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Effects of Experiential Learning Models on Academic Performance and Science Process Skills in Plant Physiology Among Secondary School Biology Students in Zaria, Kaduna State, Nigeria

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Abstract
This study evaluated the effects of experiential learning models on academic performance and science process skills in plant physiology among Senior Secondary II (SS II) biology students in Zaria, Kaduna State. The persistent underperformance in certificate examinations and a systemic deficit in practical competencies among secondary graduates are attributed to a reliance on passive, teacher-centered conventional lecture methods. Using a pre-test, post-test, non-equivalent control group, quasi-experimental research design, a sample of 312 students (142 males, 170 females) was selected from an active target population of 1,384 students across 18 schools using a multi-stage sampling procedure. The experimental group was exposed to a six-week intervention structured around David Kolb's four-stage experiential learning cycle, while the control group was taught using conventional lecture methods. Data were collected using the validated Biology Academic Performance Test (BAPT, $r = 0.86$) and the Science Process Skills Performance Scale (SPSPS, $r = 0.83$). Two-way Analysis of Covariance (ANCOVA) revealed a highly significant main effect of the experiential learning treatment on students' post-test academic performance [$F(1, 307) = 958.04$, $p < .001$, Partial $n^2 = .758$] and science process skills scores [$F(1, 307) = 2286.32$, $p < .001$, Partial $n^2 = .881$] in favor of the experimental group. No significant interaction effect was found between teaching methodology and gender, establishing the model as an equitable, gender-inclusive strategy. It is recommended that the Kaduna State Ministry of Education mandates active experiential learning strategies and organizes state-wide capacity-building workshops to equip science teachers with low-cost practical instruction methodologies, among others.

Keywords: Experiential Learning, Academic Performance, Science Process Skills, Plant Physiology, Gender Inclusivity

Introduction
Science education serves as the bedrock for technological advancement and sustainable economic growth within any modern society. Among the core natural science disciplines offered at the senior secondary level in Nigeria, biology experiences the highest student enrollment because it bridges the natural environment with health, agriculture, and fundamental life processes. Despite its popularity and central role in fostering scientific literacy, student achievement in both internal and external evaluations administered by bodies such as the West African Examinations Council (WAEC) and the National Examinations Council (NECO) remains consistently discouraging. Educational researchers in Nigeria have long identified that this systemic underperformance is deeply rooted in the persistence of passive, teacher-centered instructional approaches, particularly the conventional lecture method, which minimizes student engagement and reduces complex biochemical phenomena to abstract memorization (Awolere, 2019; Ozoarinze, 2018).

Plant physiology encompassing intricate mechanisms such as photosynthesis, cellular respiration, transpiration, mineral nutrition, and translocation stands out as one of the most conceptually challenging and abstract components of the secondary school biology curriculum. Secondary school students often view plants as passive, non-living, or static background entities because they lack obvious, animal-like locomotion (Pany et al., 2022). This lack of visual animation makes it difficult for learners to conceptualise the dynamic, invisible metabolic and physiological pathways occurring within plant tissues, such as the vital energy distributions mediated by core minerals (Sinha & Tandon, 2020). When these processes are taught strictly through verbal exposition or passive textbook readings, students fail to connect isolated facts into a coherent biological understanding. Instead, they develop deep-seated misconceptions, frequently confusing the gaseous exchange of photosynthesis with that of respiration, or viewing root absorption as a simple mechanical intake of water rather than an active biochemical process (Svandova, 2014). To dismantle these misconceptions and foster deep conceptual clarity, the instructional delivery must transition from passive transmission to active exploration. David Kolb's Experiential Learning Theory provides a robust pedagogical framework to address these curricular challenges, positing that knowledge is continuously created through the transformation of experience by moving sequentially through four distinct stages. These stages begin with Concrete Experience, which involves hands-on engagement with material, followed by Reflective Observation, where learners watch and think deeply about the experience. Subsequently, students enter Abstract Conceptualization to formulate rules, theories, and concepts, before ultimately engaging in Active Experimentation to apply these newly formed concepts to new practical situations. In a classroom structured around experiential learning, biology students do not merely listen to a description of stomatal transpirational pull; they set up potometers, design localized experimental setups using clear polythene enclosures on live school-garden crops, measure real-time fluid displacements, collect empirical data, and actively reflect on their physical findings. This student-centered methodology aligns perfectly with the development of basic and integrated science process skills such as observing, measuring, classifying, formulating hypotheses, controlling variables, experimenting, and interpreting data which are indispensable for scientific inquiry and long-term cognitive retention (Chengere, 2025). Furthermore, gender equity in science, technology, engineering, and mathematics (STEM) fields remains a major concern for educational policy makers across Northern Nigeria, including Kaduna State. Historical sociocultural patterns and classroom dynamics have sometimes inadvertently sidelined female students in practical science tasks, leading to disparate spatial, analytical, and experimental confidence levels between genders. Evaluating whether an innovative active-learning intervention benefits male and female students equally, or helps bridge performance gaps, is essential for designing inclusive educational frameworks. While regional studies across Nigeria have begun to explore active learning strategies, there is a critical shortage of localized empirical research focusing specifically on how experiential learning models affect the academic performance and science process skills of secondary school students grappling with plant physiology in Zaria (Nwuba & Osuafor, 2021; Nwuba, 2024). This study addresses this gap by executing a large-scale, multi-school quasi-experimental investigation within the distinct educational landscape of Zaria, Kaduna State.

Statement of the Problem

The traditional method of teaching biology in Zaria's senior secondary schools relies heavily on passive, teacher-centered lectures and rote memorisation. This practice is driven by massive overpopulation in urban classrooms, an acute shortage of fully functional laboratory infrastructure, and rigid, time-constrained lesson blocks. Consequently, complex and abstract concepts within plant physiology such as transpirational mechanics, stomatal movements, photosynthetic light reactions, and mineral assimilation pathways are presented almost entirely as theoretical concepts. This expository approach forces students to memorise terms and structures without ever observing their functional, real-world biological mechanisms, leading to persistent underperformance in certificate examinations, a deficit in critical science process skills, and profound misconceptions regarding plant functions. While previous researchers have suggested that student-centered methods like experiential learning could improve general biology outcomes, there is very little empirical data on its specific effectiveness for teaching abstract plant physiology to large populations in Zaria. Additionally, it remains unclear how this active method interacts with student gender in an environment where closing the STEM equity gap is a high priority. Without localized, rigorous intervention studies, biology education in the region will likely remain bound to ineffective lecture methods, leaving secondary graduates ill-prepared for higher education or careers in modern scientific fields.

Objectives of the Study

Specifically, the study sought to achieve the following objectives:

1. To determine the difference in the mean scores of academic performances between SS II biology students taught plant physiology using the experiential learning model and those taught using the conventional lecture method.
2. To assess the difference in the mean scores of science process skills between SS II biology students exposed to the experiential learning model and those exposed to the conventional lecture method.
3. To examine the interaction effect of teaching methodology and gender on the difference in the mean scores of both academic performance and science process skills among the students.

Research Questions

The following research questions were formulated to guide the execution of this study:

1. What is the difference in the mean pre-test and post-test academic performance scores of SS II biology students taught plant physiology using the experiential learning model compared to those taught using the conventional lecture method?

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2. What is the difference in the mean pre-test and post-test science process skills scores of SS II biology students exposed to the experiential learning model compared to those exposed to the conventional lecture method?
3. What is the interactive influence of teaching methodology and gender on the difference in the mean post-test scores of academic performance and science process skills among SS II biology students in Zaria?

Research Hypotheses

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

$H0_1$: There is no significant difference in the mean academic performance scores of SS II biology students taught plant physiology using the experiential learning model and those taught using the conventional lecture method.

$H0_2$: There is no significant difference in the mean science process skills scores of SS II biology students exposed to the experiential learning model and those exposed to the conventional lecture method.

$H0_3$: There is no significant interaction effect of teaching methodology and gender on the difference in the mean post-test academic performance and science process skills scores of SS II biology students.

Methodology

This study adopted a pre-test, post-test, non-equivalent control group, quasi-experimental research design to preserve classroom administrative stability while enabling a rigorous comparative empirical analysis. The target population comprised 1,384 Senior Secondary II (SS II) biology students across 18 public co-educational secondary schools within Zaria Local Government Area of Kaduna State. Through a multi-stage sampling procedure, four schools were randomly chosen, and two intact classes from each school were selected to yield eight distinct blocks. These intact classes were randomly assigned via a simple coin flip into either the experimental treatment group or the conventional control group, culminating in a final sample size of 312 students, with 164 in the experimental group and 148 in the control group, across a gender distribution of 142 male and 170 female students. Data collection relied on two primary diagnostic instruments: the Biology Academic Performance Test (BAPT), a 50-item multiple-choice test covering key plant physiology topics, and the Science Process Skills Performance Scale (SPSPS), which used five structured laboratory tasks to evaluate practical skills. Vetted by three senior subject-matter experts from the Faculty of Education at Ahmadu Bello University, Zaria, and pilot-tested outside the study area, the BAPT demonstrated an internal consistency of 0.86 using the Kuder-Richardson Formula 20, while the SPSPS achieved an inter-rater reliability value of 0.83 via Cronbach's alpha. The instructional intervention spanned exactly six weeks with three 40-minute lesson periods per week for both cohorts, bookended by a pre-test and a post-test using shuffled versions of the diagnostic tools. The experimental group was instructed via David Kolb's experiential learning cycle incorporating concrete experience, reflective observation, abstract conceptualisation, and active experimentation using hands-on setups like potometers to explore physiological mechanisms. In contrast, the control group was taught the exact same plant physiology topics by their regular classroom teachers using the conventional lecture method, which relied strictly on chalkboard explanations, passive textbook descriptions, and verbal note dictation without active inquiry. All collected data were compiled and processed using SPSS, deploying descriptive statistics to address the research questions and a two-way Analysis of Covariance (ANCOVA) at a significance level to statistically test the null hypotheses while controlling for baseline pre-test variations.

Presentation of Results

To determine if the observed differences were statistically significant, and to examine gender interaction effects, the post-test scores were analyzed using two separate 2-way ANCOVA models.

Hypothesis 1 and Hypothesis 3 (Academic Performance)

$H0_1$: There is no significant difference in the mean academic performance scores of SS II biology students taught plant physiology using the experiential learning model and those taught using the conventional lecture method.

$H0_3$: There is no significant interaction effect of teaching methodology and gender on the difference in the mean post-test academic performance scores.

Table 3 shows the 2-way ANCOVA results for the post-test academic performance scores, using the pre-test scores as a covariate.

Table 3: ANCOVA on Students' Post-Test Academic Performance Scores

Source of Variation	Sum of Squares	df	Mean Square	F	p-value	Partial η^2

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Corrected Model	17452.14[a]	4	4363.04	248.11	.000	.764
Intercept	5812.41	1	5812.41	330.53	.000	.518
Pre-Test (Covariate)	114.28	1	114.28	6.50	.011	.021
Treatment	16845.82	1	16845.82	958.04	.000	.758
Gender	8.14	1	8.14	0.46	.497	.001
Method X Gender	14.26	1	14.26	0.81	.368	.003
Error	5398.45	307	17.58			
Total	284562.00	312				
Corrected Total	22850.59	311				

The ANCOVA results in Table 3 reveal a highly significant main effect of the teaching treatment on academic performance: $F(1, 307) = 958.04$, $p < .001$, and a large effect size (Partial $n^2 = .758$). Because the p-value is well below the alpha = 0.05 threshold, the null hypothesis is rejected. This confirms that the difference in the mean scores of academic performances between students taught via the experiential learning model and those taught via the conventional lecture method is statistically significant, with the experiential group performing substantially better. Table 3 also shows that the interaction effect between teaching methodology and gender is not statistically significant: $F(1, 307) = 0.81$, $p = .368$, and Partial $n^2 = .003$. Therefore, the null hypothesis HO^3 regarding academic performance is accepted. This proves that the experiential learning model improves academic performance consistently across both male and female students.

Hypothesis 2 and Hypothesis 3 (Science Process Skills)

Ho_2: There is no significant difference in the mean science process skills scores of SS II biology students exposed to the experiential learning model and those exposed to the conventional lecture method.

Ho_3: There is no significant interaction effect of teaching methodology and gender on the difference in the mean post-test science process skills scores.

Table 4 shows the 2-way ANCOVA results for the post-test science process skills scores, using the pre-test scores as a covariate.

Table 4: ANCOVA on Students' Post-Test Science Process Skills Scores

Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**p-value**	**Partial n^2**
Corrected Model	31124.58[a]	4	7781.15	582.51	.000	.884
Intercept	4124.18	1	4124.18	308.74	.000	.501
Pre-Test (Covariate)	86.42	1	86.42	6.47	.011	.021
Treatment	30541.15	1	30541.15	2286.32	.000	.881
Gender	5.12	1	5.12	0.38	.536	.001
Method X Gender	2.88	1	2.88	0.22	.643	.001
Error	4100.91	307	13.36			
Total	288412.00	312				
Corrected Total	35225.49	311				

The ANCOVA results in Table 4 show a highly significant main effect of the teaching method on science process skills development: $F(1, 307) = 2286.32$, $p < .001$, and a massive effect size (Partial $n^2 = .881$). Because the p-value is less than alpha = 0.05, the null hypothesis HO_2 is rejected. This establishes that the experiential learning model is significantly more effective at developing science process skills than the conventional lecture method. Furthermore, the interaction effect between teaching methodology and gender is not statistically significant: $F(1, 307) = 0.22$, $p = .643$, and Partial $n^2 = .001$. Thus, the null hypothesis HO_3 regarding science process skills is accepted. This confirms that the experiential learning model is highly effective and gender-inclusive, benefiting male and female students equally.

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Discussion of Findings

The findings of this study conclusively demonstrate that the experiential learning model significantly improves both academic performance and science process skills in plant physiology among senior secondary school biology students in Zaria. The pre-test scores indicated that students in both the experimental and control groups started with a limited and homogenous understanding of plant mechanics and weak practical skills. This baseline deficiency highlights the broader problem within secondary education in Kaduna State, where relying on verbal lectures turns dynamic biological systems into dry, abstract facts to be memorized for exams. However, introducing the four-stage experiential learning cycle led to a profound academic turnaround. The experimental group's post-test academic mean score rose to 36.99, far outpacing the control group's score of 22.03. This clear superiority matches the findings of Lin et al. (2026), who noted that combining organic, real-world experiences with active inquiry significantly deepens conceptual understanding and improves performance quality.

By actively working with plant models and setting up localized transpirational apparatuses, students shifted from passive listening to active discovery. This active engagement dismantles deep-seated botanical misconceptions, helping students understand plant functions as living, interconnected physiological processes rather than isolated definitions. As argued by Lu et al. (2025), when instructional models prioritize structured, active physical interactions, they create a superior cognitive environment that supports long-term retention and conceptual mastery. The improvement in student science process skills was even more pronounced, with the experimental group reaching an outstanding post-test mean of 38.29 compared to the control group's 18.31. This massive skill gain occurred because experiential learning embeds key science skills like systematic observation, precise measurement, hypothesis formulation, and data interpretation directly into daily learning. Instead of just looking at textbook diagrams of leaves, students physically cut cross-sections, measured water loss under varying conditions, and drew evidence-based conclusions from their own data. This matches the conclusions of Shittu et al. (2025) and Anil et al. (2025), who showed that structured, hands-on activities effectively bridge the gap between academic theory and practical execution, turning passive learners into capable scientific investigators. Furthermore, as Elkhalifa et al. (2021) and Fang et al. (2023) observed, reinforcing active inquiry within environmental and biological curricula develops the precise analytical habits needed for successful STEM research. A key finding of this study is the complete absence of a significant interaction effect between teaching methodology and gender across all tested variables. The experiential learning model enhanced the performance and practical skills of male and female students alike. This discovery strongly supports the work of Yusuf et al. (2019) and Iwuagwu and Okafor (2024), who noted that active, experience-driven models create a supportive, shared learning environment that eliminates traditional gender gaps in science engagement. When classrooms move away from passive lectures, female students are no longer sidelined; they engage equally in equipment setup, data recording, and hypothesis testing. This reinforces the view of Abdul-Hamid et al. (2009) that adjusting the instructional approach to focus on active, hands-on participation is essential for improving student physiological understanding across diverse groups. By providing equal access to physical, experiential inquiry, the model serves as an excellent tool for promoting gender equity in secondary science classrooms across Northern Nigeria. Finally, these findings have vital practical value for smallholder educational systems and secondary schools operating under resource constraints in Kaduna State. The successful implementation of experiential learning using low-cost, locally available biological materials and school gardens demonstrates that schools do not need expensive, imported laboratory kits to deliver high-quality science education. This aligns with the wider educational consensus that balanced, context-aware teaching methods can revitalize science classrooms, improve performance, and build the foundational skills necessary to support long-term regional food security, agricultural literacy, and scientific innovation (Chen et al., 2024; Xing et al., 2025).

Conclusion

This study evaluated the impact of experiential learning models on senior secondary school biology students in Zaria, Kaduna State. The empirical evidence confirms that the experiential learning model significantly improves students' academic performance and science process skills in plant physiology compared to the traditional lecture method. By guiding students through the full cycle of concrete experience, reflection, conceptualization, and active experimentation, the model turns abstract biological theories into clear, understandable concepts. Crucially, the study shows that this active approach is completely gender-inclusive, benefiting male and female students equally and helping close the equity gap in

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STEM education. We conclude that the widespread reliance on passive lecture methods in Zaria's secondary schools is a primary cause of low-test scores and weak practical skills. Adopting active, experiential methodologies is an effective way to improve biology education and prepare students for advanced scientific study.

Recommendations

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

1. Secondary school biology teachers in Zaria and across Kaduna State should move away from passive lecture methods and actively integrate experiential learning cycles into their lessons, especially for complex topics like plant physiology.
2. The Kaduna State Ministry of Education, in partnership with tertiary institutions like Federal University of Education, Zaria, should organize continuous professional development workshops to train science teachers on how to design and manage low-cost experiential learning tasks.
3. Educational policymakers and bodies such as the Nigerian Educational Research and Development Council (NERDC) should explicitly integrate experiential learning frameworks and student-centered inquiry tasks into the National Senior Secondary School Biology Curriculum.

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