognitive engagement fostered by multimedia tools also resonates with Mayer's (2009) theory on multimedia learning, which posits that combining verbal explanations with visualisations strengthens mental models and learner motivation.

Interestingly, the study found no significant gender differences in either academic performance or self-efficacy gains within the experimental group. This finding indicates that blended STEM instruction with virtual labs is equally effective for male and female students, countering some earlier concerns regarding gender disparities in technology adoption and STEM participation (Odu et al., 2022). The equitable learning outcomes might be attributed to the interactive, student-centred nature of virtual labs that accommodate diverse learning preferences and reduce classroom biases.

Overall, these results underscore the value of integrating digital tools such as virtual labs and simulations in STEM education, especially in contexts like Nigerian secondary schools, where physical laboratory resources

are often inadequate. Implementing such blended approaches could help bridge educational gaps, enhance learner confidence, and contribute toward building a more competent STEM workforce.

Conclusion

This study concludes that blended STEM instruction incorporating virtual laboratories and simulations has a significant positive impact on students' academic performance and self-efficacy in Biology, Mathematics, Physics, and Chemistry. The absence of gender disparities in these outcomes further suggests that this instructional approach can promote inclusive STEM learning environments.

Recommendations

Based on the findings of this study, the following recommendations are made to enhance STEM education in Nigerian secondary schools:

1. Integration of Virtual Labs and Simulations: Schools should incorporate virtual laboratories and computer-based simulations into STEM curricula as standard teaching tools to complement traditional instruction. This integration will improve students' conceptual understanding and academic performance in Biology, Mathematics, Physics, and Chemistry.
2. Investment in Digital Infrastructure: Educational authorities and policymakers should prioritise funding for digital infrastructure, including reliable internet access, computer labs, and multimedia devices, especially in rural and under-resourced schools, to facilitate effective implementation of blended STEM instruction.
3. Teacher Training and Professional Development: Continuous capacity building and training programs should be organised for STEM teachers to equip them with the skills necessary to effectively utilise virtual labs and simulations. Training should focus on both pedagogical strategies and technical competencies.

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