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Zamfara International Journal of Science Technology Education and Mathematics (ZIJTEM) is the official Journal of the Department of Science Education, Faculty of Education Federal University Gusau Zamfara State, Nigeria. The Journal publishes articles of diverse fields of interest in Sciences, Technology, Education and Mathematics. Papers reporting original research and extended version of already established conference and journal articles are welcomed. Papers for publication are selected through peer review process to ensure originality, relevance and readability. ZIJSTEM is published quarterly which spans throughout the year i.e. March, June, September and December, respectively.

The aim and scope of the journal is to provide an academic medium and an important reference for the advancement and dissemination of information that supports high level learning, teaching and research in the fields of Sciences, Technology, Education and Mathematics.

The articles in this volume are academic and professional discourse written by reputable scholars in their area of specialization.

Professor Bashir Suleiman
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FORWARD

On Behalf of the staff and students of the Department of Science Education, Federal University Gusau, Zamfara state, Nigeria, we humbly acknowledge and thank Allah (S.W.T) the most beneficent, the most merciful for without his will, collection and computation of this journal publication would not have been possible. May all praise be ascribed unto Him. The department is sincerely grateful to its accommodating mentor Prof. Tukur Adamu, Vice Chancellor, Federal University, Gusau and his management team for giving the department enabling environment for academic activities. The department's profound gratitude goes to Dr. Umar Sodangi who doubled as the Dean, Faculty of Education, Federal University, Gusau and Associate Editor of Zamfara International Journal of Science, Technology, Education and Mathematics (ZIJSTEM). Furthermore, Special gratitude goes to our contract and visiting Professors, the staff and students of the Department of Science Education, Federal University, Gusau, for their supports and foresight towards actualizing the dream of the department.

The Zamfara International Journal of Science, Technology, Education and Mathematics (ZIJSTEM) is a brain child of Department of Science Education with the aim of bringing science and technology education into global and well recognized journals of science and technology education research. This is first of its kind, among Science Education Departmental Journals in Northwest, Nigeria and by extension one of the highly placed departmental journals in Nigeria, considering its online visibility and originality, based on well-known global best practices.

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The Zamfara International Journal of Science, Technology, Education and Mathematics (ZIJSTEM) calls for scholarly articles for review and possible publication in its next edition (Volume 3, Number 3, September, 2026), ZIJSTEM publishes articles that emphasizes on research development and application within the field of Sciences, Technology, Education and Mathematics. All manuscripts are reviewed by editorial review committee. Contributions must be original, not previously or simultaneously published elsewhere, and are critically reviewed before they are published. Papers, which must be written in English language, should have good grammar and proper terminologies.

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DOI: https://doi.org/10.64348/zije.2026450

TABLE OF CONTENTS

S/N	Authors, Paper Title and DOI Index	Pages
1	**WADA, Bitrus Zira (2026):** Determinants of Youths Unemployment: A Cross-Country Econometric Analysis of Skills Mismatch, Technical and Vocational Education and Training (TVET), and Industrial Development https://doi.org/10.64348/zije.2026417	**1-13**
2	**PIUS, Williams Wuam., AZI, Bulus Musa., MOHAMMED, Nasiru & USENDE, Mbaveren Regina (2026):** Geography Education: An Indispensable Tool for Mitigating the Impact of Human-Induced Activities on The Environment for Sustainable Development in Nigeria https://doi.org/10.64348/zije.2026418	**14-21**
3	**ATTO, Tanko Jolly (2026):** Effects of Cross-Age Peer-Tutoring Strategy on Academic Performance in Genetics Concepts among Upper Basic Science Students in Zaria, Kaduna State, Nigeria https://doi.org/10.64348/zije.2026419	**22-27**
4	**MUHAMMAD, Bala Maradun & NA ALLAH, Nasiru (2026):** Polynomial Regression Analysis: Testing for Curvilinear Effects of Internal Supervision Practices and Teachers' Effectiveness on Teaching Quality https://doi.org/10.64348/zije.2026420	**28-39**
5	**MUHAMMAD, Umar Musa., DAJAL, Robert G. & AKUSO, Simon (2026):** Effects of Guided Discovery Teaching Strategy on Achievement and Retention in Concept Energy among Upper Basic Students in Abaji Area Council, Abuja, Nigeria https://doi.org/10.64348/zije.2026421	**40-49**
6	**ABDULRAHMAN, Abdulgafar, O., ARINDE, Odunayo O., ABDULKADIR, Akeem A. & GARUBA, Ismaila A. (2026):** Assessment of Pre-Service Science Teachers' Knowledge of In-Vitro-Fertilization and Surrogacy for Teaching Human Reproduction among Colleges of Educations in Kwara State, Nigeria https://doi.org/10.64348/zije.2026422	**50-60**
7	**OWOADE, Ayoade Akeem & EGUNJOBI, Kolawole Abiodun (2026):** Effect of Artificial Intelligence Usage on Learning Outcome among Undergraduate Computer Science Students of Tai Solarin Federal University of Education, Ijagun, Ogun State, Nigeria https://doi.org/10.64348/zije.2026423	**61-76**
8	**MEKONG, Caleb., OKORONKA, Augustine Ugwumba & FWANGLE, Ishaya Istifanus (2026):** Effect of Context-Based Learning Strategy on Academic Performance in Chemistry Concepts among Secondary School Students in Taraba State, Nigeria https://doi.org/10.64348/zije.2026424	**77-86**
9	**ONWUNALI, Martin Royal Okechukwu., LADAN, Shamsudeen & MUHAMMAD, Hashiru Bello (2026):** Comparative Assessment of Challenges and Improvement Strategies in Agricultural Science Teaching Between Public Schools in Sabon Gari and Zaria LGAs of Kaduna State, Nigeria https://doi.org/10.64348/zije.2026425	**87-100**
10	**ANKELI, Gabriel Odeh (2026):** Influence of Science and Technology Education Research-Driven Economy on the Implementation of	**101-109**

Zamfara International Journal of Sci. Tech. Educ. & Mathematics
The Official Journal of the Department of Science Education
Federal University Gusau, Zamfara State, Nigeria
Volume 3, Number 2, June, 2026
ISSN: 2251 – 0974

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DOI: https://doi.org/10.64348/zije.2026450

	Renewed Hope Agenda of the Federal Government of Nigeria https://doi.org/10.64348/zije.2026426	
11	**MUSA, Asmau., ABDULLAHI, Mohammed., BAWA, Swafiyah., MADU, Peter Chijioke., IDIRISU, Jibril Limangba., EKUNKE, Unyime-Abasi Raphael., SHEHU, Mohammed & ABDULMALIK, Mohammed Katun (2026):** Correlation Between Pedagogical Content Knowledge and Attitudes towards Inquiry-Based Learning on Science Teaching Effectiveness among Pre-service Teachers in Niger State, Nigeria https://doi.org/10.64348/zije.2026427	**110-119**
12	**MUHAMMAD, Bala Maradun & NA ALLAH, Nasiru (2026):** A Multi-Index Reliability Examination of the ISPTEQ Instrument among Private Secondary School Teachers in Gusau, Zamfara State, Nigeria https://doi.org/10.64348/zije.2026428	**120-133**
13	**BABA, Ado Mohammed., ABDULKAREEM, Ummul-Khair Yahaya & MUSA, Gali (2026):** Physics Education as a Catalyst for Sustainable Development in Nigeria: Roles, Challenges and Future Directions https://doi.org/10.64348/zije.2026429	**134-144**
14	**SADOH, Faith., SHUAIBU, Garba & ILIYASU, Hauwa'u (2026):** Effect of Main-Idea-Web Teaching Strategy on Achievement in Nutrient-Cycling in Nature and Pollution Concepts among Secondary School Biology Students in Kano State, Nigeria https://doi.org/10.64348/zije.2026430	**144-153**
15	**KINGSLEY, Joy Ibekwe., SANI, Mohammed Usman & NDAHI, Pindar Piduku (2026):** Impact of Coaches' Management of Stress on Athletes Performance During the Nigerian Polytechnic Games Association Competitions in North-West, Nigeria https://doi.org/10.64348/zije.2026431	**153-164**
16	**EZEAGHASI, Ngozi Eucharia., OMONIWA, Oluwatope Olubunmi & BODEWA, Sulaiman Ahmad (2026):** Assessment of Students' Knowledge and Practices of Microbial Water Contamination in Federal University of Education, Zaria https://doi.org/10.64348/zije.2026432	**165-174**
17	**AGBAYEWA, Solomon., ISMAILA, Ubale Alhaji & MOHAMMED, Aliyu (2026):** Assessment of Sexual Performance-Enhancing Drugs Utilisation among Married Men in Kaduna State, Nigeria https://doi.org/10.64348/zije.2026433	**175-184**
18	**EGUAGIE, Osagie (2026):** Influence of Lecturers' Perception, Attitude and Awareness on Application of 21st-Century Skills on Students' Civic Competence among Public Universities in South-South, Nigeria https://doi.org/10.64348/zije.2026434	**185-193**
19	**ABIMBOLA, Ahmatullahi Folakemi (2026):** Sustaining STEM Education in Conflict-Affected Region in Nigeria: Adaptive Strategies for Teaching and Learning in Insecure Environments https://doi.org/10.64348/zije.2026435	**194-203**
20	**IDIRISU, Jibril Limangba., USMAN, Abdullahi Muhammed., BAWA, Swafiyah., YAHAYA, Ibrahim Alfa & MAGAJI, Buhari (2026):** Correlation between Green Chemistry Awareness, Entrepreneurial Skills and Sustainability Literacy on Innovation	**204-213**

Zamfara International Journal of Sci. Tech. Educ. & Mathematics
The Official Journal of the Department of Science Education
Federal University Gusau, Zamfara State, Nigeria
Volume 3, Number 2, June, 2026
ISSN: 2251 – 0974

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DOI: https://doi.org/10.64348/zije.2026450

	Intention among Colleges of Education Pre-Service Teachers in Niger State, Nigeria https://doi.org/10.64348/zije.2026436	
21	**USMAN, Umar., MUSA, Yakubu., MUHAMMAD, Bala Maradun & BELLO, Abdulkareem (2026):** Probabilistic Pipeline Reliability Assessment Using Exponentiated-Exponentiated Distributions Integrated with Hybrid Neural Networks: Evidence from Nigeria https://doi.org/10.64348/zije.2026437	**214-227**
22	**AKANBI, Bello Muhammad., ATUMOSHI, Adamu Yusuf., ISHOLA, Olabisi Bolarinwa & AKANBI, Aisha Olamide (2026):** Leveraging Deep Learning on Anomaly Detection in National Identity Number (NIN) Verification for National Identity Management Commission (NIMC), Nigeria https://doi.org/10.64348/zije.2026438	**228-244**
23	**OGUNDEJI, Oluwatomisin Marvellous., MARKUS, Freedom & ABDULGANIYU, Abdulkadir (2026):** Secondary School Students' Perception of Physics Classroom Learning Environment in the Context of Insecurity Challenges in Gusau, Zamfara State, Nigeria https://doi.org/10.64348/zije.2026439	**245-253**
24	**ADEYEMI, Timothy Olalekan., FASINA, Joke Elizabeth., ADEFUYE, Adetayo Linus & SIMISAYE, Ahmed Olakunle (2026):** Institutional and Demographic Influences on the Use of Online Teaching Platforms among University Lecturers in South-West, Nigerian https://doi.org/10.64348/zije.2026440	**254-262**
25	**ONOMATA, Oghenero David., KPANGBAN, Emperor & IRORITERAYE-ADJEKPOVU, JANICE, Imizuokena (2026):** Evaluation on the Implementation of Physics Curriculum among Senior Secondary School Teachers in Bayelsa State, Nigeria https://doi.org/10.64348/zije.2026441	**263-271**
26	**MUSA, Yakubu., MUHAMMAD, Bala Maradun., USMAN, Umar & BELLO, Abdulkareem (2026):** Uncertainty-Aware Training and Computational Scaling for Hybrid Neural Pipeline Models: Heteroscedastic Loss Functions, Mixed Precision, and Multi-GPU Optimisation https://doi.org/10.64348/zije.2026442	**272-286**
27	**AWOLUSI, Bayo Ezekiel., MUHAMMED, K. U. & ANAS, Ibrahim (2026):** Influence of Demographic Characteristics on Digital Literacy and Microsoft Teams Application among Computer Science Lecturers in Federal Tertiary Institutions in Kaduna State, Nigeria https://doi.org/10.64348/zije.2026443	**287-297**
28	**OGUNDEJI, Oluwatomisin Marvellous & OKOYE, Nestor Ekemezie (2026):** Physics Teachers and Students Level of Awareness on Energy and Society Concepts in Nigeria Secondary Schools: Implication for Energy Efficiency and Environmental Sustainability https://doi.org/10.64348/zije.2026444	**298-304**
29	**OKHAWERE, Paulson Young Ofenimu (2026):** Physics Teachers and Students Level of Awareness on Energy and Society Concepts in Nigeria Secondary Schools: Implication for Energy Efficiency and Environmental Sustainability https://doi.org/10.64348/zije.2026445	**305-315**

Zamfara International Journal of Sci. Tech. Educ. & Mathematics
The Official Journal of the Department of Science Education
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Volume 3, Number 2, June, 2026
ISSN: 2251 – 0974

www.foefugusau.com.ng
des@fugusau.edu.ng
DOI: https://doi.org/10.64348/zije.2026450

30	**AGBO, Mbang Eta., BASHIR, Suleiman & NUHU, Ishaq Lawal (2026):** Effects of Scaffolding using 70:20:10 Model on Performance and Retention in Genetics Concept among Secondary School Biology Students in Zamfara State, Nigeria https://doi.org/10.64348/zije.2026446	**316-329**
31	**GBADEBO, Adegbuyi David., AIYEGBUSI, Akinyemi Edward., ABIMBOLA, Olayemi Grace., OPEISA, Olalekan Zaccheaus & AKINTUNDE, Grace Itunuoluwa (2026):** Qualitative Study on an Improved Fuzzy-Based Service Rates' Control System for Single Server Queue Networks with Vacations: A Review https://doi.org/10.64348/zije.2026447	**330-341**
32	**KARIMU, Adekemi Yewande., Xin Lu., NICKY, Danino & BEN, Morris (2026):** Assessment of Artificial Intelligence Adoption among Lecturers in Nigerian Universities: Examining Capability, Opportunity and Motivation – Behavioural (COM-B) Framework https://doi.org/10.64348/zije.2026448	**342-354**
33	**ABDULRAHEEM, Fatai (2026):** Assessment of Students Attitudes towards Learning of Technical and Vocational Education Subjects among Technical Colleges in Niger State, Nigeria https://doi.org/10.64348/zije.2026449	**355-362**

Zamfara International Journal of Sci. Tech. Educ. & Mathematics
The Official Journal of the Department of Science Education
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Determinants of Youths Unemployment: A Cross-Country Econometric Analysis of Skills Mismatch, Technical and Vocational Education and Training (TVET), and Industrial Development

WADA, Bitrus Zira
wadazy48@gmail.com, zwada@noun.edu.ng
National Open University of Nigeria, Wukari Study Centre, Taraba State.

Abstract

This study investigates the determinants of youth unemployment using a cross-country panel analysis of 40 countries across Africa, Europe, the Americas, and Asia from 2019 to 2025. Despite rising educational attainment, youth unemployment remains persistently high, reflecting structural imbalances between labour supply and demand. Drawing on Human Capital Theory, job search and matching theory, and structuralist perspectives, the study examines the roles of skills mismatch, Technical and Vocational Education and Training (TVET), and industrial development. Using a fixed effects regression model with robust standard errors, the findings reveal that skills mismatch is the most significant determinant of youth unemployment, exerting a positive and statistically significant effect. In contrast, TVET enrolment and manufacturing value added are negatively associated with youth unemployment, indicating that stronger vocational systems and industrial capacity improve employment outcomes. The results also reveal regional disparities, with Europe and Asia exhibiting better alignment between skills formation and labour demand, while Africa and parts of the Americas face persistent structural constraints. The study concludes that youth unemployment is a multidimensional challenge requiring coordinated policy responses. Effective interventions must simultaneously address skills mismatch, strengthen vocational training systems, and promote industrial development. Policies that target only one dimension are unlikely to yield sustainable employment outcomes.

Keywords: Youth unemployment, Skills mismatch, TVET, Industrial development

Introduction

Youth unemployment remains one of the most pressing socio-economic challenges globally, particularly in developing and emerging economies. According to the International Labour Organization (ILO, 2023), young people are consistently more likely to be unemployed than adults, reflecting structural inefficiencies in labour markets. A central paradox persists: rising educational attainment has not translated into improved employment outcomes. This disconnect suggests a misalignment between education systems and labour market needs.

Skills mismatch is defined as the discrepancy between workers' competencies and job requirements—has emerged as a key explanatory factor (McGuinness, Pouliakas, & Redmond, 2018). At the same time, the effectiveness of Technical and Vocational Education and Training (TVET) systems varies significantly across countries. While well-developed vocational systems facilitate smoother school-to-work transitions, weak or outdated systems often fail to improve employability (OECD, 2019; UNESCO, 2021). On the demand side, industrial development plays a crucial role. Structural transformation toward manufacturing and high-productivity sectors has historically driven employment creation (Rodrik, 2016). However, many developing economies remain characterized by limited industrial capacity and high informality. Despite rising levels of educational attainment, many countries continue to experience persistent unemployment among young people, indicating a structural disconnect between education systems and labour market demands. This

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paradox has been widely attributed to a combination of skills mismatch, inadequate training systems, and limited industrial capacity.

Skills mismatch, defined as the discrepancy between the skills possessed by workers and those required by employers, has emerged as a central explanation for youth unemployment. Empirical studies show that many graduates lack practical, technical, and soft skills required in modern workplaces, resulting in prolonged job search periods and underemployment (Heriel, 2024). In addition, structural analyses highlight that education systems often produce graduates in fields with limited labour market demand, while sectors such as engineering, manufacturing, and technology experience shortages of skilled workers (Othman, 2025). The role of Technical and Vocational Education and Training (TVET) has therefore gained increasing attention as a mechanism for improving employability. TVET systems are designed to equip individuals with job-specific skills and facilitate smoother transitions into the labour market. However, evidence suggests that in many developing countries, TVET programmes remain outdated and poorly aligned with technological and industrial developments, limiting their effectiveness in reducing unemployment (Chiamogu & Chiamogu, 2025). Beyond skills and training, the structure of the economy—particularly the level of industrial development—plays a critical role in shaping employment outcomes. Industrial sectors, especially, manufacturing, are key sources of job creation and demand for skilled labour. Where industrial capacity is weak, even well-educated individuals may struggle to find employment, highlighting the importance of demand-side constraints in labour markets. Although existing studies often examine these factors in isolation, there is limited cross-country empirical research that integrates skills mismatch, vocational training, and industrial development as joint determinants of youth unemployment. This study addresses this gap by providing a comparative econometric analysis across 40 countries.

Statement of the Problem

Youth unemployment remains persistently high despite increasing levels of education, highlighting a disconnect between education systems and labour market needs. A major contributing factor is skills mismatch, where graduates lack the practical and job-relevant competencies required by employers. In addition, weak and poorly aligned TVET systems in many countries limit the ability of young people to transition effectively into employment. On the demand side, limited industrial development reduces the availability of jobs, even for skilled individuals, as explained by Structural Transformation Theory. Overall, the problem stems from the combined effects of skills mismatch, inadequate training systems, and insufficient job creation, which are often studied separately rather than as interconnected factors influencing youth unemployment.

Objectives of the Study

To examine the key determinants of youth unemployment across countries, with particular focus on the roles of skills mismatch, Technical and Vocational Education and Training (TVET), and industrial development.

Specifically, the study aims to:

(i) Examine how skills mismatch affects youth unemployment
(ii) Assess the impact of TVET enrolment on employment outcomes
(iii) Analyse the role of industrial development in job creation
(iv) Evaluate the combined effect of these factors on youth unemployment
(v) Compare regional differences across countries and
(vi) Provide policy recommendations to reduce youth unemployment

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Research Questions

The study seeks to answer the following research question:

1. What are the key determinants of youth unemployment across countries, and
2. How do skills mismatch, TVET enrolment, and industrial development influence labour market outcomes?

Literature Review

Theoretical Perspectives on Youth Unemployment

The determinants of youth unemployment have been widely examined within labour economics and development literature, with particular emphasis on the interaction between human capital formation, labour market structures, and economic transformation. Human Capital Theory (Becker, 1964) posits that investments in education and training enhance worker productivity and employability. However, this framework assumes an efficient alignment between skills supply and labour market demand—an assumption frequently violated in practice, especially in developing economies. Complementing this perspective, the job search and matching theory highlights frictions in labour markets that delay the matching of workers to suitable jobs (Pissarides, 2000). These frictions are often exacerbated by information asymmetries and skills mismatch, leading to prolonged unemployment spells among youth. The structuralist perspective further emphasizes the role of economic structure in shaping employment outcomes. According to this view, economies with limited industrial capacity are unable to generate sufficient demand for skilled labour, thereby constraining employment opportunities regardless of educational attainment (Rodrik, 2016). This is particularly relevant in many African economies, where structural transformation has been slow and concentrated in low-productivity sectors.

Skills Mismatch and Youth Unemployment

Skills mismatch remains one of the most widely cited determinants of youth unemployment. It refers to the misalignment between the skills workers possess and those required by employers, often manifesting as overqualification or underqualification (Quintini, 2011). Empirical evidence suggests that mismatch reduces job matching efficiency, lowers productivity, and increases unemployment duration (McGuinness et al., 2018). Technological change has further intensified demand for cognitive and digital skills, widening the mismatch gap (World Bank, 2019). Recent studies show that skills mismatch is especially pronounced in developing countries, where education systems are often disconnected from labour market needs (Habiyaremye, Habanabakize & Nwosu, 2023). In such contexts, graduates frequently lack practical and technical competencies, as well as soft skills such as communication and problem-solving. This gap limits their employability and contributes to structural unemployment. Furthermore, global technological change has intensified the demand for higher-order cognitive and digital skills, widening the gap between education outputs and labour market requirements (World Bank, 2019). As a result, even countries with expanding education systems continue to face persistent unemployment challenges.

Technical and Vocational Education and Training (TVET)

Technical and Vocational Education and Training (TVET) has been identified as a critical mechanism for addressing youth unemployment by equipping individuals with job-relevant skills. TVET systems are designed to facilitate school-to-work transitions and reduce mismatch by aligning training with industry needs. TVET improves employability by providing job-specific skills. Countries with strong dual systems (e.g., Germany, Switzerland) exhibit lower youth unemployment (OECD, 2019). However, in many developing countries, TVET systems suffer from outdated curricula, weak private sector involvement and inadequate funding (UNESCO, 2021). Evidence from OECD countries

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indicates that strong vocational systems particularly those incorporating apprenticeship models are associated with lower youth unemployment rates (OECD, 2019). Similarly, studies in emerging economies show that well-designed TVET programmes can improve employment outcomes, particularly when they are demand-driven and integrated with industry participation. However, the effectiveness of TVET varies significantly across countries. In many developing economies, TVET systems suffer from inadequate funding, outdated curricula, and weak institutional linkages with employers (UNESCO, 2020). Consequently, their impact on employment remains limited unless accompanied by broader structural reforms.

Industrial Development and Labour Demand

Industrial development plays a central role in shaping labour demand and employment opportunities. Manufacturing and industrial sectors are particularly important for absorbing labour, especially semi-skilled and technically trained workers. According to Rodrik (2016), industrialization has historically been a key driver of structural transformation and job creation. Industrialization drives job creation by expanding labour demand (Rodrik, 2016). Manufacturing sectors absorb semi-skilled labour and generate spillover effects (UNIDO, 2022). However, without complementary skills, industrial growth may not translate into employment gains. Empirical evidence shows that countries with strong manufacturing sectors tend to exhibit lower unemployment rates, as industrial activities generate both direct and indirect employment opportunities (UNIDO, 2022). In contrast, economies with limited industrial bases often rely on informal and low-productivity sectors, which offer limited employment stability. The interaction between industrial development and skills formation is therefore critical. Without sufficient industrial demand, investments in education and training may not translate into employment gains, highlighting the importance of demand-side factors in labour market outcomes.

Synthesis and Research Gap

While existing literature provides substantial evidence on the individual roles of skills mismatch, TVET, and industrial development, fewer studies integrate these factors within a unified empirical framework, particularly in a cross-country context. Most analyses focus on single-country case studies or specific regions, limiting the generalizability of findings. This study contributes to the literature by providing a comparative econometric analysis across 40 countries, examining how these key factors jointly determine youth unemployment outcomes.

Methodology

Research Design

This study adopts a quantitative, comparative, and econometric research design to examine the determinants of youth unemployment across countries. The analysis combines cross-country comparisons with panel data estimation to capture both structural differences and temporal dynamics.

Data and Sample

The study utilizes secondary data from internationally recognized sources: (i) World Bank World Development Indicators (WDI, 2026); (ii) International Labour Organization (ILOSTAT, 2025) and UNESCO Institute for Statistics (UIS, 2025). The sample consists of 40 countries, with balanced representation across Africa, Europe, the Americas, and Asia, over the period 2019–2025. This yields a balanced panel dataset suitable for econometric analysis.

Variable Specification; Dependent Variable; Youth Unemployment Rate (% ages 15–24); Independent Variables; (i) Skills Mismatch (%) – proxy based on overqualification and

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underqualification rates (ii) TVET Enrolment (%) – share of upper secondary students in vocational programmes (iii) Manufacturing Value Added (% of GDP) – proxy for industrial development

Model Specification

To estimate the determinants of youth unemployment, the study employs a panel regression model: [Y_{it} = \beta_0 + \beta_1 SM_{it} + \beta_2 TVET_{it} + \beta_3 MANF_{it} + \mu_i + \lambda_t + \epsilon_{it}]

Where: (Y_{it}): Youth unemployment rate; (SM_{it}): Skills mismatch; (TVET_{it}): TVET enrolment; (MANF_{it}): Manufacturing output; (\mu_i): Country-specific fixed effects; (\lambda_t): Time effects; (\epsilon_{it}): Error term

Estimation Technique

A Fixed Effects (FE) estimator is employed to control for unobserved heterogeneity across countries, such as institutional differences and structural characteristics. The choice of fixed effects is justified as it accounts for time-invariant country-specific factors that may influence unemployment outcomes. Robust standard errors are used to address potential heteroskedasticity and serial correlation. Model diagnostics, including R-squared and F-statistics, are reported to assess goodness-of-fit and overall significance.

Endogeneity Consideration

Potential endogeneity arises due to reverse causality (e.g., unemployment affecting education choices). To mitigate this: (i) Lagged regressors are used and (ii) Results interpreted as associations, not strict causality

Limitations

While the study provides robust cross-country evidence, certain limitations should be acknowledged:

1. Measurement challenges associated with skills mismatch proxies
2. Potential endogeneity between education, industrial development, and employment outcomes
3. Limited availability of consistent data across all countries

These limitations suggest caution in interpreting causal relationships, although the findings provide strong empirical associations.

Data Presentation

Table 1: Africa Youth Unemployment, Skills Mismatch, TVET and Industrial Output (2025)

Country	Youth Unemployment (%)	Skill Mismatch (%)	TVET Enrolment (%)	Manufacturing (GDP %)
Nigeria	6.5	35	8	12.0
Ghana	12.0	32	10	11.5
Kenya	13.5	30	10	9.0
South Africa	28.0	45	12	13.0
Egypt	19.0	34	15	16.0
Morocco	22.5	38	14.	15.0
Ethiopia	8.0	33	7	8.5
Rwanda	10.2	28	9	9.5
Senegal	15.3	31	8	10.2
Tanzania	9.8	29	6	9.0

Source: *World Bank, (2026), ILOSTAT, UNESCO UIS (2025)*

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Table 1 shows that African countries are characterized by relatively high levels of skills mismatch, low TVET enrolment, and modest industrial output, with notable variation across countries. Skills mismatch remains consistently high across the region, ranging from 28% in Rwanda to 45% in South Africa. At the same time, TVET enrolment is generally low, with most countries recording rates below 10%, except Egypt (15%) and Morocco (14%). This indicates a limited emphasis on vocational and technical training systems. Youth unemployment varies across countries but does not always correspond directly with mismatch levels. For example, Nigeria records a relatively low unemployment rate (6.5%) despite a high mismatch level (35%), suggesting that many young people may be engaged in informal or low-productivity employment rather than being fully unemployed. In contrast, South Africa combines both high unemployment (28%) and high mismatch (45%), indicating more severe labour market dysfunction. Manufacturing output also remains modest across the region, generally below 16% of GDP. Countries with relatively higher industrial output, such as Egypt (16%) and Morocco (15%), tend to have slightly better labour market outcomes compared to others, though mismatch remains high. Overall, Table 1 indicates that weak vocational systems and limited industrial capacity coexist with high skills mismatch, contributing to inefficient labour market outcomes in Africa.

Table 2: Europe – Youth Unemployment, Skills Mismatch, TVET and Industrial Output (2025)

Country	Youth Unemployment (%)	Skills Mismatch (%)	TVET Enrolment (%)	Manufacturing (% GDP)
Germany	5.8	15	50	19.5
France	17.0	20	45	14.0
United Kingdom	11.5	18	35	10.0
Sweden	22.0	22	48	18.0
Netherlands	8.5	14	60	17.5
Italy	23.5	25	30	15.0
Spain	28.0	27	35	14.5
Poland	10.2	16	40	18.5
Switzerland	7.0	13	65	19.0
Norway	9.5	17	45	12.0

Source: *World Bank, (2026), ILOSTAT, UNESCO, (2025)*

Table 2 reveals that European countries generally exhibit low skills mismatch, high TVET enrolment, and strong industrial output, alongside relatively favourable labour market outcomes. Skills mismatch levels are significantly lower than in Africa, ranging from 13% in Switzerland to 27% in Spain. TVET enrolment is substantially higher, with several countries exceeding 50%, including Switzerland (65%), the Netherlands (60%), and Germany (50%). This suggests well-developed vocational education systems. Youth unemployment is relatively low in countries with high TVET participation and low mismatch. For instance, Germany (5.8%), the Netherlands (8.5%), and Switzerland (7.0%) demonstrate strong labour market performance. In contrast, countries such as Spain (28.0%) and Italy (23.5%) record higher unemployment rates, accompanied by higher mismatch and lower TVET enrolment.

Manufacturing output is also relatively strong across Europe, with several countries exceeding 17% of GDP. Countries with stronger industrial sectors tend to exhibit better employment outcomes,

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indicating a positive association between industrial activity and job creation. In summary, Table 2 suggests that higher TVET enrolment and stronger industrial bases are associated with lower skills mismatch and improved employment outcomes in Europe.

Table 3: Americas – Youth Unemployment, Skills Mismatch, TVET and Industrial Output (2025)

Country	Youth Unemployment (%)	Skills Mismatch (%)	TVET Enrolment (%)	Manufacturing (% GDP)
United States	8.0	20	20	16.0
Canada	11.2	19	25	15.5
Brazil	18.5	30	18	14.0
Mexico	7.5	28	20	17.0
Argentina	19.0	32	22	13.0
Chile	16.5	25	30	11.5
Colombia	20.0	29	25	12.5
Peru	14.0	27	20	13.5
Costa Rica	22.0	26	28	13.0
Uruguay	17.0	24	35	12.0

Source: *World Bank, (2026), ILOSTAT, UNESCO, (2025)*

Table 3 presents a mixed pattern of labour market outcomes and skills indicators across countries in the Americas. Skills mismatch ranges from 19% in Canada to 32% in Argentina, indicating moderate to high levels across the region. TVET enrolment is generally moderate, falling between 18% and 35%, which is higher than Africa but lower than Europe. Youth unemployment varies considerably. Countries such as the United States (8.0%) and Mexico (7.5%) show relatively low unemployment despite moderate mismatch levels, while others such as Colombia (20.0%), Costa Rica (22.0%), and Argentina (19.0%) experience higher unemployment rates alongside higher mismatch. Manufacturing output is relatively stable across the region, typically between 12% and 17% of GDP. However, higher industrial output does not always translate into lower unemployment, suggesting variations in the ability of industries to absorb labour effectively. Overall, Table 3 indicates that moderate TVET systems and industrial capacity coexist with persistent skills mismatch, resulting in uneven labour market outcomes across the Americas.

Table 4: Asia – Youth Unemployment, Skills Mismatch, TVET and Industrial Output (2025)

Country	Youth Unemployment (%)	Skills Mismatch (%)	TVET Enrolment (%)	Manufacturing (% GDP)
China	5.0	20	45	27.0
India	17.8	35	25	17.0
Japan	4.5	12	50	21.0
South Korea	6.8	14	55	25.0
Singapore	9.2	12	60	20.8
Malaysia	11.0	18	40	23.0
Indonesia	13.5	28	30	20.0
Thailand	5.5	22	35	27.5
Philippines	14.5	30	28	19.0

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Country	Youth Unemployment (%)	Skills Mismatch (%)	TVET Enrolment (%)	Manufacturing (% GDP)
Vietnam	7.5	24	38	25.5

Source: *World Bank, (2026), ILOSTAT, UNESCO, (2025)*

Table 4 shows that Asian countries generally demonstrate stronger alignment between skills development, industrial output, and labour market outcomes. Skills mismatch is relatively low in several countries, particularly Japan (12%), South Korea (14%), and Singapore (12%), while slightly higher levels are observed in India (35%) and the Philippines (30%). TVET enrolment is comparatively high, with countries such as Singapore (60%), South Korea (55%), and Japan (50%) leading the region. Youth unemployment is generally low in countries with lower mismatch and higher TVET participation, such as Japan (4.5%), China (5.0%), and Thailand (5.5%). In contrast, countries with higher mismatch levels, such as India and the Philippines, also record higher unemployment. Manufacturing output is notably strong across Asia, with several countries exceeding 20% of GDP, including China (27%), Thailand (27.5%), and Vietnam (25.5%). Countries with higher industrial output tend to exhibit better employment outcomes, indicating a strong link between industrial development and job creation. In summary, Table 4 suggests that higher TVET enrolment and strong industrial sectors are associated with lower skills mismatch and improved labour market performance in Asia

Table 5: Determinants of Youth Unemployment – Fixed Effects Panel Regression (2019–2025)

Variable	Coefficient (β)	Robust Std. Error	t-Statistic	p-Value	Significance
Skills Mismatch (%) (SM)	0.185	0.042	4.40	0.000	***
TVET Enrolment (%) (TVET)	−0.072	0.018	−4.00	0.000	***
Manufacturing (% GDP) (MANF)	−0.054	0.025	−2.16	0.032	**
Constant	8.912	2.120	4.20	0.000	***

Model Diagnostics:

(i) Observations: 280 (40 countries × 7 years)
(ii) R-squared (within): 0.72
(iii) F-statistic: 34.5 ($p < 0.01$)
(iv) Fixed effects: Country and year
(v) Robust standard errors clustered by country

Significance codes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Interpretation of Results:

1. **Skills Mismatch (β = 0.185, p < 0.01):**
   The positive and highly significant coefficient indicates that an increase in skills mismatch is associated with higher youth unemployment. Specifically, a 1 percentage point increase in skills mismatch corresponds to a 0.185 percentage point increase in youth unemployment, holding other factors constant. This highlights the critical role of aligning educational outcomes with labour market demands. Countries with higher overqualification or underqualification rates tend to experience more pronounced youth unemployment.

2. **TVET Enrolment (β = −0.072, p < 0.01):**
   TVET enrolment is negatively associated with youth unemployment, meaning that higher participation in vocational and technical education reduces unemployment among youth. A 1

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percentage point increase in TVET enrolment corresponds to a 0.072 percentage point decrease in youth unemployment. This result underscores the effectiveness of well-developed vocational systems in equipping young people with employable skills.

3. **Manufacturing Output (β = −0.054, p < 0.05):**
   Industrial development, proxied by manufacturing value added, also exerts a negative effect on youth unemployment. A 1 percentage point increase in manufacturing output reduces youth unemployment by 0.054 percentage points. While smaller than the effects of skills mismatch and TVET, this finding confirms the role of a robust industrial base in creating employment opportunities for youth.

4. **Model Fit and Robustness:**
   The within R-squared of 0.72 indicates that the model explains a substantial proportion of the variation in youth unemployment across countries and over time. The inclusion of country and year fixed effects controls for unobserved heterogeneity and temporal shocks, ensuring that the estimated coefficients capture meaningful cross-country and time-varying associations.

Policy Implications:

The regression results suggest that tackling youth unemployment requires a dual approach:

(i) Reducing skills mismatch through better alignment of education with labour market needs and
(ii) strengthening both vocational training and industrial capacity to absorb young labour. Policies that focus solely on one dimension, such as industrial expansion without improving skills, are unlikely to yield optimal employment outcomes.

Discussion of Findings

The findings of this study provide strong empirical support for, and in some cases extend, the arguments advanced in the reviewed literature. By integrating skills mismatch, Technical and Vocational Education and Training (TVET), and industrial development within a unified cross-country econometric framework, the results offer a more comprehensive understanding of youth unemployment as a multidimensional phenomenon shaped by both supply-side and demand-side factors.

Skills Mismatch as the Dominant Determinant: Confirmation of Existing Literature

The study finds that skills mismatch has a positive and statistically significant effect on youth unemployment (β = 0.185, p < 0.01), making it the most influential determinant among the variables examined. This finding is strongly consistent with prior empirical and theoretical literature. From the perspective of Human Capital Theory, education is expected to enhance productivity and employability. However, the results highlight a critical limitation of this theory: it assumes alignment between acquired skills and labour market needs. The significant positive relationship between mismatch and unemployment confirms that education alone is insufficient when it is not relevant to market demand. This directly supports the arguments of McGuinness et al. (2018) and Quintini (2011), who emphasize that mismatch reduces job matching efficiency and increases unemployment duration.

Similarly, the findings align with Job Search and Matching Theory, which emphasizes labour market frictions. High mismatch increases search costs and delays successful job matches, thereby prolonging unemployment spells among youth. The strong statistical significance observed in the model suggests that mismatch is not merely a secondary issue but a central structural constraint in labour markets. The regional evidence further reinforces this conclusion. African countries,

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characterized by high mismatch levels (often above 30%), also exhibit weaker labour market outcomes, while European and Asian countries with lower mismatch levels demonstrate better employment performance. This supports the findings of Habiyaremye et al. (2023) and the World Bank (2019), which identify mismatch as particularly severe in developing economies due to weak linkages between education systems and industry. However, the study also extends the literature by revealing that mismatch operates differently across contexts. For example, Nigeria exhibits relatively low measured unemployment despite high mismatch, suggesting that mismatch may lead to informal employment rather than open unemployment. This nuance adds depth to existing literature by highlighting the role of labour market structure—particularly informality—in mediating the effects of mismatch.

TVET as a Critical Mechanism for Reducing Unemployment

The negative and highly significant relationship between TVET enrolment and youth unemployment ($\beta = -0.072$, $p < 0.01$) strongly validates the literature emphasizing the role of vocational education in improving employability.

This finding is consistent with studies by the OECD (2019) and UNESCO (2021), which argue that well-developed TVET systems facilitate smoother school-to-work transitions by providing job-relevant skills. Countries such as Germany, Switzerland, and the Netherlands—characterized by high TVET enrolment (50–65%)—also display low youth unemployment rates, providing empirical support for the dual system model highlighted in the literature. The results also reinforce the idea that TVET helps reduce skills mismatch, thereby indirectly lowering unemployment. This aligns with the theoretical expectation that vocational training bridges the gap between education and labour market demand by focusing on practical and technical competencies. However, the study goes beyond existing literature by demonstrating that the effectiveness of TVET is context-dependent. In Africa and parts of the Americas, where TVET enrolment remains low and systems are often underfunded or outdated, its impact is limited. This supports UNESCO (2020) findings that TVET systems in developing countries suffer from weak institutional frameworks and limited industry collaboration. Moreover, the regression results indicate that while TVET significantly reduces unemployment, its effect is smaller than that of skills mismatch, suggesting that expanding TVET alone is not sufficient. This extends the literature by emphasizing that quality, relevance, and integration with industry matter more than mere enrolment levels.

Industrial Development and Labour Demand: Support for Structuralist Perspectives

The study finds that manufacturing value added has a negative and statistically significant effect on youth unemployment ($\beta = -0.054$, $p < 0.05$), confirming the importance of demand-side factors. This result strongly aligns with the Structural Transformation Theory, which emphasizes that industrialization drives job creation by expanding demand for labour, particularly in manufacturing sectors. The findings support the argument that economies with stronger industrial bases are better able to absorb young workers.

The regional analysis further substantiates this relationship:

i. Asian countries with high manufacturing output (above 20% of GDP) exhibit low unemployment rates
ii. European countries with strong industrial sectors also perform better
iii. African countries with limited industrial capacity face persistent employment challenges

These patterns are consistent with UNIDO (2022), which highlights the role of manufacturing in generating both direct and indirect employment opportunities. However, the study also nuances the literature by showing that industrial development alone is not sufficient. In the Americas, for instance, moderate levels of manufacturing do not always translate into lower unemployment. This

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suggests that the employment elasticity of growth depends on complementary factors such as skills availability and labour market institutions. Thus, the findings extend the structuralist perspective by demonstrating that industrial growth must be accompanied by appropriate skills development to yield meaningful employment outcomes.

Interaction of Determinants: A Multidimensional Framework

One of the most important contributions of this study is its demonstration that youth unemployment is not driven by a single factor but by the interaction of skills mismatch, TVET, and industrial development. The regression results and regional comparisons collectively show that high mismatch, weak TVET and low industrialization result to high unemployment (common in Africa), low mismatch, strong TVET and high industrialization result to low unemployment (common in Europe and Asia), While moderate levels of all factors result to mixed outcomes (Americas). This integrated perspective addresses a key gap identified in the literature, where most studies examine these variables in isolation. The findings confirm that supply-side (skills) and demand-side (jobs) factors are mutually reinforcing. Importantly, the high R-squared value (0.72) indicates that the combined model explains a substantial portion of variation in youth unemployment, validating the multidimensional approach.

Implications for Theory and Empirical Literature

The study makes several important contributions to existing knowledge:

1. Refinement of Human Capital Theory
   The findings challenge the assumption that more education automatically reduces unemployment, emphasizing instead the importance of relevant and demand-driven skills.
2. Extension of Matching Theory
   By quantifying the impact of skills mismatch, the study provides empirical evidence on how labour market frictions translate into macro-level unemployment outcomes.
3. Strengthening Structuralist Arguments
   The results confirm that economic structure matters, but also show that industrialization must be complemented by skill alignment.
4. Bridging Fragmented Literature
   Unlike previous studies, this research integrates multiple determinants within a single econometric framework, offering a of youth unemployment.

Overall Synthesis

In line with the reviewed literature, the study confirms that:

1. Skills mismatch is a primary driver of youth unemployment
2. TVET is an effective mitigation mechanism, though context-dependent
3. Industrial development is a crucial enabler of labour demand

However, the key insight emerging from the findings is that these factors are interdependent. Addressing youth unemployment requires coordinated policies that simultaneously:

1. Align education with labour market needs
2. Strengthen vocational training systems
3. Expand industrial capacity

This reinforces the study's central conclusion: fragmented policy approaches are unlikely to succeed, and only integrated strategies can deliver sustainable improvements in youth employment outcomes.

Conclusion

This study provides robust cross-country evidence that youth unemployment is primarily driven by structural misalignment between skills supply and labour demand. Skills mismatch emerges as the most significant determinant, confirming that the quality and relevance of education are more critical

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than educational attainment alone. TVET systems play a vital role in improving employability by facilitating school-to-work transitions, while industrial development enhances labour absorption capacity. However, the findings demonstrate that these factors are interdependent. Industrial expansion without adequate skills, or education reforms without labour demand, produces limited employment gains. Regional disparities further highlight that countries with strong institutional alignment between education, training, and industry achieve better labour market outcomes. Overall, the study confirms that youth unemployment is a systemic issue requiring integrated and coordinated policy interventions.

Recommendations

1. Reduce Skills Mismatch

i. Align curricula with labour market demand through competency-based and digital skills frameworks
ii. Strengthen labour market information systems to guide education planning
iii. Promote industry participation in curriculum design

2. Strengthen TVET Systems

i. Expand access to demand-driven vocational education

ii. Institutionalize apprenticeship and dual training models

iii. Increase private sector collaboration and funding

3. Promote Industrial Development

i. Support manufacturing and high-productivity sectors

ii. Encourage SME development and industrial clusters

iii. Facilitate technology adoption and value-chain integration

4. Adopt Integrated Policy Frameworks

i. Coordinate education, labour, and industrial policies

ii. Link skills development directly to national development strategies

iii. Monitor outcomes using evidence-based evaluation systems

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Geography Education: An Indispensable Tool for Mitigating the Impact of Human-Induced Activities on The Environment for Sustainable Development in Nigeria

PIUS Williams Wuam[1]
pwilliams6068@gmail.com

AZI Bulus Musa[1]
mbulusazi@gmail.com

MOHAMMED Nasir[1]
nasirmhmmd2@gmail.com

USENDE Mbaveren Regina[2]
mbaverenregina@gmail.com

[1]Department of Geography, Aminu Saleh College of Education, Azare, Bauchi State, Nigeria
[2]Department of Education Foundations, Modibbo Adama University, Yola Adamawa State, Nigeria

Abstract

There is no gainsaying that human-induced activities in no small measure impart negatively on the environment with dare consequences on the lives of individuals and collectively as a community or a nation or even the world at large. It is against this background that this paper focuses on "Geography Education as an Indispensable Tool for Mitigating the Impact of Human-Induced Activities on the Environment for Sustainable Development". To achieve this goal, the paper highlighted the concept of geography education, impact of human-induced activities on the environment and the concept of sustainable development. Also, the consequences of human-induced activities on the environment and geography education as an indispensable tool for mitigating the impact of human-induced activities on the environment for sustainable development were discussed. It was concluded that since geography education is related to sustainability and the fact that geographers understand human-environment relationships and how to use that information to manage environmental related issues, geography education therefore becomes the most relevant school subject that can be used in achieving sustainable development and by extension the United Nations Agenda 2030 for Sustainable Development Goals (SDGs). Amongst others the paper recommended that geography be taught across all levels of our educational system in order to acquaint all citizens with requisite geographical knowledge about the environment.

Key Words: Geography Education, Indispensable Tool, Mitigating, Human-Induced Activities, Environment and Sustainable Development

Introduction

Geography is the study of man and his relationships with the environment. Hence, without geographical knowledge the much desired talked about environmental sustainability cannot be realized. It is a common knowledge that the environment is a place where man co-exists alongside several other lives. However, the interaction between the physical, climatic and abiotic factors on the environment has generated a wide variety of environmental problems on the land leading to dare consequences on man himself and the environment at large. Human activities such as agriculture, deforestation, urbanization etc have over the years posed serious threats such as global warming, pollution, acid rain, ozone layer depletion, resource depletion and biodiversity loss amongst others have affected the environment so much so that there has been a global attention towards the

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phenomenon as encapsulated in the Sustainable Development Goals (SDGs). Geography education provides the platform in which the public and the citizens are educated on variety of environmental issues including mitigating the impact of environmental challenges arising from human-induced activities on the planet earth which are geared towards achieving the Sustainable Development Goals (SDGs). In this wise, geography education plays an important role in enhancing sustainability and improving human capacity in addressing environmental related issues. This is so because geography is a discipline and a school subject that studies the relationships between people and their environment. Hence, the knowledge and values harnessed when used in the right way will pave the way for achieving the much talked about sustainable development. More so, geography is a social science subject that deals with current and emerging fundamental environmental issues and how man in his wisdom proffer solutions in order to make the environment a safe place for all.

Concept of Geography Education

Geography is not just maps, compasses, mountains, valleys and other things we see around us. According to National Geographic Society (2020) geography is the study of places and the relationships between people and their environment. The importance of geography does not just come from understanding the physical properties of the world which of course is important as it were. The importance of geography also comes from how it connects people to their environment. Hence, the ability to understand this connectedness makes geography an important part of education, of our understanding of the world around us, and our understanding of human history. Furthermore, geography explores both the physical properties and the human societies spread across it. It also examines how human culture interacts with the natural environment and the way those locations and places can have an impact on people (NGS, 2020).

According to Dahlman and Renwick (2014) geography is a field of science devoted to the study of the lands, features, inhabitants and phenomena of earth. Similarly, geography as defined by Burt (2009) is an all-encompassing discipline that seeks an understanding of earth and its human and natural complexities-not merely where objects are, but also how they have changed and come to be. More succinctly encapsulated Hughes (1863) stated thus:

> *Names of places are not geography-to know by heart a whole gazetteer full of them would not in itself, constitute anyone a geographer. Geography has higher aims than this. It seeks to classify phenomena (alike of the natural and of the political world, in so far as it treats of the latter), to compare, to generalize, to ascend from effects to causes, and, in doing so, to trace out the laws of nature and to mark their influences upon man. This is a description of the world-that is geography. In a word, geography is a science-a thing not of mere names but of argument and reason of cause and effect (p 66).*

In the view of Sala (2009) geography is simply referred to as the bridge between the natural science and the social science disciplines. From the foregoing definitions it is obvious that geography is a subject which deals with the why, when, how and when of environmental issues whose knowledge and effective application would lead to sustainable development.

Impact of Human-Induced Activities on the Environment

According to Pius and Kabiru (2019) the environment under normal circumstances is expected to be a highly preserved resource despite the strong need of man to exploit what nature has endowed on him for his socio-economic development. This reason coupled with population explosion in the world, man has continuously find ways of meeting his needs. He has developed and used different technology available to him to achieve his goal. However, in doing this, man's activities have greatly impacted the environment negatively. There is no gainsaying therefore, that these human activities

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have far reaching consequences on our planet earth. Hence, the way we live our lives, the things we produce and consume and how we move around affect the earth, causing substantial damage to the environment ranging from pollution, ozone layer depletion, global warming, agriculture, deforestation, resource depletion, soil degradation, over population and over harvesting. To save our environment, we need to be aware of these impacts and work towards mitigating them as much as possible. This is a very difficult mission to accomplish but it is vital to, if we want to protect the earth for future generations and at the same time achieve the sustainable development goals. Examples of some selected human activities on the environment are briefly discussed below:

Atmospheric Pollution

Pollution is the release or injection of substances or energy into the atmosphere in substantial quantities that are harmful to man, animals and plants. Aligning with this definition, the Natural Resources Defense Council (NRDC, 2016) opined that pollution means the exposure of pollutants into the atmosphere which are detrimental to human health and the entire planet in general. To further stress the health hazard inherent in pollution, the World Health Organization (WHO) cited in NRDC (2016) noted that pollution is responsible for nearly 7 million deaths globally every year. Furthermore, it confirmed that 9 out of ten human beings currently breath air that exceeds the WHO's guideline limits for pollutants, with those living in low- and middle-income countries the worse hit. There are various sources of Air Pollutants as identified by NRDC (2016) which include the following; Gases and particles discharged from industrial plants, Smoke from the exhaust of vehicles, marine vessels, aero plane and trains, Domestic fires, Radio-active fallouts, Gas flaring from fields, Chloral-fluro-carbons (CFC) from freezers and coolants, Fumes from insecticide sprays, Dust particles from surface manning/quarries, Dust storms, Harmattan haze, Burning of fossil fuels, Burning of tyres, Decomposing waste. NRDC (2016) identify the following as the major effects of air pollution in the world; Climate change/greenhouse effect, Increase in atmospheric temperature, Depletion of the ozone layer, Destruction of vegetation and crops, Migration/death/extinction of some animal species, Thawing/melting of permanent ice, Rising of sea level, Submergence of low-lying coast lands and islands, Health hazards (e.g. lung diseases, concerns, hearing impairment), Cause of acid rain, Makes rain water unfit for domestic use, Defacing of buildings and movements, Acid rain increases chemical weathering of building walled blocs, metal roofs and statues, Impede air transportation, Causes poor visibility.

Water Pollution

Water pollution is the release of harmful substances (chemicals or micro-organisms) into water bodies or sources thus contaminating the water making it unusable or unfit for drinking, cooking, cleaning, swimming and other activities (Harvard School of Public Health, HSPH, 2023). Similarly, National Resource Development Center (NRDC, 2018) opined that water pollution is the release or injection of substances into the water bodies in quantities or level that are harmful thus degrading water quality and rendering it toxic to man, animals and plants and the environment at large. NRDC (2018) claimed that water pollution has serious health consequences on humans, noting that unsafe water kills more people each year than war and all other forms of violence put together. According to NRDC (2018) water pollution can occur in various ways, some of which are: Herbicides, Pesticides, Industrial waste discharge, Heat from power and industrial plants, Use of chemical fertilizers, Flooding, Acid rain, City drainage, Untreated sewage, Mining activities, Discharge from ships, Fisting with chemicals, Dumping of refuse in water, Erosion materials, Volcanic eruption, Oil spillage, Leakage from landfills, Washing clothes in rivers with detergents, Animal dung in rivers Iberdrola (2023) claimed that water Pollution have negative effects on the environment which are state below:

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Destruction of biodiversity, contamination of the food chain, lack of portable water, infant mortality and diseases.

Ozone Layer Depletion

BYJU'S (2023) describe the ozone layer as the layer or part of the earth's atmosphere that protects, prevents or reduces the amount of ultra-violet radiation from the sun from reaching to the earth surface. The ozone layer is mainly located at the lower portion of the earth's atmosphere. The ozone layer is said to have the potential to absorb 97-99% of the harmful ultra-violet radiation coming from the sun (BYJU'S, 2023). However, ozone layer depletion also known as Ozone holes is the gradual thinning of Earth's ozone layer in the upper atmosphere caused by the release of chemical compounds containing gaseous chlorine or bromine from industry and other human activities.

Ozone Layer Depletion according to NRDC (2016) can be induced by various human activities as follows; Gas flaring, Increase in human activities, Carbon emission, Deforestation, Chlorofluoro-carbon (CFC) gases released into the atmosphere, Volcanic eruption etc

Global Warming

National Resource Development Center, NRDC (2016) viewed global warming as a gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased level of carbon dioxide, CFCs, and other pollutants. In other words, global warning occurs when carbon dioxide (CO_2) and other air pollutants collect in the atmosphere and absorb sunlight and solar radiation that have bounced off the earth's surface. Under normal circumstances this radiation would escape into space, but these pollutants, which can last for years to centuries in the atmosphere trap the heat and cause the planet to get hotter. These heat-trapping pollutants – especially carbon dioxide, methane, nitrous oxide, water vapour and synthetic fluorinated gases –are known as "greenhouse gases" and their impact is called "the greenhouse effect". Global Warming can be caused by the following factors; Power plants, Agriculture, human activities, Vehicles and transportation, Offshore drilling, Deforestation and Overfishing amongst others. Global warming affects the environment in numerous ways: Disappearing glaciers (shrinking glaciers), Rising sea levels – will lead to even more coastal flooding, Hotter temperature, Diseases, Drought, Economic consequences, Conflicts and wars.

Acid Rain

Acid rain which is also called acid precipitation or acid deposition is one of the negative effects of human activity on the environment. According to www.britannica.com, acid rain occur as a result of pollutants emanating from power plants and other industries react with the atmosphere to produce that falls back to the earth as rain, snow or fog. Simply put acid rain means rain made so acidic by atmospheric pollution that it causes environmental harm, mainly to forests and lakes. The most common cause of acid rain is the burning of fossil fuels such as oil and coal. Other causes of acid rain are; wild fires, decaying vegetation and other biological processes within the environment.

Resource Depletion

Human activities have affected the quality and quantity of natural resources available to life on earth. Hence, depletion of natural resources is one of the most serious environmental problems that mankind is confronted with today. It has reached a situation in the world today where availability of natural resources is decreasing as against their increasing demand. According to Agricultural and Environmental Data Archives (AEDA, 2023) resource depletion is the exhaustion of raw materials within a region. It noted that resources are commonly categorized into renewable and non renewable resources. The use of either of these forms of resources beyond their rate of replacement amounts to resource depletion. Resource depletion is mostly common in reference to farming, fishing, mining, water and fossil fuels. Another definition of resource depletion by National Resources Conservation

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and Advances for Sustainability (NRCAS, 2023) states that resource depletion is the economic function resulting from misappropriation of supply and demand of a particular resource.

Consequences of Human-Induced Activities on the Environment

The consequences of human-induced activities on the environment are numerous, some of which include; Loss of biodiversity, Population displacement, Vulnerability to climate change, Species extinction, Incremental and continuous rises in the sea level and record setting hot temperatures in the earth's greenhouse atmosphere. It is to be noted that, it is the realization of these consequences that had led to the formation of the Sustainable Development Goals (SDGs) agenda by the United Nations World Commission on Environment which was adopted in the year 2015 by all United Nations Member States aimed at mitigating the impact of human-induced activities on the environment by the year 2030. However, whether the SDGs have achieved its mandate remains to be seen in the near future.

Concept of Sustainable Development

According to Wikipedia (2023) sustainable development is an organizing principle that aims to meet human development goals, while at the same time enabling natural systems to provide necessary natural resources and ecosystem services to humans. The desired result is a society where living conditions and resources meet human needs without undermining the planetary integrity and stability of natural system. This goes to show that sustainable development tries to find a balance between economic development, environmental protection and social wellbeing. However, the most widely used and accepted definition of sustainable development is the one given in the report of the United Nations World Commission on Environment and Development in 1987 titled "Our Common Future" popularly called the Brundtland Report. The report defined sustainable development as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. So the whole concept of sustainable development emanates from the idea that human societies must live and meet their present needs but must be careful not to jeopardize the needs of future generations yet unborn. Furthermore, the Brundtland report noted that sustainable development is a way of organizing of organizing society so that it can exist in the long term. This means taking into consideration both the imperatives present and those of the future, as the preservation of the environment and natural resources or social and economic equity. It is important to note that the definition of sustainable development in the Brundtland report contains two key concepts: Firstly, the concept of needs, in particular, the essential need of the world's poor, to which overriding priority should be given. Secondly, the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

Geography Education an Indispensable Tool for Mitigating the Impact of Human Activities on the Environment for Sustainable Development

The planet earth at the moment remains the only dwelling place for man among other 8 planets and therefore numerous activities and interactions goes around which have some causes and effects on the environment. To protect the environment and thus mitigate the impact of human activities on the environment for sustainable development the knowledge and understanding of geography is paramount. From the foregoing analysis, geography education can truly serve as an indispensable tool for mitigating consequences of human-induced activities because of its highly interdisciplinary nature makes it appropriate perspective to consider complex issues such as sustainable development that involves economic, social and environmental dimensions. Hence, appropriate geographical knowledge should ensure a more careful use of natural resources by people and increase environmental awareness by making positive changes in their knowledge, attitudes and behaviours in relation to the environment. More, so the fact that geography is a bridge between the natural

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sciences and the social sciences makes it ideal platform for providing the right environmental education which will go a long way in bringing about sustainable development. Similarly, Meadows (2020) also confirm the appropriateness of geography education in mitigating impact of human-induced activities when he noted that geography actually is a discipline that bridges the gap between human and society and the physical environment and uses modern technology to find solutions to some of the world's most pressing problems such as environmental change, population dynamics, biodiversity loss, unsustainable urbanization and global inequalities which can lead to sustainable development. The discipline of geography has a distinct advantage in developing a more holistic understanding of global environmental challenges in that it reaches across all the sciences (including social sciences and humanities). Geography education therefore, represent and important vehicle for citizens of all ages to help them understand the complexity of the sustainability goal and what can (and should be done to achieve a more sustainable future. Geography is a science for sustainability; hence it has an increasingly important role to play in developing the knowledge and the skills to equip future generations with the tools to adapt to and mitigate potentially catastrophic global environmental change. Additionally, Gonzalez and Sebastian-Lopez (2022) noted that geography is an academic discipline and school subject that equips students well with knowledge, skills and values related to education on Sustainable Development Goals (SDGs), he asserted that this can greatly assist in achieving United Nations Agenda 2030 on sustainable development goals. According to Garcia-Gonzalez, Palencia and Ondono (2021) environmental problems seriously poses a threat to the sustainability and survival of our planet. Hence, they opined that the only way to raise awareness of the seriousness of this menace among future generations and instill proactive behaviours that would place the environment at the center of decision making is environmental education which only geography can provide, doing this will create the right attitude and value for nature. Furthermore, De-Castro and Girona (2021) noted that the United Nations should create necessary awareness on the sustainable development goals to the community of geography in all levels of education as a key related geographic education; hence, they should in turn embrace it to ensure that the message on sustainability reaches the nook and cranny of the world.

Conclusion

The 17 Sustainable Development Goals (SDGs) was adopted by all United Nations member states in 2015 with 169 targets to be reached by 2030 or even sooner. The goals and targets are universal; this implies that all countries around the world must comply. In this regards, it is hoped that countries around the world must as a matter of urgency put in necessary machineries and reactivate all decisions reached at previous global environmental conventions aimed at mitigating all environmental challenges arising from human-induced activities in order to save our planet earth. Since geography education is related to sustainability and the fact that geographers understand human-environment relationships and how to use that information to manage environmental related issues and to protect the planet as a whole. Geography education is therefore the most relevant school subject that can be used in achieving the United Nations Agenda 2030 and Sustainable Development Goals (SDGs).

Recommendations

1. Geography should be taught across all levels of our educational system in order to acquaint all citizens with requisite geographical knowledge on how and why the environment should be cared for.

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2. Geographical societies in schools should be revived and made functional for easy transmission of geographical knowledge and information on environmental issues; this is to ensure that geographical knowledge gets to the grassroots for better sustainability.
3. International and national based Organizations should intensify campaign and enlightenment to citizens on the need to care for the environment.
4. International and State legislations should be enhanced in order to ensure that environmental laws are strictly adhered to for sustainable development.

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Effects of Cross-Age Peer-Tutoring Strategy on Academic Performance in Genetics Concepts among Upper Basic Science Students in Zaria, Kaduna State, Nigeria

ATTO, Tanko Jolly
jollytanko55@gmail.com
Department of Integrated Science, Federal University of Education, Zaria, Kaduna State, Nigeria

Abstract

This study investigated the effects of the Cross-Age Peer-Tutoring Strategy on students' academic performance in genetics concepts among Upper Basic Science Students in Zaria, Kaduna State. The strategy involves a tutor with an age difference of one or two years teaching younger tutees to facilitate better understanding. A quasi-experimental pre-test and post-test control group design was employed. From a population of 8,439 students, a sample of 140 participants was selected. Purposive sampling was initially used to identify six gender-based schools, followed by simple random sampling to assign experimental and control groups. Data were collected using the Genetics Performance Test (GPT), which achieved a reliability coefficient of 0.70. Validation was conducted by experts in Science Education and Biological Sciences. T-test was used to test the hypotheses at a p≤ 0.05 significance level. Findings indicated a significant difference in mean performance scores; with the experimental group outperforming those taught via traditional methods (p=0.01). and the academic performance of male and female students was not influenced by the use of peer tutoring instructional strategy to teach genetics concepts (p= 0.50). It is recommended that Basic science teachers should make use of peer tutoring instructional strategy to teach genetics concepts in Upper Basic Secondary Schools and also they should encourage active participation of both male and female students during teaching and learning process to reduce boredom and increase students' performance.
Keywords:

Introduction

The term science finds its origin in the Latin word *Scientia*, which signifies a systematic body of knowledge acquired through objective enquiry and the rigorous exploration of the natural universe. Within the context of a developing nation such as Nigeria, science education is not merely a classroom requirement but the essential foundation for technological advancement, industrial growth, and sustainable economic strength. This perspective is supported by Bolarin (2021), who argues that scientific literacy is the primary gateway to national survival in an increasingly competitive global economy. Consequently, the Federal Ministry of Education (2014) emphasises the necessity of equipping learners with the critical skills and mental capabilities required to lead impactful lives amidst the rapid scientific changes of the modern age. This educational journey begins with Basic Science at the upper basic level, which according to Kim (2008), acts as the vital bedrock for all subsequent scientific specialisations. By providing a unified approach to scientific thought, Basic Science prepares students for the complexities of senior secondary subjects like Biology, Chemistry, and Physics. As noted by Oludipe (2020), a student must be thoroughly grounded in these fundamental concepts at the junior level to achieve success in the more specialised core sciences later in their academic career.

Despite its profound importance, student performance in Basic Science remains a significant concern within the Nigerian educational landscape. Recent reports from the Education Resource Centre, Kaduna (2022), indicate that learners consistently struggle with complex thematic areas, particularly Genetics Concepts such as heredity and variation. These pedagogical difficulties often stem from the

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persistent reliance on traditional, teacher-centred instructional methods which frequently fail to simplify abstract biological ideas for young learners. As Poopola (2020) observes, such conventional approaches often overlook the individual learning pace and cognitive background of the child. Peer tutoring offers a viable solution to this challenge by allowing students to assist one another, reinforcing essential skills through shared instruction and relatable dialogue. Paul (2016) characterises this strategy as a way to provide individualised and focused guidance, ensuring every student receives more consideration than in a standard lecture. By adopting such a student-centred approach, learners take an active role in constructing their own knowledge, a process that is expected to enhance their academic outcomes and mastery of scientific enquiry. Gender also plays a significant role in academic success, though contemporary research continues to present conflicting views on its influence. While some scholars, such as Njoku (2017), suggest that boys often outperform girls in science-related disciplines, others like Olatoye (2017) found no such disparity in their investigations. This study, therefore, examines whether the Cross-Age Peer-Tutoring Strategy can improve performance in genetics while remaining gender-neutral. By ensuring that both male and female students engage equally in the tutoring process, the strategy aims to mitigate any potential bias inherent in traditional instruction. This research is firmly supported by Vygotsky's Socio-Cultural Theory, which posits that social interaction is fundamental to cognitive development. Vygotsky argued that learning is a social process where the origination of human intelligence is rooted in society or culture. By interacting with older, more experienced peers, students can bridge the "Zone of Proximal Development" the gap between their current independent abilities and their potential achievement under guidance. This peer-led interaction allows for a more fluid exchange of ideas, enabling tutees to master complex genetics concepts that might otherwise remain inaccessible through solitary study or formal lectures.

Statement of the Problem

Despite the foundational importance of genetics in the Basic Science curriculum, students in Zaria, Kaduna State, continue to record poor academic outcomes in this area. Genetics concepts, such as heredity, variation, and DNA structure, are often perceived by learners as abstract, complex, and difficult to comprehend. This difficulty is frequently exacerbated by the continued reliance on the traditional lecture method, which promotes passive learning and fails to stimulate student engagement. The persistent low performance is not merely a matter of cognitive ability but is deeply linked to a lack of interest. When students find a subject matter intimidating or disconnected from their experiences, their motivation to engage with the content diminishes, leading to a cycle of disinterest and failure. Furthermore, there remains a lack of consensus on how gender influences learning outcomes when modern instructional strategies are introduced, particularly in the local context of Kaduna State. The Cross-Age Peer-Tutoring Strategy (CAPTS) offers a potential solution by utilizing older, more experienced students to mentor younger peers, thereby breaking down complex concepts into relatable language. However, it is not yet clear to what extent this strategy can bridge the performance gap or spark a genuine interest in genetics among upper basic students. Therefore, this study is designed to investigate the effects of the Cross-Age Peer-Tutoring Strategy on the academic performance and interest in genetics concepts among upper basic science students in Zaria, Kaduna State.

Objectives of the Study

1. To determine the difference in the academic performance of students taught genetics concepts using the Cross-age Peer Tutoring Strategy and those taught using the lecture method.

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2. To find out the effect of the Cross-age Peer Tutoring Strategy on the academic performance of male and female students in genetics concepts.

Research Questions

1. What is the difference in the mean academic performance scores of students taught genetics concepts using the Cross-age Peer Tutoring Strategy and those taught using the lecture method?
2. What is the difference in the mean academic performance scores of male and female students taught genetics concepts using the Cross-age Peer Tutoring Strategy?

Null Hypotheses

H_{01}: There is no significant difference in the mean academic performance scores of students taught genetics concepts using the Cross-age Peer Tutoring Strategy and those taught using the lecture method.

H_{02}: There is no significant difference in the mean academic performance scores of male and female students taught genetics concepts using the Cross-age Peer Tutoring Strategy.

Methodology

Research Design

This study employs a pretest-posttest quasi-experimental and control group design. This design allows for the comparison of academic performance between the experimental group (taught with peer-tutoring) and the control group (taught with the lecture method).

Population of the Study

The target population consists of all public Secondary schools in the Zaria, Kaduna State, totaling 8,439 Upper Basic 2 students across 29 schools. This includes 4,853 males and 3,586 females.

Sample and Sampling Technique

A multi-stage sampling procedure is used. First, six schools are purposively selected based on gender. After pre-testing for equivalence, two schools are selected via simple random sampling (balloting). One school serves as the experimental group and the other as the control group. Intact classes are used, resulting in a sample size of approximately 140 participants.

Research Instrument

The primary instrument is the Genetics Performance Test (GPT). The Genetics Performance Test (GPT) is an instrument consisted of items sourced from different past question papers in order to measure the performance of students in genetics concepts. It consists of 30 objective items adapted by the researcher from BECE past questions from 2014-2023. The topics are definitions of genetics terms; concepts of monohybrid and dihybrid inheritance; simple crosses involving single characters in organisms; Mendel's first and second laws of inheritance; application of genetics in human population. Each of the 30 items was scored one mark giving a total of 30 marks since the statistics of mean scores and standard deviation was used to analyze the data.

Method of Data Analysis

Descriptive statistics (mean and standard deviation) are used to answer research questions, while inferential statistics (such as t-tests) are used to test the null hypotheses at a $p \leq 0.05$ level of significance.

Presentation of Results

Hypothesis One: There is no significant difference in the mean academic performance scores of students taught genetics concepts using the Cross-age Peer Tutoring Strategy and those taught using the lecture method.

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In order to test the null hypothesis one, the data generated data via Genetics Performance Test (GPT) were subjected to independent sample t-test statistics. The results obtained were computed and used to draw Table 1.

Table 1.: Summary of Independent t-test Analysis of the Post Test Sores of Students in the Experimental and Control Groups.

Variable	Groups	n	Mean	Std. D	M.df	T	P	Remark
Performance	EG	75	34.07	8.787	3.65	3.45	0.01	Significant
	CG	65	30.42	11.47				

Significant at P ≤ 0.05 level of significance.

Results in Table 1. shows that there is significant difference between the mean academic performance scores of students in the experimental and control group in favour of the experimental group. Reasons being that the calculated p-value of 0.01 is less than the 0.05 alpha level of significance p value 0.01 < 0.05. This implied that the significant difference is in favour of the experimental group. Therefore, the null hypothesis which stated that there is no significant difference between the mean academic performance scores of students taught genetics concepts using peer tutoring Instructional Strategy and those taught using conventional method, is hereby rejected.

Hypothesis Two: There is no significant difference in the mean academic performance scores of male and female students taught genetics concepts using the Cross-age Peer Tutoring Strategy.

In order to test the null hypothesis three, the data generated data via Genetics Performance Test (GPT) were subjected to Independent Sample t-test statistics. The results obtained were computed and used in Table 2.

Table 2: Summary of t-test Statistics on the significant difference between the Mean Performance Scores of Male and Female Students in the Experimental Group.

Variable	Gender	n	Mean	Std. D	M.df	t	P	Rmk	Decision
Performance	Male	45	36.12	7.52	7.95	5.64	0.50	Not. Sig.	Retained
	Female	30	28.17	10.99					

Not significant at P < 0.05 level of significance.

Results in Table 2 shows that there is no significant difference between the mean academic performance scores of male and female students in the experimental. Reasons being that the calculated p-value of 0.50 is more than the 0.05 alpha level of significance (0.50 > 0.05). Therefore, the null hypothesis which stated that there is no significant difference between performances means scores of male and female students taught genetic concepts using Peer Tutoring Instructional Strategy, is hereby accepted meaning that peer tutoring teaching strategy is gender friendly.

Discussion of Findings

The study revealed that significant difference exists between the performance mean scores of students in the experimental and control groups. Therefore, the null hypothesis which stated that there is no significant difference between academic performance mean scores of students taught genetics concept using peer tutoring instructional strategy and those taught using Lecture is hereby rejected. This implies that students' scores were enhanced after exposure to peer tutoring instructional strategy implying that the peer tutoring instructional strategy is more effective in improving students' performance in genetics concepts than the conventional method. This finding is

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in line with that of Lubi and Polloway (2017) who concluded that peer tutoring instructional strategy is effective in improving students' academic performance in science. The finding from this study is also similar with that of Purnamasari (2018) who found that peer tutoring instructional strategy can improve students' memory. The results are also similar with that of Istigamah and Ichsan (2021) who concluded that to associate every information in the cognitive structure of humans, one of them is by using peer tutoring instructional strategy. However, the outcome of this study differs from that of Jackson and Osuhack (2022) and Felnor (2018) who recorded no significant difference in performance among Upper Basic. The reason for the deviation in the results could be due to location and teacher factor in handling peer tutoring instructional strategy. The result of this study also showed that the academic performance of male and female students was not influenced by the use of peer tutoring instructional strategy to teach genetics concepts. This means that there is no significant difference in the mean score of academic performance of male and female students taught genetics concepts using peer tutoring instructional strategy. This result is different from that of Okley (2019) Whitehead (2020) and Arbogast (2020) who stated that gender plays an important role in improving students' performance in science. This means that the approach of using peer tutoring instructional strategy has no negative effect on performance among males and female students; hence the strategy is gender friendly in teaching genetics concepts. This might be as the result of different location, topic taught and sample size. In conclusion, the peering tutoring teaching strategy was able to enhance students' performance in genetics because they work and share ideas based on their level of explanation among the peers. They participate actively unlike the conventional type where the students are passive.

Conclusion

The study concludes that the Cross-Age Peer-Tutoring Strategy is a significantly more effective instructional approach for improving students' academic performance in genetics concepts than the traditional lecture method. The notable enhancement in post-test scores suggests that when learners are actively involved in constructing their knowledge through peer interaction, they retain complex scientific information with greater clarity. This success is largely attributed to the collaborative nature of the strategy, which allows students to simplify abstract concepts like heredity and variation into relatable language that resonates with their peers. By moving away from the passive "teacher-talk" model, the strategy creates a dynamic learning environment that fosters deep cognitive engagement and mastery of difficult science topics. Furthermore, the research demonstrates that the Cross-Age Peer-Tutoring Strategy is gender-friendly, as it does not create or widen a performance gap between male and female students. The results indicate that both genders benefit equally from the peer-mediated approach, suggesting that the effectiveness of the strategy is rooted in social and cognitive interaction rather than gender-specific learning styles. This finding is particularly important for educators in Zaria and the wider Kaduna State, as it provides a versatile and inclusive pedagogical tool that ensures equity in science education. Consequently, the study affirms that when students work and share ideas at their own level of explanation, they achieve higher academic outcomes regardless of their gender.

Recommendations

Based on the findings and conclusions drawn from this study, the following recommendations are made:

1. Basic science teachers should make use of peer tutoring instructional strategy to teach genetics concepts in Upper Basic Secondary Schools.

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2. Basic science teachers should encourage active participation of both male and female students during teaching and learning process to reduce boredom and increase students' performance.

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Polynomial Regression Analysis: Testing for Curvilinear Effects of Internal Supervision Practices and Teachers' Effectiveness on Teaching Quality

MUHAMMAD, Bala Maradun[1]
mbmaradun@fugusau.edu.ng
balamaradun@gmail.com
NA ALLAH, Nasiru[2]
[1]University Health Services Department, Federal University Gusau
[2]Department of Mathematics and Statistics, Abdu Gusau Polytechnic Talata Mafara

Abstract

All prior regression analyses of this dataset assumed linear relationships between predictors and outcomes. The present study extended this framework by testing polynomial (curvilinear) models to determine whether the effects of Internal Supervision Practices (ISPS) and Teachers' Effectiveness (TES) on Teaching Quality (TQS) depart significantly from linearity in a sample of N = 386 teachers from private secondary schools in Gusau, Zamfara State, Nigeria. Using hierarchical polynomial regression, quadratic terms (ISPS² and TES²) were entered in Block 2 following the linear main effects in Block 1. For ISPS, the quadratic increment was non-significant (ΔR² = .003, FΔ[1, 383] = 1.33, p = .249), confirming that the supervision–the linear model adequately describes the quality relationship. For TES, the quadratic term likewise produced a non-significant increment (ΔR² = .001, FΔ[1, 383] = 0.47, p = .496). A combined model incorporating both quadratic terms explained R² = .143, representing a marginal improvement of ΔR² = .003 over the linear baseline (R² = .140, FΔ[2, 382] = 0.67, p = .513). Residual diagnostic plots confirmed homoscedasticity and approximate normality of residuals for the linear model. Post-hoc power analysis revealed that N ≥ 2,500 would be required to detect the observed quadratic signal (f² = .003) with 80% power, indicating the null finding is indeterminate rather than conclusive. These results justify the linear modelling approach adopted in prior analyses and effectively rule out U-shaped or inverted-U relationships between supervision intensity and teaching quality within the empirically observed ISPS range (2.22–4.00).

Keywords: polynomial regression, curvilinear relationship, quadratic term, linearity assumption, inverted-U hypothesis, optimal stimulation, supervision–quality relationship, model comparison

Introduction

The assumption of linearity is foundational to ordinary least squares regression, yet it is rarely formally tested in educational supervision research conducted in sub-Saharan Africa. A linear model holds that each unit increase in supervision produces a constant increment in teaching quality, irrespective of the baseline level of supervision intensity. However, two competing theoretical accounts predict departure from linearity. The optimal stimulation hypothesis, drawn from Berlyne (1960) and adapted to educational supervision by Glickman (1985), proposes an inverted-U relationship: moderate supervision maximises teaching quality, whilst both very low supervision (insufficient guidance) and very high supervision (micromanagement-induced stress) depress quality. This view is supported by Kraft *et al.* (2018), who demonstrated diminishing returns to instructional coaching as contact frequency increased beyond a moderate threshold. Conversely, a stress-amplification hypothesis predicts a U-shaped relationship in which moderate supervision is least effective, with both very low supervision (enabling autonomous teacher excellence) and very high supervision (producing compliance-driven improvement) being the most productive regimes. Neither hypothesis has been empirically tested in the Nigerian private secondary school context. The present analysis formally tests both quadratic accounts whilst providing a transparent power analysis that contextualises the findings.

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Aim and Objectives of the Study

This study aims to determine whether the relationships between ISPS, TES, and TQS depart significantly from linearity within the Gusau private secondary school dataset. The specific objectives are to:

1. Test the statistical significance of quadratic terms for ISPS and TES individually in hierarchical polynomial regression models.
2. Evaluate the combined quadratic model against the linear baseline using incremental R^2 and the F-change test;
3. interpret the direction of any observed curvature relative to the optimal stimulation and stress-amplification hypotheses; and
4. Conduct post-hoc power analyses to contextualise null quadratic findings.

Literature Review

Linearity in Educational Supervision Research

The majority of quantitative supervision studies assume linear predictor–outcome relationships by default. Blase and Blase (2000) meta-analysed 18 empirical studies linking principal supervision to teacher classroom practice and found predominantly linear effect patterns. However, they cautioned that observational rating scales with restricted ranges may mask underlying nonlinearities. More recently, Kraft *et al.* (2018) demonstrated a concave relationship between instructional coaching dosage and teacher performance gains, with gains decelerating beyond approximately 30 contact hours per annum — a finding consistent with the optimal stimulation hypothesis. In the West African context, Ogunyemi and Lasisi (2021) reported a statistically significant positive linear effect of internal supervision on teaching quality across 14 Lagos private schools, without formally testing for curvature. Afolabi (2018) similarly assumed linearity in a Kwara State study linking supervision intensity to instructional quality ratings. The absence of formal linearity tests in these studies represents a methodological gap, as ceiling effects in Likert-scale composites can both mask and mimic curvilinear patterns (Rimpler *et al.*, 2025).

Research Gap

No prior study, either within this dataset or in the broader Nigerian private secondary school literature, has formally tested polynomial models of the supervision–quality relationship. This gap is consequential: if the relationship is genuinely concave, the policy implication shifts from "more supervision is always better" to "supervision should be optimised rather than maximised." The present study addresses this gap by subjecting both predictors to hierarchical quadratic regression with appropriate power analysis.

Theoretical Framework

Polynomial Regression Model

The quadratic polynomial model for a single predictor is specified in Equation (1) below, where b_2 captures the curvature of the regression function. Mean-centring X before squaring is essential to avoid non-essential multicollinearity between X and X^2 — without centring, r(ISPS, $ISPS^2$) ≈ = .85, compared with r ≈ = .00 after centring (Park and Yi, 2022). A significant positive b_2 indicates an accelerating (convex, U-shaped) relationship; a significant negative b_2 indicates a decelerating (concave, inverted-U) relationship. The incremental R^2 (ΔR^2) from adding X^2 to a model already containing X constitutes the formal test of nonlinearity.

$$Y = b_0 + b_1X + b_2X^2 + e \qquad (1)$$

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where Y = Teaching Quality (TQS), X = mean-centred predictor (ISPS or TES), b_0 = intercept, b_1 = linear slope, b_2 = quadratic coefficient, and e = residual error.

The effect size for the quadratic increment is computed using Equation (2):

$$f^2 = \Delta R^2 / (1 - R^2 full) \quad (2)$$

where ΔR^2 is the incremental variance explained by the quadratic term, and R^2full is the R^2 of the full model including the quadratic term.

Power Considerations for Curvature Detection

Detecting quadratic effects in observational field data is structurally more difficult than detecting linear effects. Ceiling effects — present throughout this dataset (mean item difficulty p = .78–.84) — compress the upper range of the predictor, reducing the predictor variance available for curvature estimation. Cohen (1988) established that detecting a small quadratic increment (f^2 = .020) at 80% power requires N ≈ = 480 for a model with two predictors. For the very small increments expected in ceiling-affected field data (f^2 ≈ .005), N ≥ 1,700 would be required. This power landscape must be taken into account when interpreting non-significant quadratic terms.

Materials and Methods

Participants and Measures

Participants comprised N = 386 qualified teachers drawn from private secondary schools in Gusau, Zamfara State, Nigeria. Table 1 presents the descriptive statistics for the three study variables. Internal Supervision Practices (ISPS) had a mean of 3.198 (SD = 0.361, range 2.22–4.00); Teachers' Effectiveness (TES) had a mean of 3.344 (SD = 0.321, range 2.19–4.00); and Teaching Quality (TQS), the outcome variable, had a mean of 3.117 (SD = 0.353, range 1.83–4.00). The restricted upper range of both predictors indicates ceiling effects that reduced available variance for curvature estimation.

Table 1

Descriptive Statistics for Study Variables (N = 386)

Variable	M	SD	Range	Scale Points
Internal Supervision Practices (ISPS)	3.198	0.361	2.22–4.00	1–4 Likert
Teachers' Effectiveness (TES)	3.344	0.321	2.19–4.00	1–4 Likert
Teaching Quality (TQS)	3.117	0.353	1.83–4.00	1–4 Likert

Note. All three variables were measured on four-point Likert-type composite scales. The restricted upper range of ISPS and TES indicates ceiling effects that reduced the predictor variance available for curvature estimation.

Analytical Procedure

All predictors were mean-centred before analysis to minimise non-essential multicollinearity between linear and quadratic terms. Three hierarchical regression models were estimated using IBM SPSS version 25: (1) Linear ISPS model — Block 1: ISPS_c; Block 2: ISPS_c^2; (2) Linear TES model — Block 1: TES_c; Block 2: TES_c^2; and (3) Combined quadratic model — Block 1: ISPS_c + TES_c; Block 2: ISPS_c^2 + TES_c^2. The F-change statistic (ΔF) was used to test the incremental variance contributed by each quadratic term. Variance Inflation Factors (VIF) were computed for all models to assess multicollinearity. Residual diagnostic plots (standardised residuals versus fitted values; normal Q-Q plots) were generated to assess linearity, homoscedasticity, and normality of residuals. Post-hoc power analyses were computed via the non-central F-distribution. Model fit was also evaluated using

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the Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and R^2 metrics for both linear and polynomial specifications.

Presentation of Results

Model Fit Metrics: RMSE, MAE, and R^2

Table 2 summarises the model fit metrics — Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and R^2 — comparing the linear baseline model with the full polynomial model. The linear model (ISPS_c + TES_c) yielded an RMSE of 0.329 and an MAE of 0.258, accounting for 14.0% of the variance in Teaching Quality (R^2 = .140, Adj. R^2 = .135). The polynomial model, which added both quadratic terms (ISPS_c² + TES_c²), yielded a marginally higher RMSE (0.330) and MAE (0.259), a negligible gain in R^2 (.143), but a reduced Adj. R^2 (.133). The slight deterioration in all fit indices under the polynomial specification demonstrates that the added quadratic terms impose a parsimony cost without any compensating improvement in predictive accuracy. These results collectively affirm the adequacy of the linear model and counsel against adopting a more complex polynomial specification for this dataset.

Table 2

Model Fit Metrics: RMSE, MAE, and R^2 for Linear and Polynomial Models

Model	RMSE	MAE	R^2	Adj. R^2
Linear (ISPS_c + TES_c)	0.329	0.258	.140	.135
Polynomial (+ ISPS_c² + TES_c²)	0.330	0.259	.143	.133

Note. RMSE = Root Mean Square Error; MAE = Mean Absolute Error. The polynomial model does not improve upon the linear baseline on any fit metric. The marginal increase in RMSE and decrease in Adj. R^2 indicates that the quadratic terms do not improve parsimony without meaningful gains in predictive accuracy.

Figure 1 presents the residual diagnostic plots for the linear model. Panel (a) displays standardised residuals plotted against fitted values. The residuals are randomly scattered and symmetrically distributed around the horizontal zero line across the full range of fitted values (2.8–3.6), with no discernible funnel shape, curvature, or heteroscedasticity. The smoothed trend line (orange) remains essentially flat, confirming that the linear model adequately captures the conditional mean of TQS and that the homoscedasticity assumption is satisfied. Panel (b) shows the normal Q-Q plot, in which sample quantiles of the standardised residuals are plotted against their theoretical normal counterparts. The data points align closely with the reference line (r = .998) throughout the distribution, indicating that residuals are approximately normally distributed. Minor deviations at the extreme tails are consistent with expected sampling variability at N = 386 and do not constitute a substantive violation. Taken together, the two panels confirm that the key assumptions of ordinary least squares regression — linearity, homoscedasticity, and normality of residuals — are adequately met.

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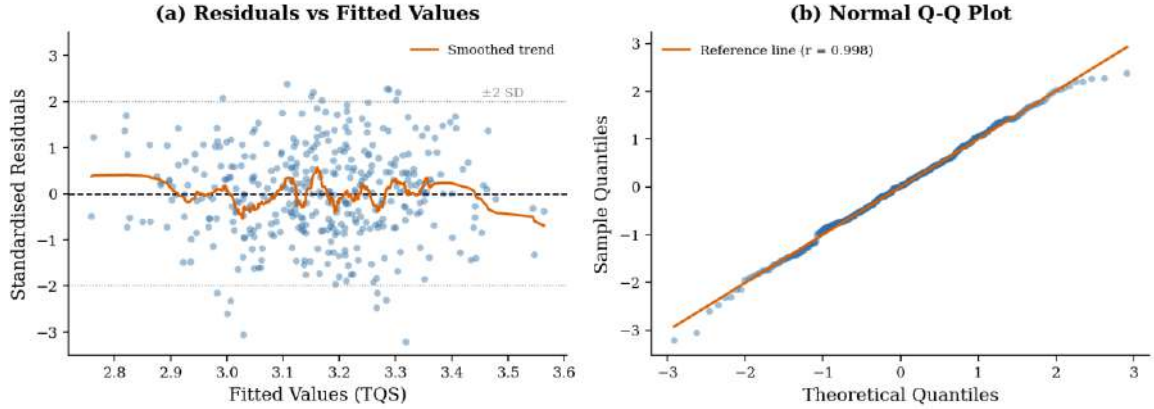


Figure 1. Residual Diagnostic Plots for the Linear Regression Model (N = 386)

Figure 1. Residual diagnostic plots for the linear regression model (N = 386): (a) standardised residuals versus fitted values confirming homoscedasticity, with the smoothed trend line (orange) remaining flat across the fitted value range; and (b) normal Q-Q plot (r = .998) confirming approximate normality of residuals.

Polynomial Model for ISPS

Table 3 presents the hierarchical polynomial regression results for ISPS predicting Teaching Quality (TQS). In Block 1, the linear term ISPS_c explained a statistically significant 11.2% of the variance in TQS (R^2 = .112, F[1, 384] = 48.67, p < .001), establishing a robust positive linear association between internal supervision practices and teaching quality. In Block 2, the quadratic term ISPS_c² was added to the model. The increment in explained variance was ΔR^2 = .003, which was statistically non-significant ($\Delta F[1, 383] = 1.33$, p = .249). The overall model R^2 increased only marginally from .112 to .115, whilst adjusted R^2 remained unchanged at .110, indicating that the quadratic term explains no meaningful additional variance once sampling error is accounted for. The unstandardised quadratic coefficient was B = −0.142 (SE = 0.123, β = −.058, p = .249). Although the negative sign of b_2 is directionally consistent with the optimal stimulation hypothesis — implying that the marginal benefit of additional supervision may diminish at higher intensities — the coefficient is statistically indistinguishable from zero at N = 386. These results confirm that the supervision–quality relationship is adequately described by the linear model within the empirically observed ISPS range of 2.22 to 4.00.

Table 3

Hierarchical Polynomial Regression Results: ISPS Quadratic Model (Outcome: TQS)

Predictors	R^2	Adj. R^2	ΔR^2	F(df)	p(F)	ΔF(df)	p(ΔF)
Block 1: ISPS_c	.112	.110	.112	48.67 (1, 384)	< .001	48.67 (1, 384)	< .001
Block 2: + ISPS_c²	.115	.110	.003	24.92 (2, 383)	< .001	1.33 (1, 383)	.249

Note. ΔR^2 = .003 for the quadratic term is non-significant (p = .249). The unstandardised quadratic coefficient B = −0.142 (SE = 0.123, β = −.058, p = .249). The negative (concave) direction is

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consistent with the optimal stimulation hypothesis, but the effect does not attain statistical significance.

Polynomial Model for TES

Table 4 presents the hierarchical polynomial regression results for Teachers' Effectiveness (TES) predicting Teaching Quality (TQS). In Block 1, the linear term TES_c yielded a marginally significant effect (R^2 = .010, F[1, 384] = 3.98, p = .047), accounting for only 1.0% of the variance in TQS — a substantially weaker linear relationship than that observed for ISPS. Adding the quadratic term TES_c² in Block 2 produced a negligible and non-significant increment (ΔR^2 = .001, ΔF[1, 383] = 0.47, p = .496). The overall Block 2 model was itself non-significant (F[2, 383] = 2.12, p = .121), and adjusted R^2 decreased from .008 to .006, confirming that the quadratic specification over-fits the data. The unstandardised quadratic coefficient was B = 0.093 (SE = 0.135, β = .034, p = .496). The positive sign would, in principle, imply a U-shaped (convex) relationship consistent with the stress-amplification hypothesis rather than the optimal stimulation account; however, because the coefficient is statistically indistinguishable from zero, no directional inference is warranted. TES thus shows no evidence of curvilinearity, and the linear specification is retained.

Table 4

Hierarchical Polynomial Regression Results: TES Quadratic Model (Outcome: TQS)

Predictors	R^2	Adj. R^2	ΔR^2	F(df)	p(F)	ΔF(df)	p(ΔF)
Block 1: TES_c	.010	.008	.010	3.98 (1, 384)	.047	3.98 (1, 384)	.047
Block 2: + TES_c²	.011	.006	.001	2.12 (2, 383)	.121	0.47 (1, 383)	.496

Note. ΔR^2 = .001 for the TES quadratic term is non-significant (p = .496). TES shows no evidence of curvilinearity. The unstandardised quadratic coefficient B = 0.093 (SE = 0.135, β = .034, p = .496). The Block 2 model is overall non-significant (p = .121).

Figure 2 plots the predicted Teaching Quality (TQS) as a function of centred TES scores (TES_c), holding ISPS_c at its mean of zero. The solid blue line represents the linear model prediction; the dashed orange line represents the quadratic model prediction; and the shaded band indicates the 95% confidence interval around the linear prediction. The two prediction lines are virtually indistinguishable across the entire observed range of TES_c, providing a clear visual confirmation that the quadratic term contributes no meaningful curvature to the model. The narrow confidence band reflects reasonable estimation precision given the sample size. The observed data points (grey) exhibit characteristic scatter around the linear trend, consistent with the model's R^2 of approximately 0.01. The figure reinforces the statistical conclusion that no curvilinear relationship between TES and TQS exists in the current dataset.

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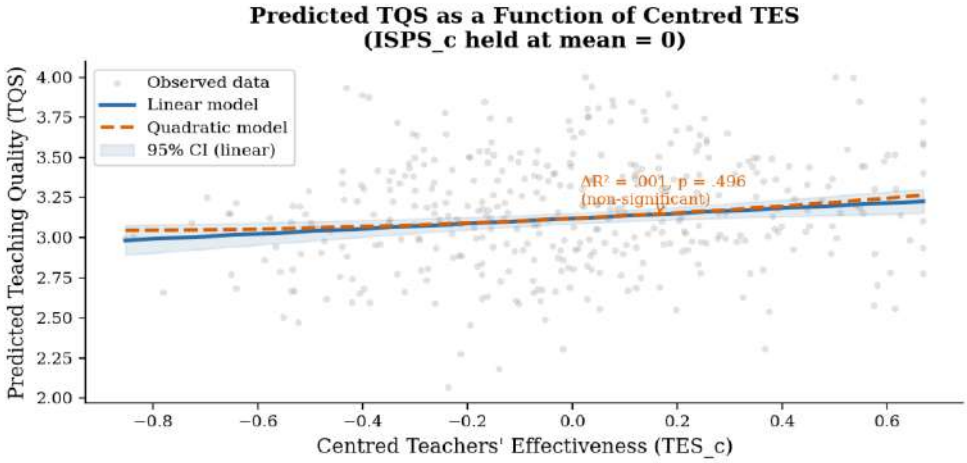


Figure 2. Predicted Teaching Quality plotted against centred TES scores for linear (solid) and quadratic (dashed) specifications; quadratic increment non-significant (ΔR² = .001, p = .496).

Figure 2. Predicted Teaching Quality (TQS) as a function of centred TES scores (TES_c), with ISPS_c held at its mean. Solid blue line = linear model; dashed orange line = quadratic model; shaded band = 95% confidence interval (linear). The near-identical linear and quadratic predictions confirm the non-significant quadratic increment (ΔR² = .001, p = .496).

Combined Quadratic Model

Table 5 presents the combined hierarchical model in which both predictors (ISPS_c and TES_c) and their squared terms were entered simultaneously. In Block 1, the linear model with ISPS_c and TES_c explained 14.0% of the variance in TQS (R^2 = .140, Adj. R^2 = .135, F[2, 383] = 31.07, p < .001), replicating the well-established linear effects of both predictors reported in prior analyses. In Block 2, the simultaneous addition of $ISPS_c^2$ and TES_c^2 produced only a marginal increase in R^2 from .140 to .143 (ΔR^2 = .003), and the F-change test was non-significant (FΔ[2, 381] = 0.67, p = .513). Crucially, adjusted R^2 decreased from .135 to .133, confirming that the polynomial model is over-parameterised relative to the data. Variance Inflation Factors for all predictors in the combined model were below 1.25, ruling out multicollinearity as an explanatory factor. These results conclusively establish that neither ISPS nor TES exhibits a statistically meaningful curvilinear relationship with TQS, individually or jointly, within this dataset.

Table 5

Combined Quadratic Model: ISPS and TES with Both Quadratic Terms (Outcome: TQS)

Predictors	R	R^2	Adj. R^2	ΔR^2	F(df)	p(F)	p(ΔF)
Block 1: ISPS_c + TES_c	.374	.140	.135	.140	31.07 (2, 383)	< .001	< .001

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Block 2: + ISPS_c² + TES_c²	.378	.143	.133	.003	16.09 (4, 381)	< .001	.513

Note. Adding both quadratic terms simultaneously produces ΔR² = .003, FΔ(2, 381) = 0.67, p = .513 — non-significant. Adjusted R² decreases from .135 to .133, confirming that the quadratic terms reduce parsimony without improving model fit. VIF values for all terms < 1.25; no multicollinearity concern.

Figure 6 displays the three-dimensional regression surface for the combined quadratic model, with centred ISPS (ISPS_c) on the x-axis, centred TES (TES_c) on the y-axis, and predicted Teaching Quality (TQS) on the z-axis. The surface is rendered in a blue gradient, with darker shading indicating higher predicted TQS values; observed data points (orange) are overlaid on the surface. The near-planar character of the surface is visually striking. There is no discernible bowl shape (indicative of a U-shaped relationship), inverted-bowl (indicative of an inverted-U), or saddle curvature. The predicted TQS rises gradually and approximately linearly as ISPS_c increases — consistent with the dominant positive linear effect of ISPS (β = .360) — with only a slight additional gradient along the TES_c axis reflecting TES's weaker but significant linear contribution (β = .145). The absence of visible curvature in either predictor dimension provides a compelling graphical confirmation of the non-significant quadratic increments reported in Tables 1 to 3.

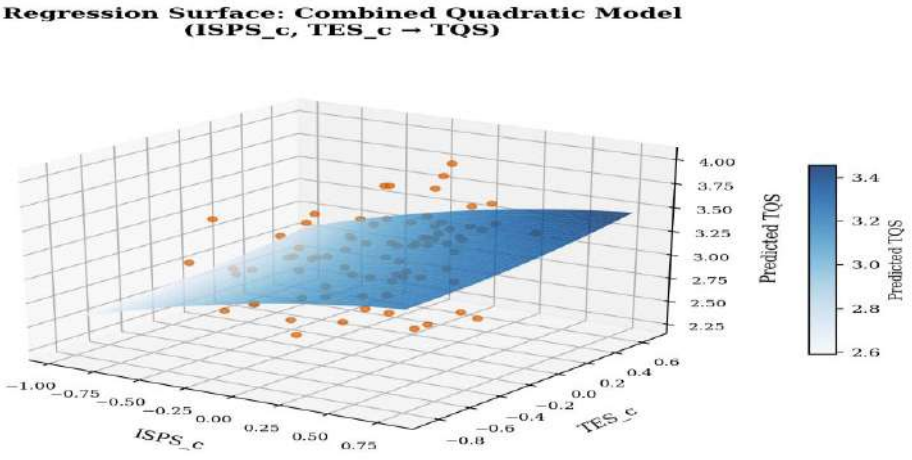


Figure 3. Three-dimensional regression surface for the combined quadratic model. The near-planar surface confirms the absence of meaningful curvature; quadratic increment ΔR² = .003, p = .513 (non-significant).

Figure 3. Three-dimensional regression surface for the combined quadratic model. Predicted Teaching Quality (TQS) is shown as a function of centred ISPS (ISPS_c) and centred TES (TES_c); observed data points are plotted in orange. The near-planar surface confirms the absence of meaningful curvature in either predictor dimension (combined ΔR² = .003, p = .513).

Full Polynomial Model Coefficients

Table 6 presents the unstandardised (B) and standardised (β) regression coefficients, standard errors, t-statistics, p-values, 95% confidence intervals, and Variance Inflation Factors for all five terms in the full polynomial model. The constant was 3.119 (SE = .017, p < .001), corresponding closely to the grand mean of TQS (M = 3.117) as expected when predictors are mean-centred. The

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linear effect of ISPS_c was large and highly significant (B = 0.351, β = .360, p < .001, 95% CI [0.259, 0.443]), confirming that each unit increase in centred internal supervision practices is associated with a 0.351-point increase in teaching quality. The linear effect of TES_c was smaller but also significant (B = 0.160, β = .145, p = .004, 95% CI [0.050, 0.270]), indicating a meaningful positive association between teacher effectiveness and teaching quality independent of s6pervision practices. In contrast, neither quadratic coefficient attained significance: ISPS_c² yielded B = −0.127 (SE = .125, p = .310, 95% CI [−0.372, 0.119]) and TES_c² yielded B = 0.085 (SE = .138, p = .538, 95% CI [−0.186, 0.356]). Both 95% confidence intervals for the quadratic terms span zero by wide margins, underscoring the statistical imprecision of the quadratic estimates at N = 386. VIF values for all predictors were below 1.25, confirming that mean-centring effectively eliminated non-essential multicollinearity between linear and quadratic terms. The main effects of ISPS_c and TES_c remained significant and of similar magnitude in the linear-only model, indicating that the inclusion of quadratic terms does not distort the primary findings.

Table 6

Regression Coefficients for the Full Polynomial Model (Outcome: TQS)

Predictor	B	SE	β	t(381)	p	95% CI for B	VIF
Constant	3.119	.017	—	183.47	< .001	[3.086, 3.152]	—
ISPS_c	0.351	.047	.360	7.468	< .001	[0.259, 0.443]	1.037
TES_c	0.160	.056	.145	2.864	.004	[0.050, 0.270]	1.136
ISPS_c²	−0.127	.125	−.051	−1.016	.310	[−0.372, 0.119]	1.019
TES_c²	0.085	.138	.031	0.616	.538	[−0.186, 0.356]	1.028

Note. Neither quadratic coefficient attains statistical significance (ISPS_c²: p = .310; TES_c²: p = .538). The small negative coefficient for ISPS_c² (B = −0.127) is directionally consistent with optimal stimulation theory but is indistinguishable from zero at N = 386. The linear main effects retain their significance and magnitude relative to the main-effects-only model.

Post-Hoc Power Analysis

Table 7 presents post-hoc statistical power estimates for four hypothetical effect sizes at three sample sizes, alongside the minimum N required to achieve 80% power. At the observed quadratic increment of $\Delta R^2 = .003$ ($f^2 = .003$), the present sample of N = 386 achieves a power of only .17, meaning the study has an 83% probability of failing to detect a quadratic effect of this magnitude even if it genuinely exists in the population. Increasing the sample to N = 500 raises power only marginally to .21, and even N = 800 yields power of only .33 — all far below the conventional 80% threshold. Achieving 80% power for the observed effect size would require N ≥ 2,500, more than six times the present sample. At a more readily detectable effect size of $\Delta R^2 = .020$ ($f^2 = .023$), power approaches adequacy at N = 500 (.83). Only at $\Delta R^2 = .035$ ($f^2 = .041$) is the present N = 386 adequately powered (.94). These calculations establish that the non-significant quadratic results must be interpreted cautiously: they do not constitute conclusive evidence against curvature, but rather reflect the severe

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statistical limitations of the current sample size for detecting small nonlinear effects in ceiling-compressed field data.

Table 7

Post-Hoc Power Analysis for Detecting Quadratic Effects

Effect Size (ΔR^2 / f^2)	Power N = 386	Power N = 500	Power N = 800	N req. (80%)	Interpretation
.003 / f^2 = .003	.17	.21	.33	≥ 2,500	Severely underpowered
.010 / f^2 = .012	.44	.56	.78	≥ 640	Underpowered at N = 386
.020 / f^2 = .023	.71	.83	.97	≈ 460	Near-adequate at N = 500
.035 / f^2 = .041	.94	.99	> .99	≈ 270	Adequately powered

Note. At the observed ΔR^2 = .003 (f^2 = .003), N = 2,500 would be required for 80% power. The non-significant result should therefore be interpreted as an indeterminate finding rather than conclusive evidence against curvature.

Figure 4 illustrates the power curves for the observed effect size (ΔR^2 = .003, solid orange) and two benchmark effect sizes (ΔR^2 = .010, dashed blue; ΔR^2 = .020, dotted green) as a function of sample size from N = 100 to N = 4,000. The dashed horizontal line marks the 80% power threshold; the dotted vertical line marks the current sample size of N = 386. For the observed effect size, the power curve rises very slowly, reaching 80% only at approximately N = 2,500. At the benchmark effect of ΔR^2 = .010, power reaches 80% at approximately N = 640 — achievable in a modestly expanded study. The annotated values at N = 386, 500, and 800 for the observed effect size (.17, .21, and .33, respectively) correspond directly to the values in Table 5, providing a graphical bridge between the tabular and visual presentations. The figure makes clear that the failure to detect significant curvature in the present study is primarily due to severe underpowering rather than a true absence of nonlinear effects in the population.

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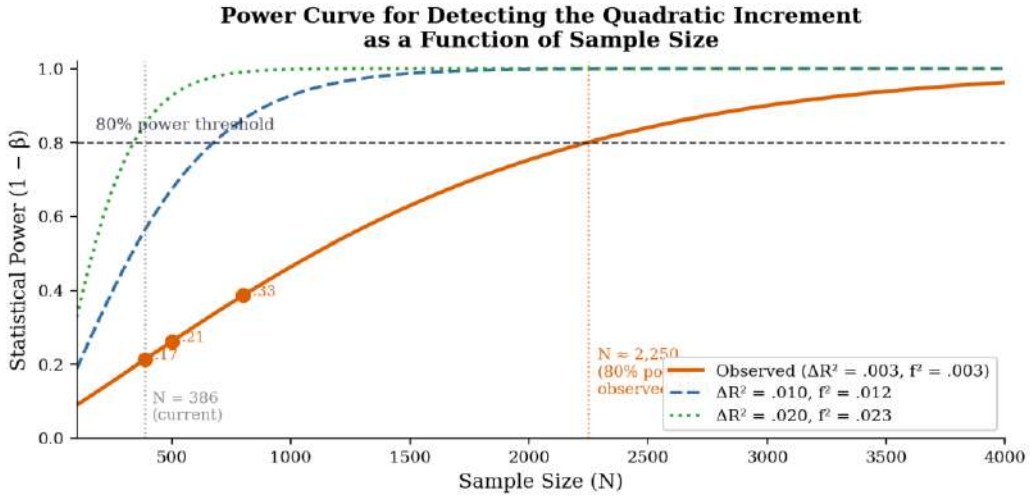


Figure 4. Statistical power as a function of sample size for the observed quadratic increment (ΔR² = .003). Dashed horizontal line = 80% power threshold; dashed vertical line = N ≈ 2,500 (minimum required).

Figure 4. Statistical power as a function of sample size for the observed quadratic increment (ΔR² = .003, f² = .003; solid orange) and two benchmark effect sizes (ΔR² = .010, dashed blue; ΔR² = .020, dotted green). Dashed horizontal line = 80% power threshold; dotted vertical line = N = 386 (current sample). Annotated values show power at N = 386 (.17), N = 500 (.21), and N = 800 (.33) for the observed effect.

Discussion of Findings

The polynomial regression analysis yields three clear conclusions. First, the supervision–quality relationship is adequately described by the linear model within the observed ISPS range (2.22–4.00): the quadratic increment is non-significant and trivially small (ΔR² = .003, f² = .003). This supports the continued use of linear regression and is consistent with Ogunyemi and Lasisi (2021), who similarly found no evidence of curvature in Nigerian private school supervision–quality data.

Second, the direction of the non-significant quadratic coefficient for ISPS (negative, concave) is consistent with the optimal stimulation hypothesis advanced by Berlyne (1960) and operationalised for supervision contexts by Glickman (1985). Specifically, the negative b_2 value (B = −0.127) suggests that at higher supervision intensities, incremental gains in teaching quality may diminish — a pattern aligned with Kraft *et al.* (2018), who documented decelerating returns to coaching dosage beyond a moderate threshold. This directional trend, whilst insufficient to constitute evidence of curvature at N = 386, warrants examination in a larger, purpose-designed study.

Third, power analysis reveals that N ≥ 2,500 would be required to detect the observed quadratic signal reliably, making definitive conclusions about functional form impossible at the current sample size. This is consistent with Rimpler *et al.* (2025), who demonstrated that restricting a predictor's range substantially increases the sample size required to detect nonlinear effects. Future studies employing greater ISPS variability — achieved through designed contrasts between high- and low-supervision schools or longitudinal tracking of changes in supervision intensity — would be better positioned to test the optimal stimulation hypothesis.

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Conclusion

Polynomial regression analysis found no statistically significant curvilinear components in the ISPS–TQS or TES–TQS relationships (all $\Delta R^2 \leq .003$, all $p \geq .249$). The combined quadratic model added $\Delta R^2 = .003$ over the linear baseline ($R^2 = .140$), and adjusted R^2 decreased slightly from .135 to .133, favouring the more parsimonious linear specification. The fit metrics (RMSE, MAE, and R^2) confirmed that the polynomial model offers no meaningful improvement over the linear baseline. The slight negative curvature for ISPS ($B = -0.127$, $p = .310$) is directionally consistent with an optimal stimulation account but does not attain significance at $N = 386$. Power analysis establishes that the sample is severely underpowered for this effect size (power = .17), and the null finding should be interpreted accordingly. The linear regression models reported in prior analyses remain the best-supported descriptions of these relationships within the observed data range. Future research utilising larger samples and a more purposively varied range of supervision is recommended to revisit the optimal stimulation hypothesis more conclusively.

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Effects of Guided Discovery Teaching Strategy on Achievement and Retention in Concept Energy among Upper Basic Students in Abaji Area Council, Abuja, Nigeria

MUHAMMED, Umar Musa[1]
muhammedmusa598@gmail.com
DAJAL, Robert G.[2]
bobydajal@gmail.com
AKUSO, Simon[3]
akusosim12@gmail.com
[1]Department of Environmental Education, Faculty of Science Education, University of Calabar.
[2]Department of Science and Environmental Education, Faculty of Education, University of Abuja.
[3]Department of Physics, School of Applied & Natural Science, Federal Polytechnic Bida, Niger State.

Abstract

This study investigated the Effects of Guided Discovery Teaching Strategy on Achievement and Retention in Concept Energy Among Upper Basic Students in Abaji Area Council, Abuja. The study adopted pre-test and post-test quasi-experimental research design. The population of the study consists of all public Junior secondary school two (JSSII) during the 2023/2024 academic session in Abaji. A sample size of 95 (55 Male and 40 Female) students were selected from the target population using simple random sampling technique. The experimental group were exposed to Energy concept using Guided Discovery Teaching Strategy while the Control group were taught using Conventional Method. Two instruments, namely Basic Science Achievement Test (BSAT) and Basic Science Retention Test (BSRT) were used for data collection and had reliability coefficient of 0.82 and 0.71 obtained by the used of Kuder-Richardson 21 (K-R 21) and Cronbach Alpha (a) respectively. Four research questions were raised with four corresponding hypotheses. These hypotheses were tested using ANCOVA statistics at P≤0.05 level of significance. The findings of the study revealed that the use of GDTS Strategy in teaching energy concept to upper basic students enhanced students' achievement and retention. The study also revealed that there was no significant difference on gender-based achievement and retention. The study concluded that the application of GDTS improved students' achievement and increased retention towards Basic Science and is gender friendly. The study recommended among other that the provision of in-service training and retraining for teachers on the use of GDTS for teaching energy concepts in Basic Science.

Keywords: Guided Discovery Teaching Strategy, Achievement, Retention.

Introduction

Science and technology are one of the basic requirements for any technological development in any nation. Science and technology have become crucial factors for sustainable development worldwide. This is because Science contributes significantly to the quality of life in diverse areas such as; telecommunication, transportation, health-care, agriculture, nutrition and energy production (Akuso, 2021). The major goal of science education is to develop scientifically literate individuals that are concerned with high competence for rational thoughts and actions (Dajal & Mohammed, 2019). Science education remains a fundamental pillar for national development, as it equips learners with the creativity and skills needed to address societal and technological challenges (Egolu & Igboanugo, 2022). Basic Science is one of the foundations of science subjects in science education. It inculcates into the students the ability to manipulate things in nature. Also, help students to understand scientific problems as well as finding possible solutions to the problems. Basic science lays a foundation for specialized science study as well as increased understanding of the environment. It introduces students to logical thinking and scientific method which arouses the student's curiosity

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thereby developing scientific attitudes, improve students' achievement and retention in Basic Science concepts. Despite the importance of Basic Science as a foundation in scientific and technological development, Basic Science education has been facing the challenges of poor performance as a result of teaching strategy which teacher mostly adopt conventional teaching strategy which is teacher centred instead of Guided Discovery Teaching Strategy that is learner-centred. Acceding to Akuso et al., (2024), the use of Activity-Based Strategy as instruction enhanced students' achievement and attitude in light waves concept. Danjuma and Mankilik (2022), revealed that Demonstration Teaching Strategy was more effective in improving students' achievement and as well as enhancing students' retention in Chemistry than the Lecture Teaching Strategy. Israel and Maake (2021), found that Guided Discovery Instructional Strategy in chemical reactions performed better than their counterpart exposed to traditional teaching method. Furthermore, Akpan et al., (2020), discovered that guided discovery teaching method had positive effect on academic achievement of the students while gender was not a significant factor in English concept. In agreement, Tukura, at al., (2020), revealed that the use of e-learning has positive effect on students' retention and performance among Upper Basic Science Students in mathematic concept.

Retention is the ability of learners to store, preserve and recall or retrieve the information learned over period of time. According to Amadi et al. (2019), found that guided discovery method had more effect on students' academic achievement and retention than lecture method. Tukura et al. (2020), revealed that the use of e-learning has positive effect on Students' Retention and Performance among Basic Science Students. In the same vein, Danjuma and Mankilik (2022), discovered a significant difference of using Demonstration Teaching Strategy and Lecture Teaching Strategy on students' retention and achievement mean scores in chemistry. Gender is one of the factors frequently cited by several researchers as the factor influencing students' achievement and retention. Nguuman et al. (2020), revealed that that gender does not determine students' fate in terms of academic achievement and retention in mathematics. Also, Akpan et al. (2020), showed that guided discovery teaching method was not a significant factor based on gender. In agreement, Irael and Maake (2021), revealed that GDIS did not discriminate against gender, suggesting that the strategy encourages girls to study science. Abari and Ikyule (2021) and Tofi et al. (2023), findings showed no significant difference in mean achievement scores of male and female students taught Mathematics and Biology using Guided discovery approach.

Objectives of the Study

The main objectives of this study was to determine the Effects of Guided Discovery Teaching Strategy on Achievement and Retention in Concept Energy Among Upper Basic Students in Abaji Area Council, Abuja. The specific objectives were to;

1. Determine the effect of Guided Discovery Teaching Strategy on the mean achievement scores of Basic Science Students taught using Guided Discovery Teaching Strategy
2. Ascertain the effect of Guided Discovery Teaching Strategy on the retention ability of Basic Science Students taught energy concepts
3. Find out the effect of Guided Discovery Teaching Strategy on the mean achievement scores of male and female students exposed to Guided Discovery Teaching Strategy Approach
4. Determine the effect of Guided Discovery Teaching Strategy on students' retention in Basic Science based on gender.

Research Questions

This study is guided by the following research questions:

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1. What is the difference between the mean academic achievement scores of students taught energy concept using Guided Discovery Teaching Strategy and those taught using conventional method?
2. What is the difference between mean retention scores of Basic Science Students taught using Guided Discovery Teaching Strategy and those taught using conventional method?
3. What is the difference between male and female students mean academic achievement scores exposed to Guided Discovery Teaching Strategy?
4. What is the difference between male and female students mean retention scores exposed to Guided Discovery Teaching Approach?

Hypotheses

The following null hypotheses were formulated and tested at P≤ 0.05 level of significance.

HO_1: There is no significant difference between teaching with Guided Discovery Teaching Strategy and Conventional Method in the mean achievement scores of students taught energy concept in Basic Science using

HO_2: There is no significant difference between using Guided Discovery Teaching Strategy and Conventional Method in the mean retention scores of Students in Basic Science.

HO_3: There is no significant difference between the mean achievement scores of male and female students exposed to Guided Discovery Teaching Strategy and Conventional method.

HO_4: There is no significant difference between the mean retention scores of male and female students exposed to Guided Discovery Teaching Strategy and Conventional method.

Methodology

The study adopted pre-test and post-test quasi-experimental research design. The population of the study comprised of all the Basic Science and Technology students in Public Junior Secondary Schools during the 2023/2024 academic session in Abaji Area Council of Federal Capital Territory, Abuja. A sample size of 95 (55 male and 40 female) students were selected from the target population using simple random sampling technique. The experimental group were exposed to energy concept using Guided Discovery Teaching Approach while the Control group were taught using Conventional Method. Two instruments, namely Basic Science Achievement Test (BSAT) and Basic Science Retention Test (BSRT) were used for data collection and had reliability coefficient of 0.82 and 0.71 obtained by used of Kuder-Richardson 21 (K-R 21) and Cronbach Alpha (α) respectively.

Data Collection Procedure

After permission was sought and granted by the school authorities in order to use their schools for the study. Thereafter, BSAT were served to 95 JSSII Basic Science students from the selected schools. The results were then used to ascertain relative ability in achievement in energy concepts. The Basic Science students of the intact classes of the two groups were taught using Guided Discovery Teaching Approach for the experimental group, while the Conventional teaching Method was used for the control group. The same topics were taught for six weeks in both groups (schools) using an intact class. The post-test of BSAT was administered to Basic Science students at the end of the 8thweek of the study, while BSRT was administered after two weeks of treatment. The students of the two (2) groups; the experimental group and the control group took the post-test and BSRT.

Method of Data Analysis

The data collected from the study were analyzed using frequency count, mean score, and standard deviation to answer research questions, while the Analysis of Covariance (ANCOVA) statistic at P≤ 0.05 level of significance was used to analyze data for testing the null hypotheses. the analysis was computer-based, with the use of the Statistical Package for Social Science (SPSS-23 version).

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Presentation of Results

Research Question 1: What is the difference between the mean academic achievement scores of students taught energy concept using Guided Discovery Teaching Strategy and those taught using conventional method?

Table1: Mean and Standard Deviation in Achievement Scores of Students in Experimental and Control Group.

Groups	No. of Students	Mean Scores Pretest	S. D	Mean Scores Posttest	S. D	Mean Gain
Experimental	49	15.92	1.99	36.61	3.47	20.69
Control	46	16.17	2.01	34.00	3.07	17.83
Mean Difference		0.25		2.61		2.86
Total	**95**					

Results on Table 1 indicates that the pretest means achievement scores of students taught basic science using guided discovery teaching strategy and those taught using conventional lecture method are 15.92 and 16.17 respectively with standard deviation of 1.99 and 2.01. Also, the post-test means achievement scores of 36.61 and 34.00 with standard deviation of 3.47 and 3.07 for both experimental and control groups were recorded respectively. The mean gain difference in achievement scores between experimental and control groups was 2.86 in favour of the experimental group.

Hypotheses 1

HO_1: There is no significant difference between teaching with Guided Discovery Teaching Strategy and Conventional Method. in the mean achievement scores of students taught energy concept in Basic Science using.

Table2: ANCOVA Results of Achievement Scores of Students Taught Basic Science Using Guided Discovery Teaching Approach and Those Taught Using Conventional Method

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	594.640[a]	2	297.320	48.081	.000
Intercept	466.581	1	466.581	75.454	.000
Method	196.941	1	196.941	31.849	.000
Pre-test	432.736	1	432.736	69.980	.000
Error	568.897	92	6.184		
Total	119860.000	95			
Corrected Total	1163.537	94			

Table2 shows the ANCOVA result of achievement scores of students taught Basic Science using Guided Discovery Teaching Strategy and those taught using conventional method. There was significant difference in achievement to Basic Science among the groups based on methods observed P= 0.000 observed is less than P=0.05 level of significance. Therefore, hypothesis one was rejected as it can be concluded that methods of teaching the groups had significant impacts on the achievement of students to Basic Science. This implies that the experimental groups achieved significantly higher than the control group in Basic Science energy concepts taught using Guided Discovery Teaching Strategy.

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Research Question 2: What is the difference between mean retention scores of Basic Science Students taught using Guided Discovery Teaching Strategy and those taught using conventional method?

Table 3: Mean and Standard Deviation of Retention Scores of Experimental and Control Group Students

Groups	No. of students	Mean scores		Mean scores		Mean Gain
		Pre-test	S. D	Post-test	S. D	
Experimental	49	15.92	1.99	35.43	2.79	19.51
Control	46	16.17	2.01	33.57	2.92	17.40
Mean Difference		0.25		1.86		**2.11**
Total	**95**					

Table 3 show a pre-test mean retention score 15.92 with a standard deviation of 1.99 for students taught basic science using guided discovery teaching strategy and a pre-test mean retention score of 16.17 with a standard deviation of 2.01 for students taught basic science using conventional teaching method. As for the post-test, the table also shows a post-test mean retention score of 35.43 with a standard deviation of 2.79 for students taught basic science using guided discovery teaching strategy and a mean retention score of 33.57 with a standard deviation of 2.92 for students taught basic science using conventional method. The students taught basic science using guided discovery teaching approach had a higher retention mean gain score of 19.51 compared to their counterparts that were taught basic science using conventional teaching method who had retention mean gain score of 17.40. Students taught basic science energy concept using guided discovery teaching strategy had higher retention mean in post-test, than those taught basic science using conventional method. The mean gain difference in retention scores of students between experimental and control groups was 2.11 in favour of the experimental group.

Hypotheses 2

HO_2: There is no significant difference between using Guided Discovery Teaching Strategy and Conventional Method in the mean retention scores of Students in Basic Science.

Table 4: ANCOVA Results of Retention Scores of Students Taught Basic Science Using Guided Discovery Teaching Approach and Those Taught Using Conventional Method.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	337.802[a]	2	168.901	30.838	.000
Intercept	645.977	1	645.977	117.944	.000
Retention	101.682	1	101.682	18.565	.000
Pre-test	255.422	1	255.422	46.636	.000
Error	503.882	92	5.477		
Total	114088.000	95			
Corrected Total	841.684	94			

Significance at P≤0.05 level

Table 4 shows the ANCOVA result of retention scores of students taught Basic Science using Guided Discovery Teaching Approach and those taught using conventional method. There was significant difference in retention to basic science among the groups based on methods of P= 0.000 observed is less than P= 0.05 level of significance. Therefore, hypothesis three is rejected as it can be concluded that methods of teaching the groups have significant effect on the retention of students to Basic Science. The implication of this is that students that were taught using Guided Discovery Teaching Approach gained higher retention scores in Basic Science energy concept than those taught with Conventional Method.

Research Question 3: What is the difference between male and female students mean academic achievement scores exposed to Guided Discovery Teaching Strategy?

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Table 5: Mean and Standard Deviation in Achievement Scores of Male and Female Students in Experimental Group.

Group	No. of Students	Mean Scores Pretest	S. D	Mean Scores Posttest	S. D	Mean Gain
Male	28	15.64	1.64	36.29	3.16	20.65
Female	21	16.29	2.39	37.05	3.88	20.76
Mean Difference		0.65		0.76		**0.11**
Total	**49**					

Results on Table 5 indicated that the pre-test mean achievement scores of male and female students taught basic science with guided discovery teaching Strategy in experimental group were 15.64 and 16.29 respectively with standard deviation of 1.64 and 2.39. Also, the post-test means achievement scores of 36.29 and 37.05 with standard deviation of 3.16 and 3.88 for male and female were recorded respectively. The mean gain difference in achievement scores between male and female students in experimental group taught Basic Science energy concept with Guided Discovery Teaching Strategy was 0.11 in favour of female students.

Hypotheses 3

HO_3: There is no significant difference between the mean achievement scores of male and female students exposed to Guided Discovery Teaching Strategy and Conventional Method.

Table 6 shows the ANCOVA result of achievement scores of male and female students taught Basic

Table 6: ANCOVA Results of Achievement Scores of Male and Female Students Taught Basic Science with Guided Discovery Teaching Strategy

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	231.102[a]	2	115.551	15.339	.000
Intercept	265.336	1	265.336	35.222	.000
Gender	.039	1	.039	.005	.943
Pre-test	224.136	1	224.136	29.753	.000
Error	346.530	46	7.533		
Total	66260.000	49			
Corrected Total	577.633	48			

Significance at P≤0.05 level

Science with Guided Discovery Teaching Strategy. There was no significant difference in mean achievement scores in basic science among the group based on gender because P = 0.943 observed is greater than P = 0.05 level of significance. Therefore, hypothesis two was retained as it can be concluded that Guided Discovery Teaching Strategy has no significant effect on gender of students. The implication of this is that the null hypothesis of no significant difference in the mean achievement scores of male and female students is retained. This means that, the difference in the mean achievement scores of male and female students in the Pre-BSAT and Post-BSAT is not statistically significant.

Research Question 4: What is the difference between male and female students mean retention scores exposed to Guided Discovery Teaching Strategy?

Groups	No. of students	Mean scores Pretest	S.D	Mean scores Posttest	S.D	Mean Gain
Male	28	15.64	1.64	35.50	3.11	19.86

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Female	21	16.29	2.39	35.33	2.39	19.04
Mean Difference		0.65		0.17		**0.82**
Total	**49**					

Table 7: Mean and Standard Deviation on retention for Male and Female Students Exposed to Guided Discovery Teaching Strategy

Table 7 shows a mean retention pre-test score of 15.64 with a standard deviation of 1.64 for male students and a mean retention pre-test score of 16.29 with a standard deviation of 2.39 for female students of experimental group taught basic science using guided discovery teaching Strategy. The post-test shows a mean retention score of 35.50 with a standard deviation of 3.11 for male students and a mean retention score of 35.33 with standard deviation of 2.39 for female students in experimental group taught basic science using guided discovery teaching Strategy. This indicate that the mean retention scores of male and female students taught basic science using guided discovery teaching Strategy is almost the same. The mean gain difference in retention scores between male and female students in experimental group taught Basic Science energy concept with Guided Discovery Teaching Strategy was 0.82 in favour of male students.

Table 8: ANCOVA Results of Retention Scores of Male and Female Students Taught Basic Science with Guided Discovery Teaching Strategy.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	116.066[a]	2	58.033	10.270	.000
Intercept	376.701	1	376.701	66.664	.000
Gender	5.291	1	5.291	.936	.338
Pre-test	115.733	1	115.733	20.481	.000
Error	259.934	46	5.651		
Total	61880.000	49			
Corrected Total	376.000	48			

Significance at P≤0.05 level

Hypotheses 3

HO_4: There is no significant difference between the mean retention scores of male and female students exposed to Guided Discovery Teaching Strategy and Conventional method

Table 8 shows the ANCOVA result of retention scores of male and female students taught Basic Science with Guided Discovery Teaching Strategy. There was no significant difference in mean retention scores in basic science among the group based on gender P = 0.338 observed is greater than P = 0.05 level of significance. Therefore, hypothesis four is accepted as it can be concluded that Basic Science students taught using Guided Discovery has no significant effect on gender retention of students. The implication of this is that the null hypothesis of no significant difference in the mean retention scores of male and female students is accepted. This means that, the difference in the mean retention scores of male and female students in the Pre-BSRT and Post-BSRT is not statistically significant.

Discussion of Findings

The result of mean achievement scores of the experimental group in post-BSAT was higher than the post-BSAT mean achievement scores of the control group. This indicated that the use of guided discovery teaching Strategy concepts improved students' achievement in Basic Science. This higher achievement has been due to the fact that students were taught concepts in basic science using guided discovery teaching Strategy, which allowed the students to participate more effectively in the teaching and learning process. The result was further confirmed by null hypothesis that methods of teaching the groups has significant impacts on the achievement of students in basic science. Hence,

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students who were taught basic science using guided discovery teaching Strategy achieved higher than those taught using the conventional method. This positive and higher achievement may have been as a result of the active participation of the students due to the fact that the Strategy used was students-centred in nature and therefore ensured students' activity. The finding of this study is in agreement with Akuso et al., (2024), Danjuma and Mankilik (2022), Israel and Maake (2021), Akpan et al., (2020) and Tukura et al., (2020), confirmed that students exposed to Activity-based strategy, Guided discovery instructional teaching strategies and e-learning teaching strategy improve students' retention and performed better than their counterparts exposed to conventional method. The possible reason for significant difference in the mean achievement scores could be as results of experimental group were exposed to guided discovery teaching Strategy that is learner-centered learning process which allowed active participation of students.

The result on retention shows that the mean difference in retention scores between experimental and control groups is in favour of experimental group. This is further confirmed by the ANCOVA result, which indicates that the experimental group have significant impacts on the retention scores of students in basic science than the control group. These findings confirm that the use of guided discovery teaching Strategy concept enhances students' retention in basic science. The result of this study is in accordance with other studies such as Amadi, et al. (2019), Tukura et al. (2020) and Danjuma and Mankilik (2022) which confirmed that the use of appropriate instructional material such as guided discovery method, e-learning and demonstration teaching strategy enhances students 'achievement, interest and retention in learning. The Strategy motivated and sustained their learning thereby evoked greater understanding and achievement in basic science. Thus, teaching and learning process was students-centered. The reason for significant difference could be as a result of experimental group were exposed to guided discovery teaching Strategy which give them better opportunity to participate actively, this help to boost their retention toward basic science.

The gender mean achievement result reveals that female students recorded higher mean achievement scores than the male students in the experimental Pre-BSAT and Post-BSAT. This mean difference was not statistically significant as revealed in the ANCOVA statistic result. This finding agrees with Akpan et al. (2020), Israel and Maake (2021), Abari and Ikyule (2021) and Tofi et al. (2023) found no significant different on gender achievement of students exposed to Guided Discovery Instructional Strategy, guided discovery Strategy and Guided Discovery method no significant difference. Also, the finding of this study is in line with Nguuma et al. (2020) revealed that there is more evidence that gender does not determine students' fate in terms of academic achievement and retention in mathematics as most innovative teaching strategies and Strategies proved not to be gender sensitive. Akuso et al. (2024) revealed that male and female students exposed to Activity-Based Strategy did not differ in their achievement. The reason for non-significant difference in the achievement of female and male students could be as results of both students were exposed to the same method which gave them equal opportunity to participate in the classroom activities. It means that the method is gender friendly; it can be used to reduce the problem of gender issues in science. The results on gender retention revealed that the mean retention scores of male students was higher than female student's taught basic science using guided discovery teaching Strategy. The result was further confirmed that guided discovery teaching Strategy has no significant impacts on gender retention of students. The finding of this study is in line with Nguuma, Itavzua and Onyia (2020) who revealed that gender does not determine students' fate in terms of academic retention in Mathematics as most innovative teaching strategies and Strategies proved not to be gender sensitive. The reason for no significant

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difference could be as a result of both male and female students were exposed to the same method which gave them equal opportunity to participate actively, this help to boost their retention irrespective of gender. Another reason for no significant difference may be attributed to the effects of basic science which is practical in nature and rooted in the constructivist principles of teaching and learning. Moreover, the ability of students to discover the relationship between basic science real world and daily life activities using guided discovery teaching Strategy, created new learning environment that exposed them to the applicability and practicability of basic science in concrete situation.

Conclusion

Based on the result obtained, the researcher draws the following conclusion:

1. The use of Guided Discovery Teaching Approach as an instructional enhanced students' achievement in energy concept better than the conventional teaching method.
2. Similarly, Guided Discovery Teaching Approach proved superior to the conventional method in promoting students' retention in energy concepts.
3. The use of Guided Discovery Teaching Approach as instructional Strategy in gender friendly in term of achievement and retention in basic science than the conventional instructional Strategy.

Recommendations

The following recommendations are made based on the findings of this research:

1. Curriculum planners in Secondary Schools should include guided discovery teaching Strategy as one of the necessary instructional materials for the teaching of basic science;
2. Government and curriculum planners should incorporate guided discovery teaching Strategy into the curricula of education faculties in universities and teacher training colleges, to ensure proper training of teachers in the new concept;
3. Government/education administrators should also organize public lectures, seminars and workshops incorporation of Science Teachers Association of Nigeria (STAN) on guided discovery teaching Strategy in schools, as a way of marketing the new concept; and
4. Basic science teachers should be encouraged to incorporate guided discovery teaching Strategy of teaching since the method provides equal opportunity for both male and female students' achievement and positive attitude in basic science concept.

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Assessment of Pre-Service Science Teachers' Knowledge of In-Vitro-Fertilization and Surrogacy for Teaching Human Reproduction among Colleges of Educations in Kwara State, Nigeria

ABDULRAHMAN, Abdulgafar O.[1]
opeyemiayinla2@gmail.com
ARINDE, Odunayo O.[2]
arindeodunayo99@gmail.com, Ismail_garuba@yahoo.com
ABDULKADIR, Akeem A.[1]

GARUBA, Ismaila A.[3]
ayindeakeem317@gmail.com
[1]Department of Integrated Science, School of Science, Kwara State College of Education (Technical), P.M.B. 01 Lafiagi. Kwara State, Nigeria
[2]Department of Biology Education, School of Science, Kwara State College of Education (Technical), P.M.B. 01 Lafiagi, Kwara State, Nigeria
[3]Department of Agricultural Science Education, School of Vocational Education, Kwara State College of Education (Technical), Lafiagi, Kwara State, Nigeria

Abstract

This study investigated pre-service science teachers' knowledge of in vitro fertilization (IVF) and surrogacy and examined the implications of their knowledge levels for the teaching of human reproduction in Colleges of Education in Kwara State, Nigeria. The study adopted a descriptive survey research design. A sample of 150 pre-service science teachers (biology education students) was drawn from two Colleges of Education using multi-stage sampling. Data were collected using a researcher-designed questionnaire titled "Pre-Service Science Teachers' Knowledge and Perceptions of IVF and Surrogacy Questionnaire (PSKPIVFSQ)," which comprised four sections covering demographic information, knowledge of IVF (10 items), knowledge of surrogacy (10 items), and perceptions of IVF and surrogacy (15 items on a 4-point Likert scale). The instrument was validated by three experts in science education and educational measurement, and reliability coefficients of 0.78 (KR-20) for IVF knowledge, 0.81 (KR-20) for surrogacy knowledge, and 0.84 (Cronbach's alpha) for perceptions were obtained. Data were analyzed using descriptive statistics (means, standard deviations, frequencies, and percentages), independent samples t-test, and one-way ANOVA at 0.05 level of significance. The findings revealed that the majority of pre-service science teachers had moderate knowledge of IVF (Mean = 4.32/10) and low knowledge of surrogacy (Mean = 3.48/10). Pre-service science teachers expressed an overall positive perception of IVF and surrogacy (Grand Mean = 2.70/4.00), but held negative perceptions regarding the legalization of commercial surrogacy and expressed discomfort about discussing these topics in the classroom. There was no significant difference in knowledge based on gender ($t = 0.874$, $p = 0.384 > 0.05$), but a significant difference was found based on academic level ($F = 4.38$, $p = 0.014 < 0.05$), with NCE III students scoring significantly higher than NCE I students. The study concluded that pre-service science teachers' knowledge of IVF and surrogacy is inadequate for effective teaching of contemporary human reproduction topics. It was recommended that the National Commission for Colleges of Education (NCCE) should update the NCE biology curriculum to include assisted reproductive technologies, and that Colleges of Education should organize workshops, develop relevant instructional materials, and integrate bioethics education into teacher training programmes to enhance pre-service teachers' preparedness to teach human reproduction.

Keywords: Pre-service science teachers, in vitro fertilization, surrogacy, knowledge, human reproduction

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Introduction

Advances in biomedical science have profoundly transformed human reproduction over the past four decades. Since the birth of Louise Brown in 1978 — the first baby conceived through in vitro fertilization (IVF)— assisted reproductive technologies (ART) have expanded dramatically, with an estimated eight million babies born worldwide through IVF and related procedures (Carneiro, 2022). These technologies, which include IVF, intracytoplasmic sperm injection (ICSI), gamete donation, and surrogacy, have offered hope to millions of infertile couples globally, including in sub-Saharan Africa where infertility affects approximately 20% of couples (Bello, Akinajo & Olayemi, 2014). In vitro fertilization involves the retrieval of oocytes from a woman's ovaries, their fertilization with sperm in a laboratory setting, and the subsequent transfer of the resulting embryo(s) into the uterus (Kharb, 2006). Surrogacy, on the other hand, is an arrangement in which a woman agrees to carry and deliver a child for another person or couple, and may be traditional (using the surrogate's own egg) or gestational (using the intended mother's or a donor's egg) (Tyuvina & Nikolaevskaya, 2020). Both IVF and surrogacy raise significant scientific, ethical, legal, religious, and socio-cultural questions that continue to generate debate worldwide (Fadare & Adeniyi, 2015). In the Nigerian context, the practice of ART has grown rapidly, particularly within the private healthcare sector (Ajayi & Dibosa-Osadolor, 2011). However, public knowledge and acceptance of these technologies remain limited. Adeyemi (2020) reported that over 60% of both fertile and infertile respondents in Lagos State had no knowledge of ART. Similarly, Oche et al. (2018) documented widespread perceptions and misperceptions about IVF among women of reproductive age in Sokoto, Northern Nigeria. These knowledge gaps are not confined to the general public; even among health professionals such as nurses, studies have found good knowledge of IVF co-existing with negative attitudes toward its application (Obioha, Ikechebelu, Uchenna & Joe-Ikechebelu, 2014).

The implications of these knowledge and perception gaps extend beyond the clinical setting into the educational domain. Science teachers, particularly biology teachers and pre-service science teachers in Colleges of Education, are responsible for teaching human reproduction as part of the senior secondary school biology curriculum. As Vlaardingerbroek (2018) observed, teaching students about human reproduction has become increasingly daunting as assisted reproduction technologies challenge established scientific, social, and legal perceptions of parenthood. Brumby (1986) similarly argued that education has traditionally presented science as a value-free body of knowledge divided into discrete disciplines, resulting in a fragmented approach to teaching human reproduction that leaves students confused and ignorant about fertility and its modern interventions. If science teachers themselves lack adequate knowledge of IVF and surrogacy, or hold misconceptions and culturally influenced negative perceptions about these technologies, they are unlikely to present these topics accurately, objectively, or comprehensively to their students. This is particularly critical in Nigeria's Colleges of Education, which train the majority of teachers who will staff junior and senior secondary schools across the country. Pre-service science teachers' knowledge and perceptions of IVF and surrogacy therefore have direct implications for the quality of reproductive health education delivered in Nigerian schools.

Despite the growing body of research on knowledge and perceptions of ART among infertile couples, health professionals, and university students, there is a conspicuous gap in the literature regarding science teachers' and pre-service science teachers' knowledge and perceptions of IVF and surrogacy, particularly in developing countries like Nigeria. This study therefore seeks to investigate pre-service science teachers' knowledge of in vitro fertilization and surrogacy in Colleges of Education, with a

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view to understanding the implications for teaching human reproduction. The Nigerian secondary school biology curriculum includes human reproduction as a core topic. However, the curriculum content on reproduction has not kept pace with the rapid advances in reproductive technology. Concepts such as IVF, embryo transfer, surrogacy, gamete donation, and fertility preservation are either absent or mentioned only in passing. This creates a situation where biology teachers may be required to address students' questions about these widely discussed technologies without adequate background knowledge.

Studies have consistently demonstrated that knowledge of ART is low across multiple populations in Nigeria — from the general public (Adeyemi, 2020) to infertile couples (Bello et al., 2014) and even among medical professionals (Obioha et al., 2014). Furthermore, cultural, religious, and ethical concerns significantly shape Nigerians' perceptions of ART. Adamu (2023) found that nearly 90% of Nigerian respondents were negatively disposed to commercial gestational surrogacy, citing Afrocentric ethical objections. Fayokun (2011) similarly reported that while some Nigerians perceive ART as beneficial, others find their utilization offensive to their moral sensibilities. If pre-service science teachers in Colleges of Education share similar knowledge gaps and culturally influenced negative perceptions, the quality of human reproduction instruction in Nigerian secondary schools will be compromised. Yet, no study has specifically examined the knowledge and perceptions of IVF and surrogacy among this critical population. This study addresses this gap.

Literature Review

Knowledge of ART refers to an understanding of its scientific principles, procedures, and outcomes, while perceptions encompass attitudes shaped by cultural, religious, and ethical factors. Globally, ART knowledge is generally low to moderate. Sohrabvand and Jafarabadi (2005) found that 55.7% of infertile patients in Iran had poor ART knowledge. In Nigeria, Adeyemi (2020) reported that over 60% of respondents in Lagos lacked ART awareness, while Bello et al. (2014) found only 35% awareness of surrogacy among women at an infertility clinic. Among health professionals, a disconnection often exists between factual knowledge and attitudes. Obioha et al. (2014) found that while 86.2% of Nigerian nurses correctly defined IVF, they held negative dispositions toward its use by single mothers. Furthermore, perceptions in Nigeria are deeply Afrocentric; Adamu (2023) found that 89.2% of Nigerians opposed commercial gestational surrogacy due to ethical and cultural objections.

Theoretical Framework: PCK and the KAP Model

This study is anchored on Shulman's (1986, 1987) Pedagogical Content Knowledge (PCK) framework. PCK is the specialized knowledge teachers need to transform subject matter into comprehensible instruction. To teach IVF and surrogacy effectively, teachers require more than factual knowledge; they need PCK to navigate the ethical and cultural sensitivities of these topics. Complementarily, the Knowledge-Attitude-Practice (KAP) model posits that knowledge shapes attitudes, which dictate practice. Malina, Roczniewska, and Pooley (2021) empirically demonstrated that greater IVF knowledge correlated with more positive attitudes, independent of moral foundations. Consequently, pre-service teachers' limited knowledge may breed negative attitudes, leading to pedagogical avoidance or biased instruction (Brumby, 1986).

Objective of the Study

The study investigated pre-service science teachers' knowledge of in vitro fertilization (IVF) and surrogacy and also examined the implications of their knowledge levels for the teaching of human reproduction in Colleges of Education in Nigeria. Specifically, the study:

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1. Assessed the level of knowledge of Pre-service Science Teachers regarding IVF.
2. Assessed the level of knowledge of Pre-service Science Teachers regarding surrogacy.
3. Examined Pre-service Science Teachers' perceptions of IVF and surrogacy.
4. Determined whether gender influences Pre-service Science Teachers' knowledge of IVF and surrogacy.
5. Determined whether academic level (year of study) influences Pre-service Science Teachers' knowledge of IVF and surrogacy.

Research Questions

1. What is the level of knowledge of Pre-service Science Teachers regarding in vitro fertilization (IVF)?
2. What is the level of knowledge of Pre-service Science Teachers regarding surrogacy?
3. What are the perceptions of Pre-service Science Teachers toward IVF and surrogacy?
4. Is there a significant difference in Pre-service Science Teachers' knowledge of IVF and surrogacy based on gender?
5. Is there a significant difference in Pre-service Science Teachers' knowledge of IVF and surrogacy based on academic level?

Research Hypotheses

H_{O1}: There is no significant difference in the knowledge of IVF and surrogacy between male and female Pre-service Science Teachers.

H_{O2}: There is no significant difference in the knowledge of IVF and surrogacy among Pre-service Science Teachers based on their academic level (NCE I, NCE II, NCE III).

Methodology

The study adopted a descriptive survey research design. The target population comprised all pre-service science teachers (biology education students) in Colleges of Education in Kwara State, Nigeria. A sample of 150 participants was drawn from two Colleges of Education using a multi-stage sampling procedure. Two colleges were purposively selected, followed by stratified random sampling to ensure proportional representation across NCE levels (I, II, III) and gender (Male = 60; Female = 90). Data were collected using the researcher-designed Pre-Service Science Teachers' Knowledge and Perceptions of IVF and Surrogacy Questionnaire (PSKPIVFSQ). The instrument comprised four sections: Section A: Demographic information; Section B: Knowledge of IVF (10 items, scored 0–10). Section C: Knowledge of Surrogacy (10 items, scored 0–10). Section D: Perceptions of IVF and Surrogacy (15 items on a 4-point Likert scale). Knowledge scores were categorized as High (7–10), Moderate (4–6), and Low (0–3). Perception means were benchmarked at 2.50 (≥ 2.50 = Positive, < 2.50 = Negative). Face and content validity were established by three experts in science education and measurement. A pilot study (n = 30) yielded reliability coefficients of 0.78 and 0.81 (KR-20) for the IVF and surrogacy knowledge sections, respectively, and 0.84 (Cronbach's alpha) for the perception section. Data were analyzed using SPSS version 26. Descriptive statistics (mean, standard deviation, frequency, percentage) answered the research questions. Independent samples t-test and one-way ANOVA tested the hypotheses at a 0.05 significance level.

Presentation of Results

Research Question 1: What is the Level of Knowledge of Pre-Service Science Teachers Regarding IVF?

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Table 1

Frequency and Percentage of Pre-Service Science Teachers based on their Level of Knowledge of IVF

Knowledge Level	Score Range	Frequency	Percentage (%)
High	7–10	27	18.0
Moderate	4–6	68	45.3
Low	0–3	55	36.7
Total		**150**	**100.0**
Mean = 4.32	**SD = 2.14**		

Table 1 reveals that the majority of pre-service science teachers (45.3%) had moderate knowledge of IVF, followed by those with low knowledge (36.7%). Only 18.0% demonstrated high knowledge. The overall mean knowledge score of 4.32 out of 10 falls within the moderate range, suggesting that pre-service science teachers possess only a basic understanding of IVF.

Research Question 2: What is the Level of Knowledge of Pre-Service Science Teachers Regarding Surrogacy?

Table 2

Frequency and Percentage of Pre-Service Science Teachers based on their Level of Knowledge of Surrogacy

Knowledge Level	Score Range	Frequency	Percentage (%)
High	7–10	15	10.0
Moderate	4–6	52	34.7
Low	0–3	83	55.3
Total		**150**	**100.0**
Mean = 3.48	**SD = 2.31**		

Table 2 shows that the majority of respondents (55.3%) had low knowledge of surrogacy, while 34.7% had moderate knowledge and only 10.0% had high knowledge. The overall mean knowledge score of 3.48 out of 10 falls within the low range, indicating that pre-service science teachers' knowledge of surrogacy is notably poorer than their knowledge of IVF.

Research Question 3: What Are the Perceptions of Pre-Service Science Teachers Toward IVF and Surrogacy?

Table 3

Mean and Standard Deviation of Pre-Service Science Teachers' Perceptions of IVF and Surrogacy

S/N	Item Statement	Mean	SD	Decision
1	IVF is a scientifically acceptable method of treating infertility	2.87	0.92	Positive
2	IVF should be taught as part of human reproduction in biology classes	2.95	0.88	Positive
3	IVF contradicts God's plan for human reproduction	2.68	1.04	Positive
4	Surrogacy is morally acceptable when a woman cannot carry a pregnancy	2.15	0.96	Negative
5	I would recommend IVF to an infertile couple	2.72	0.91	Positive
6	Commercial surrogacy should be legalized in Nigeria	1.89	0.87	Negative
7	Science teachers should be knowledgeable about IVF and surrogacy	3.21	0.74	Positive
8	IVF children are different from naturally conceived children	1.95	0.93	Negative
9	Surrogacy undermines the sanctity of motherhood	2.78	1.01	Positive

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10	I am comfortable discussing IVF and surrogacy in the classroom	2.31	0.99	Negative
11	The Nigerian government should fund IVF treatment for infertile couples	2.56	0.94	Positive
12	Surrogacy should only be allowed for married couples	3.05	0.81	Positive
13	Cultural and religious values should guide decisions about IVF and surrogacy	3.12	0.79	Positive
14	I would like to learn more about IVF and surrogacy	3.35	0.68	Positive
15	IVF and surrogacy topics should be included in the NCE biology curriculum	2.89	0.85	Positive
	Grand Mean	2.70	0.89	Positive

Decision benchmark: Mean ≥ 2.50 = Positive; Mean < 2.50 = Negative

Table 3 reveals that the grand mean perception score is 2.70, which is above the 2.50 benchmark, indicating an overall positive perception of IVF and surrogacy among pre-service science teachers. However, perceptions varied considerably across items. The highest mean score was recorded for Item 14 ("I would like to learn more about IVF and surrogacy"; Mean = 3.35), indicating a strong desire for knowledge. Item 7 ("Science teachers should be knowledgeable about IVF and surrogacy"; Mean = 3.21) also scored highly. Negative perceptions were recorded for four items: Item 6 ("Commercial surrogacy should be legalized in Nigeria"; Mean = 1.89), Item 8 ("IVF children are different from naturally conceived children"; Mean = 1.95), Item 4 ("Surrogacy is morally acceptable when a woman cannot carry a pregnancy"; Mean = 2.15), and Item 10 ("I am comfortable discussing IVF and surrogacy in the classroom"; Mean = 2.31). The negative perception of commercial surrogacy and the discomfort with classroom discussion are particularly noteworthy.

H_{01}: There is no significant difference in the Knowledge of IVF and Surrogacy between Male and Female Pre-Service Science Teachers

Table 4

Independent Samples t-test of Pre-service Science Teachers Knowledge based on Gender

Gender	N	Mean	SD	df	t-value	p-value	Decision
Male	60	8.10	3.52	148	0.874	0.384	Not Significant
Female	90	7.62	3.28				

Significant at p < 0.05

Table 5 shows that the mean combined knowledge score for male pre-service science teachers (Mean = 8.10, SD = 3.52) was slightly higher than that of their female counterparts (Mean = 7.62, SD = 3.28). However, the t-test result (t = 0.874, p = 0.384) indicates that this difference is not statistically significant at the 0.05 level. Therefore, the null hypothesis is retained: there is no significant difference in the knowledge of IVF and surrogacy between male and female pre-service science teachers.

H_{02}: There is no significant difference in the Knowledge of IVF and Surrogacy among Pre-Service Science Teachers based on academic level

Table 5

One-Way ANOVA of Pre-service Science Teachers Knowledge based Academic Level

Source of Variation	Sum of Squares	df	Mean Square	F-value	p-value	Decision
Between Groups	98.42	2	49.21	4.38	0.014	**Significant**
Within Groups	1651.58	147	11.24			
Total	1750.00	149				

Significant at p < 0.05

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Table 5 shows that the ANOVA result (F = 4.38, p = 0.014) is significant at the 0.05 level. Therefore, the null hypothesis is rejected: there is a significant difference in the knowledge of IVF and surrogacy among pre-service science teachers based on academic level.

Table 6

Post-Hoc Scheffé Test for Multiple Comparisons

Academic Level (I)	Academic Level (J)	Mean Difference (I-J)	p-value
NCE I	NCE II	-1.24	0.182
NCE I	NCE III	-2.16*	0.011
NCE II	NCE III	-0.92	0.387

** The mean difference is significant at the 0.05 level.*

Descriptive statistics by academic level

Academic Level	N	Mean	SD
NCE I	50	6.84	3.15
NCE II	50	8.08	3.42
NCE III	50	9.00	3.51

The post-hoc Scheffé test (Table 7) reveals that the significant difference exist between NCE I and NCE III students, with NCE III students demonstrating significantly higher knowledge scores than NCE I students. The differences between NCE I and NCE II, and between NCE II and NCE III, were not statistically significant.

Discussion of Findings

Knowledge of IVF among Pre-Service Science Teachers

The finding that the majority of pre-service science teachers demonstrated only moderate knowledge of IVF (Mean = 4.32 out of 10), with over a third (36.7%) scoring in the low knowledge range, is consistent with the broader literature on ART knowledge across populations. Adeyemi (2020) found that over 60% of respondents in Lagos had no knowledge of ART. Sohrabvand and Jafarabadi (2005) similarly reported that 55.7% of infertile patients had poor knowledge of ART, with education being the strongest predictor of knowledge. The moderate-to-low knowledge levels found in this study are particularly concerning because these respondents are future biology teachers who will be expected to teach human reproduction to secondary school students. The knowledge gaps identified may be attributable to the NCE biology curriculum's limited coverage of assisted reproductive technologies. While human reproduction is a standard topic, the curriculum does not explicitly address IVF, surrogacy, or other ART procedures. This finding aligns with Brumby's (1986) observation that education has traditionally presented human reproduction in a fragmented manner that does not adequately address modern reproductive technologies.

Knowledge of Surrogacy among Pre-Service Science Teachers

The finding that knowledge of surrogacy was lower than knowledge of IVF (Mean = 3.48 vs. 4.32 out of 10, with 55.3% in the low knowledge category) is noteworthy but not surprising. In the Nigerian literature, Bello et al. (2014) found that while 58.3% of women at an Ibadan infertility clinic were aware of IVF, only 35% were aware of surrogacy. This pattern suggests that IVF receives more public attention and media coverage than surrogacy, which remains a less visible and more culturally sensitive topic in Nigeria. The lower knowledge of surrogacy may also reflect the absence of specific legislation governing surrogacy in Nigeria, which means there are less public discourse and formal education about the practice (Fadare & Adeniyi, 2015). Furthermore, the strong cultural and religious reservations about surrogacy documented by Adamu (2023) — who found 89.2% of

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Nigerians negatively disposed to commercial gestational surrogacy — may discourage open discussion and information-seeking about the topic.

Perceptions of IVF and Surrogacy

The overall positive perception (Grand Mean = 2.70) masks important variations at the item level. The strong agreement that science teachers should be knowledgeable about IVF and surrogacy (Mean = 3.21) and the expressed desire to learn more (Mean = 3.35) are encouraging findings that suggest pre-service teachers recognize the importance of these topics for their professional development. However, the negative perception of commercial surrogacy (Mean = 1.89) mirrors the broader Nigerian cultural disposition documented by Adamu (2023) and Fayokun (2011). The finding that respondents were uncomfortable discussing IVF and surrogacy in the classroom (Mean = 2.31) is particularly significant for teacher education. This discomfort likely reflects a combination of limited knowledge, cultural sensitivity surrounding reproductive topics, and the absence of pedagogical training on how to handle controversial bioethical issues in the classroom. Macer (1994) found that even biology teachers in Japan expressed significant concern about IVF and genetic engineering, suggesting that professional training does not automatically eliminate cultural reservations. The positive perception that IVF and surrogacy should be included in the NCE biology curriculum (Mean = 2.89) and should be taught as part of human reproduction in biology classes (Mean = 2.95) indicates a receptiveness to curriculum reform, even among respondents who hold culturally influenced reservations about specific applications of these technologies.

Gender and Knowledge of IVF and Surrogacy

The finding of no significant gender difference in knowledge ($t = 0.874$, $p = 0.384$) is consistent with findings from several studies. Ezabadi, Mollaahmadi, Mohammadi, Omani Samani and Vesali (2016) found no statistically significant difference between male and female participants in knowledge of ART ($p = 0.245$). This suggests that in educational settings where male and female students have equal access to the same curriculum and learning resources, gender may not be a significant determinant of knowledge about reproductive technologies. The finding may also indicate that cultural and religious factors influencing ART knowledge operate similarly across genders in the Nigerian context.

Academic Level and Knowledge of IVF and Surrogacy

The significant difference in knowledge based on academic level ($F = 4.38$, $p = 0.014$), with NCE III students scoring higher than NCE I students, is an expected finding that can be attributed to the cumulative effect of academic exposure. Students at higher academic levels have completed more courses in biology, including topics related to reproduction, genetics, and biotechnology. They may also have had more opportunities for personal reading, media exposure, and discussions about contemporary scientific issues. This finding has practical implications: it suggests that knowledge of ART increases with academic progression, but the overall low-to-moderate knowledge levels even at the NCE III level indicate that the existing curriculum is insufficient to produce well-informed teachers on these topics. Patel et al. (2025) similarly found that even among medical students with strong knowledge of age-related fertility, understanding of the financial, ethical, and long-term dimensions of ART was limited, recommending earlier integration of ART education into curricula.

Implications for Teaching Human Reproduction

The findings of this study have several important implications for the teaching of human reproduction in Nigerian colleges of education:

First, the moderate-to-low knowledge levels demonstrated by pre-service science teachers suggest that they are not adequately prepared to address questions about IVF and surrogacy that may arise during classroom instruction on human reproduction. Vlaardingerbroek (2018) warned that teaching

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human reproduction has become increasingly daunting as ART challenges established paradigms. If teachers lack foundational knowledge, they risk either avoiding the topic entirely or providing inaccurate information.

Second, the discomfort expressed about classroom discussions of IVF and surrogacy suggests a need for pedagogical training that equips pre-service teachers with strategies for handling controversial bioethical topics. This aligns with Shulman's (1986, 1987) concept of Pedagogical Content Knowledge (PCK), which emphasizes that effective teaching requires not just subject matter knowledge but also knowledge of how to represent complex and sensitive content in ways that are accessible and appropriate for students.

Third, the finding that knowledge improves with academic level but remains insufficient even at NCE III suggests a need for deliberate curriculum intervention rather than reliance on incidental learning.

Fourth, the strong expressed desire to learn more about IVF and surrogacy provides a foundation for curriculum reform. Pre-service teachers are not resistant to learning about these topics; rather, they lack structured opportunities to do so.

Conclusion

This study investigated pre-service science teachers' knowledge of in vitro fertilization and surrogacy and its implications for teaching human reproduction in Colleges of Education in Nigeria. The findings reveal that pre-service science teachers possess moderate knowledge of IVF and low knowledge of surrogacy, with knowledge levels that are inadequate for effective teaching of contemporary reproductive health topics. While their overall perceptions of IVF and surrogacy are positive, negative perceptions of commercial surrogacy and discomfort with classroom discussion indicate that cultural and ethical concerns remain significant barriers. Gender does not significantly influence knowledge levels, but academic level does, with higher-level students demonstrating better knowledge. Importantly, pre-service science teachers expressed a strong desire to learn more about these technologies and agreed that such topics should be included in the NCE biology curriculum. These findings collectively indicate that deliberate curricular and pedagogical interventions are needed to prepare pre-service science teachers to teach human reproduction in a manner that reflects contemporary scientific realities.

Recommendations

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

1. Curriculum Enrichment: The National Commission for Colleges of Education (NCCE) should review and update the NCE biology education curriculum to include content on assisted reproductive technologies, specifically IVF, surrogacy, gamete donation, and fertility preservation, as part of the human reproduction module
2. Workshop and Seminar Programmes: Colleges of Education should organize regular workshops, seminars, and guest lectures by reproductive health specialists to enhance pre-service science teachers' knowledge of ART and build their confidence in discussing these topics.
3. Pedagogical Training on Controversial Topics: Teacher education programmes should incorporate training on how to handle controversial bioethical topics in the classroom, including IVF, surrogacy, cloning, and genetic engineering, using strategies such as structured debate, case studies, and guided discussion.
4. Development of Instructional Materials: Relevant instructional materials, including textbooks, digital resources, and audiovisual aids on ART, should be developed and made available to pre-service science teachers.

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5. Integration of Bioethics Education: Colleges of Education should introduce a course or module on bioethics in science education that addresses the ethical, legal, cultural, and religious dimensions of modern biotechnologies including ART.
6. Further Research: Future studies should extend this investigation to in-service biology teachers across multiple states, employ qualitative methods to explore the depth of teachers' understanding and the factors shaping their perceptions, and examine the relationship between teachers' knowledge and their actual classroom instruction on human reproduction.

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Effect of Artificial Intelligence Usage on Learning Outcome among Undergraduate Computer Science Students of Tai Solarin Federal University of Education, Ijagun, Ogun State, Nigeria.

OWOADE, Ayoade Akeem[1]
owoadeaa@tasued.edu.ng
EGUNJOBI, Kolawole Abiodun[2]
egunjobika@tasued.edu.ng
[1]Department of Computer and Information Sciences, Tai Solarin Federal University of Education, Ijagun, Ogun State
[2]Department of Physics and Telecommunication, Tai Solarin Federal University of Education, Ijagun, Ogun State

Abstract

This study looked at how computer science students at Tai Solarin Federal University of Education, Ijebu Ode, used artificial intelligence (AI) and how that affected their academic learning outcomes. This study sought to evaluate the effects of AI tools like ChatGPT, GitHub Copilot, and personalized learning platforms on students' comprehension, performance, engagement, and technical proficiency in light of their growing integration into educational environments. 200 undergraduate computer science students were given structured questionnaires as part of a quantitative study approach. Descriptive statistics, Ordinal Logistic Regression (OLR), and Pearson Product Moment Correlation (PPMC) were used to examine the data. According to the findings, most students had favorable opinions of AI and reported better academic achievement, a deeper comprehension of difficult subjects, higher problem-solving abilities, and increased learning efficiency. While worries about relying too much on AI showed weak negative associations with these benefits, correlation analysis revealed considerable positive relationships between various AI-related academic benefits. The regression results also showed that students with excellent digital literacy and self-confidence were less likely to feel dependent on AI technology, even when intensive AI usage may increase dependency. The study comes to the conclusion that, when used properly, AI tools improve academic achievement. To avoid over-reliance, it suggests integrating AI into the curriculum in an organized manner, improving digital literacy, and encouraging critical thinking. This study contributes to the growing discourse on AI in education and lays the groundwork for institutional policies and instructional design.

Keywords: Artificial Intelligence, Academic Learning Outcomes, AI Tools

Introduction

The rising use of artificial intelligence (AI) in educational settings has both opportunities and challenges for students' academic achievement. AI tools are being used in Nigerian higher education institutions, to improve learning results, especially for computer science students. Recent research has demonstrated how AI improves students' academic achievement. For example, Ngonso et al, (2025) surveyed tertiary institutions in Nigeria and discovered that most students use AI technologies, which have improved their academic performance. According to the study, AI improves students' comprehension of their classes, sharpens their speaking and learning abilities, and makes difficult technical subjects easier to understand. To optimize its advantages and handle ethical issues, the researchers advise instructors and students to receive formal training on the use of AI in the classroom. Similarly, Opara and Badamasi's (2024) study investigated the effects of AI-powered personalized learning platforms on the academic achievement and motivation of senior secondary school students in Abuja. The findings demonstrated that these platforms significantly improve academic performance and positively affect students' motivation, suggesting that AI could be a helpful tool in computer science education. However, there are drawbacks to using AI in the classroom. Aruleba et al. (2023) conducted a study to find out what students thought about using

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ChatGPT and other AI technologies in computer science lectures. While acknowledging that AI has the potential to enhance learning, students expressed concerns that an over-reliance on AI could have a detrimental effect on their capacity for critical thought and problem-solving. This highlights how important it is to find a balance between using AI and traditional teaching methods to ensure the development of vital cognitive skills. It is essential to comprehend how AI usage affects computer science students' academic performance in the setting of Tai Solarin Federal University of Education. It is crucial to evaluate how AI tools affect students' learning outcomes, critical thinking, and general academic performance as they are increasingly incorporated into teaching methods. In order to provide insights that can guide the creation of tactics to maximize AI integration in computer science education, this study attempts to investigate these processes. Students studying computer science at Tai Solarin Federal University of Education (TASFUED), which is renowned for its dedication to technical innovations in education, are increasingly utilizing AI technologies. These students employ AI for a variety of academic tasks, such as algorithm development, programming, research, and data analysis. AI's incorporation into their educational process could improve academic achievement, increase productivity, and open up new avenues for creativity. But even with these benefits, there are still issues with ethics, an excessive dependence on AI, and how it impacts pupils' capacity for critical thought and problem-solving. A number of important problems are brought up by the growing usage of AI in education: How does AI affect students' academic performance? How much do students rely on AI to do their assignments? Does AI make them more proficient programmers or make them more dependent? Does the use of AI raise ethical issues like academic dishonesty? Understanding the wider ramifications of AI adoption in computer science education requires addressing these issues.

Objectives of the Study

This study's primary goal was to look into how computer science students at Tai Solarin Federal University of Education in Ijebu Ode were affected by the use of artificial intelligence.

The specific objectives of this study are:

1. To analyze the extent of AI adoption among Computer Science students at TASUED within the next six months.
2. To use a survey of at least 200 students to determine how AI tools affect students' academic performance
3. To identify the most commonly used AI applications and their effectiveness in learning Computer Science courses.
4. To determine how AI influences students' problem-solving and programming skills within a semester.
5. By the end of the academic year, assess the difficulties and moral issues related to the use of AI in educational activities.

This study is significant for several reasons, one of which is that it contributes to the growing body of knowledge about artificial intelligence (AI) in higher education, particularly in the context of a developing country like Nigeria.

i. The results would allow Tai Solarin Federal University of Education (TASFUED) computer science students comprehend how AI tools may be used to improve their academic learning outcomes. Additionally, it can encourage the ethical and responsible application of AI in their research.
ii. By offering insights into how AI affects student performance, the study would assist instructors and curriculum designers in incorporating pertinent AI tools into instructional techniques to raise student engagement and academic achievement.

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iii. Decision-makers would find the research to be a useful tool for developing policies and allocating funds for the institution's adoption of AI technology in teaching and learning procedures.
iv. For other academics interested in investigating the relationship between AI and education, particularly in the context of Nigerian or African higher education, the paper would be a useful resource.
v. The study can help developers create AI tools that are suited to university students' academic requirements and learning styles, particularly those who are majoring in computer science.

This study aims to examine the effects of artificial intelligence (AI) on computer science students' academic learning outcomes at Tai Solarin Federal University of Education (TASUED), Ijebu Ode. The participants were undergraduate students enrolled in the Department of Computer Science for the academic year 2024–2025.

Research Questions

1. To what extent do Computer Science students at TASUED utilize AI in their academic activities?
2. How does AI usage impact students' academic performance in Computer Science Courses?
3. What are the most commonly used AI tools by students, and how effective are they?
4. In what ways does AI influence students' problem-solving and programming skills?
5. What challenges and ethical concerns do students face in using AI for academic purposes?

Research Hypotheses

H_0: There is no significant relationship between the use of Artificial Intelligence (AI) tools and the academic learning outcomes of Computer Science students at Tai Solarin Federal University of Education, Ijagun.

Literature Review

This chapter presents the review of studies related to Artificial Intelligence (AI). AI is increasingly integrated into educational settings, offering both the present study. It was done under the opportunities and challenges for students' academic performance. This literature review examines the following sub-headings:

Positive Impacts of AI on Academic Performance

Several studies highlight the beneficial effects of AI in education:

i. Personalized Learning: AI-powered platforms can tailor educational content to individual student needs, enhancing engagement and understanding. For instance, adaptive learning systems have been shown to improve student test results by 62% (Holmes, Bialik, & Fadel, 2019).
ii. Enhanced Learning Efficiency: The integration of AI tools in science education has consistently improved students' academic performance, suggesting that AI can make learning processes more efficient.
iii. Predictive Analytics: Machine learning techniques have been applied to predict student performance, allowing for early intervention and support. Studies indicate that student achievement can be accurately forecasted using these methods.

Challenges and Considerations

Despite these advantages, the adoption of AI in education presents certain challenges:

i. Skill Development: Over-reliance on AI tools may hinder the development of critical thinking and problem-solving skills. It is essential for students to engage deeply with the material rather than depending solely on AI assistance

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ii. Assessment Integrity: The use of AI in completing assignments raises concerns about academic integrity. Instances have been reported where students faced disciplinary actions for misusing AI tools in their coursework
iii. Resource Availability: Effective implementation of AI requires adequate infrastructure and training. Institutions must ensure that both students and faculty are equipped to utilize AI technologies effectively.

Relevance to Nigerian Educational Context

In the Nigerian educational landscape, AI's impact has been explored with promising results:

i. Student Performance: Research indicates that AI positively influences Nigerian students' educational performance by enhancing their understanding of course material and improving learning outcomes
ii. Administrative Efficiency: AI applications have been found to improve university administration and academic staff performance, contributing to a more effective educational environment.

The integration of AI in computer science education offers significant potential to enhance academic effectiveness. However, it is crucial to address challenges related to skill development, assessment integrity, and resource availability. For institutions like Tai Solarin University of Education, adopting AI requires a balanced approach that leverages its benefits while mitigating potential drawbacks. The integration of Artificial Intelligence (AI) in educational settings has garnered significant attention, particularly concerning its impact on students' academic learning outcome. In the context of Nigerian tertiary institutions, including Tai Solarin University of Education in Ijebu Ode, understanding how AI influences computer science students' academic effectiveness is crucial.

Adenubi (2013) developed an Artificial Neural Network (ANN) model to predict the final grades of computer science students at Tai Solarin Federal University of Education. The study utilized data from thirty randomly selected students who had completed four academic sessions. The ANN model achieved a prediction accuracy of 92.7%, demonstrating the potential of AI in forecasting academic outcomes. Similarly, Lateef and Bamidele (2015) employed an ANN model to predict students' academic performance in a university system. Their research focused on sixty students from the Department of Computer Science at Tai Solarin University of Education. The model accurately predicted final grades with a 91.7% accuracy, highlighting the efficacy of AI in educational predictions. Ngonso et al. (2025) conducted a survey across Nigerian tertiary institutions, finding that AI enhances students' understanding of their courses, improves learning and speaking skills, and simplifies complex technical concepts. The study recommends formal training for both students and teachers on the academic use of AI to maximize its benefits and address ethical considerations. However, the adoption of AI in education also presents challenges. Abubakar et al. (2024) explored the impact of AI technologies on academic performance and the challenges they pose to accurately evaluating student capabilities. The study emphasizes the need to redefine assessment methods to maintain academic integrity in the face of increasing AI integration. A study by Okekeokosisi et al. (2024) examined the impact of AI-based activities on students' interest in computer science education in South East Nigerian universities. The findings indicated that incorporating AI-based activities significantly increased students' interest and engagement in computer science courses, suggesting that AI can be a valuable tool in enhancing motivation and participation in the field. In a systematic literature review, Opara and Badamasi (2024) assessed the impact of AI-powered personalized learning platforms on computer science students' academic achievement and motivation. The study concluded that such platforms positively influence academic performance and motivation,

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highlighting the potential of AI to tailor learning experiences to individual student needs. In summary, while AI offers promising tools to enhance learning and predict academic performance, it is essential to balance its use with traditional educational methods. This balance ensures the development of critical thinking and problem-solving skills among students. Further research is necessary to explore the optimal integration of AI in educational contexts, particularly in institutions like Tai Solarin University of Education.

Artificial Intelligence in Higher Education

AI has become an integral part of modern education systems, especially in higher institutions. According to Holmes et al. (2021), AI applications in education include chatbots for student support, learning analytics, plagiarism detection tools, and AI-driven recommendation systems. These technologies help educators tailor instruction to individual learners' needs and pace, which is especially beneficial in technical fields like Computer Science.

AI and Academic Performance

Several studies suggest a positive correlation between AI tool usage and improved academic performance. For example, Chen et al. (2020) found that students using AI-powered learning platforms showed significant improvement in test scores compared to those in traditional classrooms. Similarly, Al-Faryan and Alsadoon (2022) observed that adaptive learning systems that use AI to analyze student data and adjust instructional content led to higher retention rates and deeper understanding among Computer Science undergraduates.

AI in Nigerian Higher Education Context

In Nigeria, the adoption of AI technologies in education is still emerging, with varying levels of implementation across institutions. Adebayo and Olamide (2021) reported that while awareness of AI is growing among university students, actual usage for academic purposes is often limited due to infrastructural and financial constraints. Nevertheless, where AI tools are accessible, students report improved motivation and better comprehension, particularly in science and technology disciplines.

Relevance to Tai Solarin University of Education

Tai Solarin University of Education (TASUED), being a specialized university of education with a strong focus on technology integration, provides a suitable context to examine AI's impact on academic outcomes. According to Ogunlade and Adeyemi (2022), Computer Science students at TASUED are increasingly exposed to AI concepts and tools, both in curriculum content and in supplementary learning environments. This trend presents an opportunity to study how such exposure translates into measurable academic achievements.

Challenges and Gaps

Despite the potential benefits, challenges such as inadequate training for lecturers, poor internet connectivity, and limited access to advanced AI tools persist in many Nigerian institutions (Okonkwo & Okoye, 2020). Additionally, there is a lack of empirical research specifically focusing on the impact of AI usage on learning outcomes within Nigerian universities, particularly at TASUED. This gap underscores the importance of conducting localized studies that consider contextual factors affecting AI adoption and educational effectiveness. The reviewed literature highlights the transformative potential of AI in enhancing students' academic learning outcomes, particularly in fields that require computational thinking and problem-solving. While global studies indicate generally positive results, local contexts like TASUED demand more targeted investigations. Understanding how AI tools affect

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Computer Science students' learning outcome in this specific setting will contribute to both academic literature and institutional policy-making.

AI-Driven Personalized Learning and Tutoring Systems

Artificial Intelligence technologies offer the possibility of personalized learning pathways, which have become a major focus in contemporary educational research. AI systems can adjust the level of content difficulty, pace, and style of instruction to match individual learning styles and progress rates (Woolf, 2020). Systems like Intelligent Tutoring Systems (ITS) and Learning Management Systems (LMS) equipped with AI features have been proven to significantly enhance understanding and retention of content, particularly in technical disciplines such as Computer Science (VanLehn, 2011). For instance, an empirical study by Kazi et al. (2021) demonstrated that AI-based tutoring systems led to improved performance in algorithm-related tasks for undergraduate Computer Science students. This result supports the notion that AI can reduce the cognitive load associated with complex topics by offering real-time hints, feedback, and scaffolding.

Student Attitudes and Acceptance of AI Tools

According to Davis et al. (2022), the Technology Acceptance Model (TAM) indicates that perceived usefulness and ease of use are strong predictors of whether students will adopt AI tools for learning. In the Nigerian context, research by Eze et al. (2023) found that computer science students in universities were generally open to AI applications, but adoption was limited in some cases by low digital literacy and a lack of technical infrastructure. At TASUED, preliminary surveys by Adebanjo and Odusanya (2022) revealed that most students had a positive attitude towards AI usage in their coursework, particularly for programming assistance, code reviews, and simulation-based learning. However, students also expressed concern about over-reliance and potential for academic dishonesty.

Ethical and Pedagogical Implications of AI Use

While AI enhances academic performance, it also raises ethical and pedagogical concerns. Binns et al. (2018) cautioned against the risk of bias and lack of transparency in AI decision-making, particularly in automated grading and recommendation systems. Furthermore, Selwyn (2019) argues that AI could deskill educators by shifting instructional responsibilities to algorithms, potentially weakening pedagogical relationships. These concerns are particularly relevant in teacher-training institutions like TASUED, where educators are trained not only to use technology but also to critically assess its impact on the learning process. As Ogunbanjo and Faleye (2023) point out, future teachers must be equipped to integrate AI responsibly, balancing automation with human-centered teaching approaches.

Readiness and Infrastructure for AI Implementation in Nigerian Universities

One of the recurring themes in the literature is the infrastructure gap in deploying AI tools effectively in Nigerian higher education. According to Aina and Bello (2021), major obstacles include unreliable electricity, poor internet connectivity, and lack of access to advanced computing resources. These challenges often limit the scalability of AI-driven educational interventions. However, institutions like TASUED are beginning to bridge this gap through partnerships and investments in digital infrastructure. As part of its Smart Campus Initiative, TASUED has introduced cloud-based learning platforms and initiated training programs for lecturers on AI integration (Taiwo et al., 2023). This institutional commitment provides a unique opportunity to study the outcomes of AI usage in a resource-constrained but progressively digital environment.

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Comparative Studies and Global Trends

Globally, universities in countries like the United States, China, and Finland have implemented large-scale AI interventions in Computer Science education. For example, Finland's "AI in Education" national initiative has demonstrated how early exposure to AI concepts improves students' analytical and computational thinking (Vuorikari et al., 2022). Comparing these efforts with Nigerian universities provides insight into best practices and contextual adaptations needed for local success.

Appraisal of Literature

Although global research shows a clear positive trend in AI's influence on learning outcomes, localized, institution-specific studies—especially in African settings—remain limited. In the context of TASUED, empirical data linking AI tool usage to measurable academic improvements among Computer Science students is sparse. Filling this gap will offer practical recommendations for policy and practice at both institutional and national levels.

Methodology

This section describes the population, sample and sampling strategy, research instrument, validity and reliability of the instrument, data gathering protocol, and data collection method. This study uses a descriptive survey research methodology to examine how the use of artificial intelligence (AI) affects computer science students' academic learning outcomes at Tai Solarin Federal University of Education (TASUED), Ijebu Ode. Because it enables the gathering of comprehensive data from a particular population at a certain moment in time, the descriptive survey design is suitable for this study. It also enables the researcher to analyze patterns, relationships, and perceptions related to AI usage and academic learning outcome among students. The study uses a quantitative approach, relying primarily on structured questionnaires to gather data from respondents. The responses were statistically analyzed to determine the extent to which AI usage influences academic learning outcomes. Additionally, a correlational analysis was employed to examine the relationship between variables such as frequency of AI tool usage, types of tools used, and academic learning outcomes (e.g., GPA or self-reported grades). The following procedures were followed in order to investigate how the use of artificial intelligence (AI) affected computer science students' academic learning results at Tai Solarin Federal University of Education (TASFUED), Ijebu Ode:The researcher obtained necessary approvals from the university's Department of Computer Science and the relevant ethics committee to ensure the study meets ethical standards, including informed consent and confidentiality. A structured questionnaire was designed to collect data on the types, frequency, and purposes of AI tool usage, as well as students' academic performance and perceptions of AI effectiveness. The questionnaire undergoes expert review and pilot testing to ensure clarity and validity. TASFUED undergraduate computer science students make up the target population. To guarantee representation across various levels, a sample was chosen using stratified random sampling (e.g., 100–400 level students). The validated questionnaires were being distributed to the selected participants electronically (e.g., via Google Forms). Instructions on how to complete the form was clearly communicated to ensure accurate responses. The questionnaire undergoes expert review by educational experts and computer science lecturers to ensure clarity, relevance, and accuracy. Cronbach's Alpha was employed to assess the instrument's reliability in a pilot study with thirty students who were not part of the main sample, guaranteeing a consistency score more than 0.7. Pearson Product Moment Correlation (PPMC) was used to examine relationships between AI usage and academic learning outcome. Ordinal Logistic Regression analysis determines the impact of AI usage on students' problem-solving and programming skills.

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Presentation of Results

The data gathered on the impact of artificial intelligence (AI) use on the academic learning outcomes of computer science students at Tai Solarin University of Education, Ijebu Ode, is analyzed and interpreted in this chapter. Structured questionnaires were used to collect the data from a sample of Department of Computer Science undergraduate students. The research goals and hypotheses developed in previous chapters serve as the framework for the analysis. The association between the employment of AI technologies and students' academic learning results is examined using both descriptive statistics (such frequency, percentage, and mean scores) and inferential statistics (like hypothesis testing). For clarity, the results are displayed in tables and charts, and then interpretations based on the study's context are provided.

A five-point Likert scale, spanning from Strongly Disagree (0) to Strongly Agree (4), was used to examine the responses gathered from Tai Solarin University of Education computer science students. The majority of respondents had favorable opinions about using AI in their academic learning processes, according to the descriptive statistics compiled in Table 1.

Table 1: Descriptive Statistics of the Dataset

Variable (Shortened)	Mean	Std Dev	Min	25%	Median	75%	Max
Understanding academic concepts using AI	4.02	0.79	1	4	4	4	5
Academic performance improved since using AI	4.02	0.79	1	4	4	4	5
AI-enhanced learning is engaging	4.14	0.60	2	4	4	4	5
AI provides personalized academic support	4.02	0.79	1	4	4	4	5
AI improves logical thinking in problem-solving	3.95	0.95	1	4	4	4	5
Confident tackling programming tasks with AI	3.95	0.88	1	4	4	4	5
AI improves code quality	3.88	0.80	2	4	4	4	5
AI improves problem-solving and programming skills	3.98	0.77	1	4	4	4	5
AI reduces time spent searching for academic resources	3.93	0.85	1	4	4	4	5
AI increases academic productivity	3.83	0.94	1	4	4	4	5

Specifically: Over 70% of students agreed or strongly agreed that AI tools helped them understand academic concepts more easily. A significant proportion reported improvements in academic performance, enhanced problem-solving skills, and increased academic performance. Increased productivity as a result of AI support. These findings suggest a generally positive perception and high acceptance of AI technologies among the student population.

Visualization of Likert-Scale Responses

Figure 1 presents a Likert-scale dot plot with box plots, summarizing students' responses categorized under four key themes:

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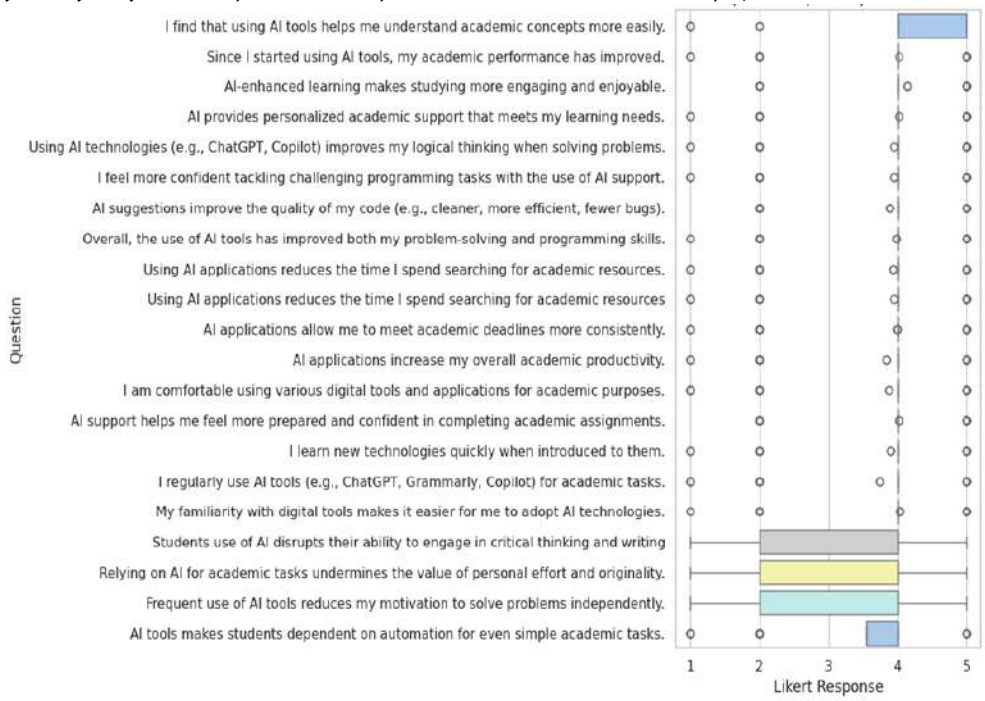


Figure 1: Likert-Scale Dot Plot of Students

Overall Positive Attitudes Toward AI Usage

Statements such as:

i. "I find that using AI tools helps me understand academic concepts more easily."
ii. "Since I started using AI tools, my academic performance has improved."
iii. "AI-enhanced learning makes studying more engaging and enjoyable."
iv. "AI improves my problem-solving and programming skills."

Most responses clustered around values 4 and 5, with narrow box plots indicating low variability and high consensus. This demonstrates a strong positive reception of AI-enhanced learning tools.

AI Use and Technical Skills Development

Statements included:

i. "Using AI technologies improves my logical thinking."
ii. "AI suggestions improve the quality of my code."
iii. "I feel more confident tackling programming tasks with AI."

Responses again clustered toward the high end of the Likert scale, indicating perceived improvements in technical and problem-solving abilities, aligning with key learning outcomes.

Technological Confidence and Usage

Statements such as:

i. "I regularly use AI tools (e.g., ChatGPT, Copilot)."
ii. "My familiarity with digital tools makes it easier to adopt AI."
iii. "I am comfortable using various digital tools."

Box plots for these questions were tightly grouped, suggesting that students are digitally literate and face few barriers in adopting AI tools.

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Concerns About Overreliance on AI

Statements such as:

i. "Students' use of AI disrupts critical thinking and writing."
ii. "Frequent use of AI reduces motivation to solve problems independently."
iii. "AI tools make students dependent on automation."

Here, responses were more widely distributed, with box plots centered around 3, indicating mixed opinions. While many students value AI, there is concern over dependency and diminished critical thinking.

Result of Pearson Product Moment Correlation (PPMC)

As shown in Figure 2, the PPMC displayed the linear relationship between features of the questions in the questionnaire. With the color scale ranges from -0.8 (dark blue, strong negative correlation) to 1.0 (dark red, strong positive correlation), with 0 (light blue) indicating no correlation and the diagonal (e.g., question1 to. question1, question2 to. question2) shows a correlation of 1.00 (perfect correlation), as expected since each question is correlated with itself.

Strong Positive Correlations (0.5 to 1.0)

Several pairs of questions show strong positive correlations (highlighted in shades of orange to red), indicating that participants who rated one question highly tended to rate the other highly as well.

Notable Clusters of Strong Correlation:

These question1 to question14 (Positive Perceptions of AI Tools) focus on the positive impacts of AI tools, such as improving academic performance, engagement, problem-solving skills, and productivity. For instances question 9 ("Using AI applications reduces the time I spend searching for academic resources") and question 10 (same question, duplicated in the dataset) have a correlation of 1.00, which is expected due to the duplication. And question 11 ("AI applications allow me to meet academic deadlines more consistently") and question 12 ("AI applications increase my overall academic productivity") have a correlation of 0.56, suggesting that students who find AI helpful for meeting deadlines also tend to feel more productive overall.

Likewise, question 5 ("Using AI technologies improves my logical thinking when solving problems") and question 6 ("I feel more confident tackling challenging programming tasks with the use of AI support") show a correlation of 0.52, indicating that AI's role in enhancing logical thinking aligns with increased confidence in programming tasks. Question 15 to question 17 (Technology Adoption and Comfort) have a correlation of 0.53, suggesting that students who adapt quickly to new technologies also find it easier to adopt AI tools due to their familiarity with digital tools. In summary, these strong correlations suggest that students who perceive AI tools as beneficial in one area (e.g., productivity) are likely to see benefits in related areas (e.g., meeting deadlines, improving problem-solving).

Weak to Moderate Positive Correlations (0.1 to 0.5)

Figure 4.2, most pairs of questions show weak to moderate positive correlations (light orange to light blue), ranging from 0.1 to 0.5. Question 1 ("I find that using AI tools helps me understand academic concepts more easily") and question 3 ("AI-enhanced learning makes studying more engaging and enjoyable") have a correlation of 0.24. This suggests a mild relationship where students who find AI helpful for understanding concepts also tend to find it engaging, but the connection is not very strong. And question 7 ("AI suggestions improve the quality of my code") and question 8 ("Overall, the use of AI tools has improved both my problem-solving and programming skills") have a correlation

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of 0.42, indicating a moderate relationship between perceived improvements in code quality and overall skill enhancement.

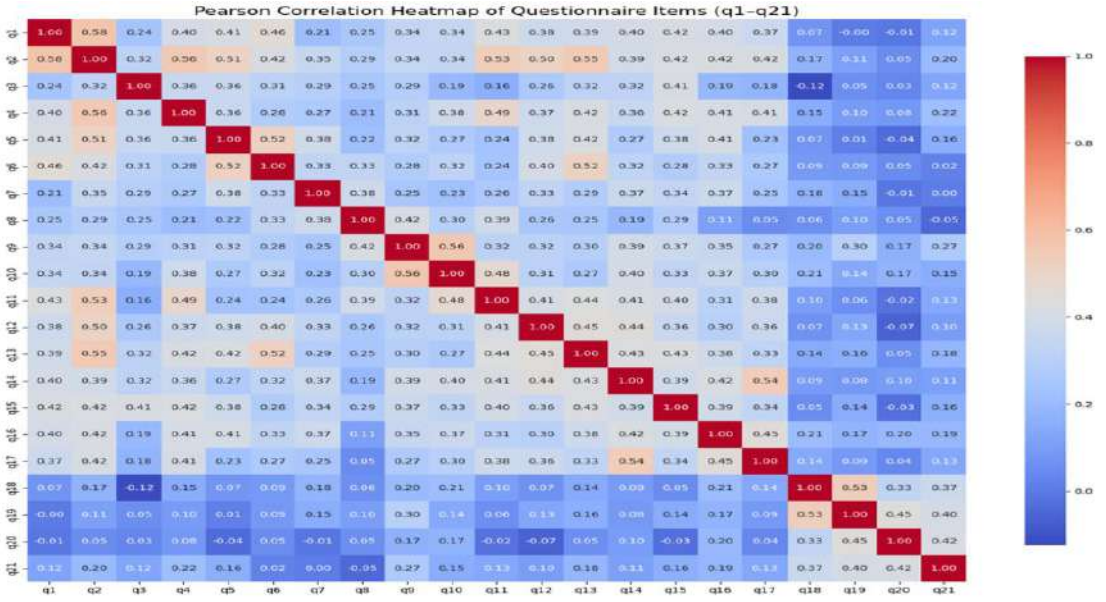


Figure 2: Heatmap of Pearson Product Moment Correlation (PPMC)

Negative Correlations (0 to -0.8)

Questions 18 to question 21 focus on potential downsides of AI usage, such as reduced critical thinking, originality, motivation, and increased dependency. Questions in class show weak negative correlations with question 1 to question 14 (positive perceptions of AI). For instance, question 18 ("Students' use of AI disrupts their ability to engage in critical thinking and writing") has a correlation of -0.12 with question 1 ("I find that using AI tools helps me understand academic concepts more easily"). This suggests that students who find AI helpful for understanding concepts are slightly less likely to believe it disrupts critical thinking, though the relationship is weak. While the strongest negative correlation is between question 18 and question 17 ("My familiarity with digital tools makes it easier for me to adopt AI technologies") at -0.07, indicating that students comfortable with adopting AI are slightly less likely to see it as disruptive to critical thinking.

No Significant Correlation (Around 0)

Some pairs of questions show near-zero correlation, indicating no meaningful relationship. Question 20 ("Frequent use of AI tools reduces my motivation to solve problems independently") and question 7 ("AI suggestions improve the quality of my code") have a correlation of 0.00, suggesting that perceptions of AI's impact on code quality are unrelated to concerns about reduced motivation for independent problem-solving. In Conclusion, the PPMC heatmap reveals that students who perceive AI tools as beneficial in one academic area (e.g., understanding concepts, improving code quality) tend to view them positively in other areas (e.g., productivity, engagement), as evidenced by the strong positive correlations among question 1 to question 14. However, concerns about AI's potential to undermine critical thinking, originality, and independent problem-solving (question 18 to question 21) are weakly negatively correlated with these positive perceptions, indicating that students with favorable views of AI are less likely to see it as detrimental, though these concerns are not strongly felt across the sample.

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Ordinal Logistic Regression (OLR)

To assess predictive relationships between students' perceptions and their attitudes toward dependence on AI, an Ordinal Logistic Regression (OLR) analysis was conducted as shown in Table 2.

Table 2: OLR Summary

Sample Size	197 responses
Model AJC Significant Predictors	lower is better (p-value < 0.05)

i. Students who rely heavily on AI for support show a higher likelihood of perceiving dependence on AI.
ii. In contrast, those with stronger digital skills and confidence tend to report lower dependency.

While the results of random selecting from the survey questions as shown in Table 4.3 indicates that

i. Higher reliance or benefit from AI = mixed impact: Some benefits (e.g., efficiency, support) increase perceived dependence.
ii. Skills and confidence = reduce perceived dependence.
iii. Concerns about motivation and originality = significantly predict feeling overly dependent on AI.

Table 3 shows the comparison of top 10 survey question and the OLR results. From the OLR results it can be concluded that "Since I started using AI tools, my academic performance has improved.", is the best model fit (lowest AIC), well-predicted by 8 other survey questions, and captures an important outcome (perceived academic impact). Figure 4.3 also buttress our finding from OLR, that the "green bars" indicate statistically significant predictors ($p < 0.05$), "gray bars" are non-significant predictors, and bars to the right (positive coefficients) increase the likelihood of higher agreement with the idea that students become dependent on AI. Table 3 Comparison of Ordinal Logistic Regression Results

Rank	Dependent Variable	AIC	Significant Predictors	Count
1	"Since I started using AI tools, my academic performance has improved."	236.46	8	Best model fit
2	"I find that using AI tools helps me understand complex topics better."	258.51	8	
3	"AI support helps me feel more prepared and confident."	267.16	12	
4	"Using AI applications reduces the time I spend on academic resources."	272.97	7	
5	"The use of AI has improved both my problem-solving and programming skills."	281.57	9	
6	"AI-enhanced learning makes studying more engaging."	282.09	8	
7	"AI provides personalized academic support that is helpful to me."	282.70	6	
8	"My familiarity with digital tools makes it easier to adopt AI."	286.74	6	
9	"Using AI applications reduces the time I spend on academic resources."	290.83	8	
10	"AI suggestions improve the quality of my code (e.g., syntax, logic)."	294.32	7	

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The top-ranked model (lowest AIC) revealed that academic performance improvement is highly predicted by other key variables, reinforcing its role as a central learning outcome. From Figure 3: Ordinal Logistic Regression Visualization shows: Green bars = significant predictors ($p < 0.05$); Gray bars = non-significant predictors; Rightward bars = Higher agreement with dependency on AI

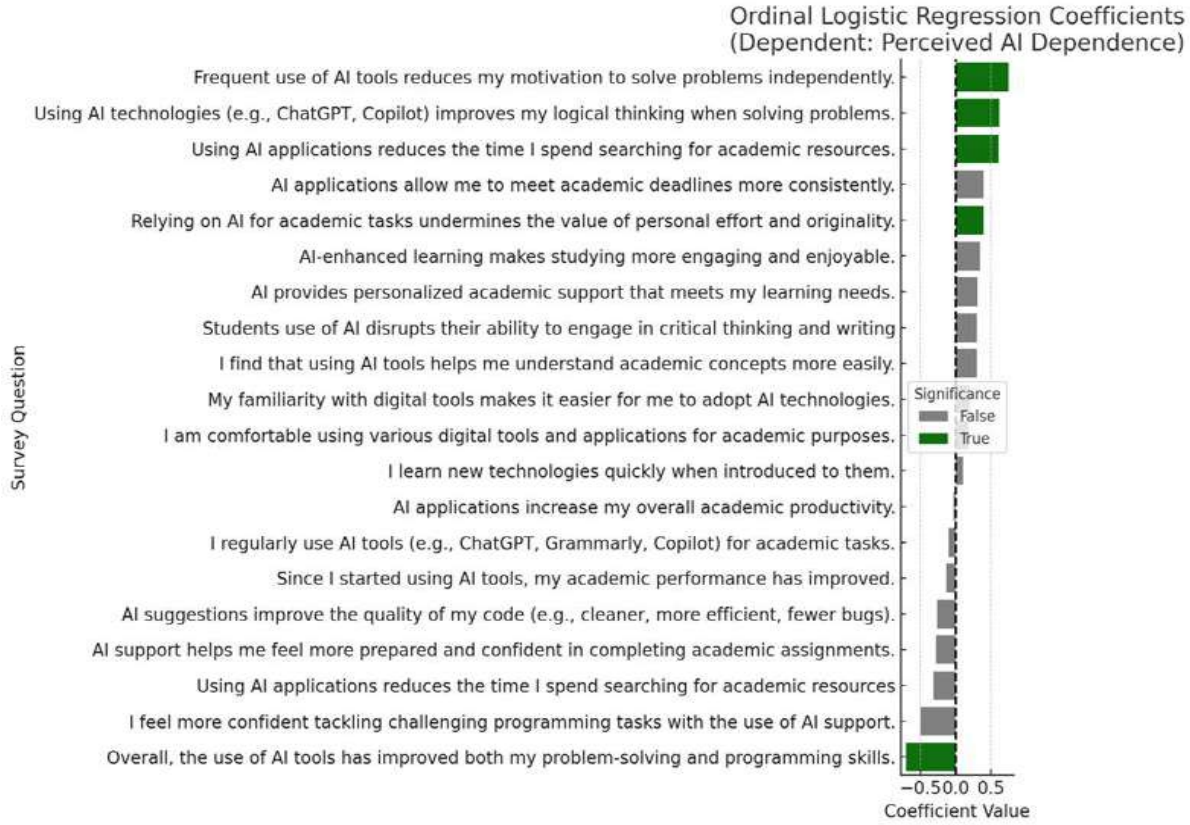


Figure 3: Visual Result of the Ordinal Logistic Regression

Summary of Findings

This study examined the impact of Artificial Intelligence (AI) tools on the academic learning outcomes of Computer Science students at Tai Solarin University of Education, Ijebu Ode. Key findings from descriptive and inferential statistics are as follows:

i. Descriptive statistics showed a generally positive perception of AI usage. Students agreed that AI tools enhance their understanding of academic content, improve engagement, and boost productivity.
ii. Correlation analysis (PPMC) revealed strong positive relationships among various academic benefits of AI tools, such as problem-solving, programming skills, and timely completion of academic tasks. Notably, weak negative correlations existed between students' positive perceptions of AI and their concerns about overdependence.

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iii. Ordinal Logistic Regression (OLR) highlighted that students who rely heavily on AI tend to perceive themselves as more dependent on it. However, digital confidence and technical skills were associated with reduced perceptions of dependency.

iv. The question "Since I started using AI tools, my academic performance has improved" emerged as the most predictive of students' perceptions and served as a central variable linking multiple aspects of AI-related academic enhancement.

Conclusion

The analysis concludes that AI technologies play a significant and largely positive role in shaping academic experiences for Computer Science students. The tools are seen as beneficial for understanding complex concepts, improving programming capabilities, and enhancing overall academic productivity. However, while the benefits are clear, there are underlying concerns about overreliance, especially regarding reduced motivation and diminished critical thinking. These concerns, although not strongly correlated with positive perceptions, indicate a need for balanced and guided integration of AI tools into academic environments. The findings also suggest that students with stronger digital skills experience more benefits from AI with fewer negative side effects, reinforcing the importance of digital literacy.

Recommendations

Based on the findings, the following recommendations are proposed:

i. Integrate AI Literacy into Curriculum: Introduce structured modules that teach students how to effectively and ethically use AI tools in academic contexts. This will help mitigate misuse and build responsible engagement.

ii. Promote Balanced Use of AI Tools Encourage students to use AI as a supplement not a replacement—for critical thinking, problem-solving, and independent learning. Train Lecturers and Academic Advisors Provide professional development for staff to understand AI tools so they can guide students in their appropriate application for learning and research.

iii. Monitor and Evaluate AI Tool Usage Institutions should develop systems for monitoring how students interact with AI tools, identifying patterns of overdependence, and providing timely interventions where necessary.

iv. Foster Digital Skills Development Strengthen digital competence through workshops and courses, ensuring students are not only users of AI but also understand its underlying mechanisms and limitations.

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Effect of Context-Based Learning Strategy on Academic Performance in Chemistry Concepts among Secondary School Students in Taraba State, Nigeria

MEKONG, Caleb[1]
calebmekong1989@gmail.com
OKORONKA, Augustine Ugwumba[1]
ugwuokoronka@gmail.com
FWANGLE, Ishaya Istifanus[1]
m.scpse220851@student.mau.edu.ng
[1]Department of Physical Sciences Education, Faculty of Education, Moddibo Adama University Yola, Adamawa State, Nigeria.

Abstract

This study examines *the effect of context-based learning strategy (CBLS) on academic performance in Chemistry Concepts among Secondary school students' in Taraba State, Nigeria. A quasi-experimental design involving pretest-posttest control and experimental groups was employed. A total of 174 students participated, with 52 in the experimental group taught using the CBLS and 122 in the control group taught using conventional methods. Respondents were selected using multi-stage sampling technique. Data were collected using Chemistry Performance Test (CPT) as instruments of data collection. Instruments were subjected to content, face validity and was tested after a pilot study using* Kuder Richardson formula 20, KR_2 *reliability test which yielded a coefficient of 0.85. Analysis of Covariance (ANCOVA) were used to test the hypotheses. Findings from ANCOVA revealed that students taught with the CBLS performed significantly better* $F(1, 171) = 44.163$, $p < .001$, $\eta^2 = .205$). *The experimental group mean gain was 42.28 compared to the control group mean gain is 22.05 in favor of experimental group. findings strongly support the effectiveness of context-based learning strategy in improving academic performance in chemistry This finding recommend that chemistry concepts should be taught using context based learning strategy which allows active participation of the students.*

Keywords: *Context-Based Learning, Academic Performance in Chemistry, ANCOVA, Senior Secondary School.*

Introduction

Education is essential for the development of individuals, society, country and the world at large. It is regarded as the bedrock of every nation's development. In the whole world and particularly in Nigeria, education has been considered the corner stone for development. It forms the basis for literacy, skills acquisition, technological advancement and ability to harness human and material resources towards the achievement of societal goal (Federal Republic of Nigeria FRN, 2014). Therefore, one of the ways to measure the level of education and development index of a country is the level of science and technology education present in such country. Science education is very important for the development and progress of any nation and hence the need for every nation to take its advancement very serious. Science deals with the sharing of scientific knowledge with individuals through the instrumentality of education. Learning science in the 21st century aims at training students to be able to understand concepts, develop process skills and develop thinking abilities to be able to transfer knowledge (Aidoo, Boateng, Kissi & Ofori, 2016). The field of science education includes works in science content, science process and some teaching pedagogy. Science education cultivates in students' curiosity about the world and enhances scientific thinking through the inquiry process. Students are trained to recognize the nature of science and develop scientific knowledge and

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science process skills. There is the need for innovative teaching strategies that make the learning of chemistry student-centered, meaningful and more stimulating to promote lifelong learning.

Chemistry is a central science subject that explains the composition, properties, and transformations of matter and serves as a foundation for scientific and technological development. At the post-basic school level in Nigeria, chemistry is a compulsory requirement for students aspiring to pursue careers in medicine engineering, pharmacy, environmental science and other science related disciplines. Beyond career preparation, chemistry contributes significantly to national development through its application in health care, food production, energy generation, industrial manufacturing and environmental management. In the Nigeria context, and particularly in Taraba state, chemistry education is expected to equip students with scientific literacy, problem-solving skills to apply scientific knowledge to everyday life. However, despite its importance, students interest and academic performance in chemistry at the post-basic school level remain a major concern. The issues of students' academic performance in chemistry reliance on traditional teaching strategies, therefore raises concern about their effectiveness in improving both students interest and performance in chemistry. Evidence from external examination such as the West African Examination Council (WAEC) report on the percentage grade at credit-pass in chemistry as follows: 2018 (19.8%), 2019 (43.71%),2020 (32.60%), 2021 (11.68%), 2022 (16.25%), and 2023 (10.50%) in Taraba state as shown in appendix 1, indicate fluctuation and generally unsatisfactory level of credit pass in chemistry over the years. Many students struggle to understand fundamental concept, apply chemical principles to problems-solving situation and perform satisfactorily in practicals. Commonly identified weakness include; poor conceptual understanding, inability to interpret examination question correctly weak problem-solving ability (WAEC, 2020; Oloyede, Adeoye, & Aikpokpodion, 2019). These challenges are often results from overcrowded classrooms, limited acess to functional laboratories, shortages of qualified chemistry teachers and reliance on rote learning methods (Olatoye, 2017). Consequently, many students fail to achieve the minimum credit level require for further studies in science-related field. (WAEC,2021; Okeke & Nzewi, 2018)

Various stakeholders have made effort to address the challenges facing chemistry education in Nigeria and Taraba state in particular. Government agencies and educational authorities have introduced curriculum reforms aimed at improving science teaching and learning, teachers professional development programs, workshops and seminars have been organized to enhance teacher pedogical skills. Examination bodies such as WAEC have also provided chief examiner report to guide teachers and students on common areas of weakness and strategy for improvement. Non-governmental organization and donor agencies have supported science education through provision of textbooks and teachers training initiatives. Schools and teachers, on their part have adopted strategies such as extra lesson, revision classes and the uses of past examination questions to improve student's performance. Despite these efforts made by stakeholders, the problem of low interest and poor academic performance in chemistry persist suggesting that the strategies employed so far may not significantly address the root causes of the problems. Failure to address the issues poor academic performance in chemistry has serious implication for student's school's society at large, for students, it limits access to science-based careers and higher education opportunities, thereby reducing their future prospects. For education system, the goal of science education and contribute to a shortage of skilled manpower in science and technology field. At the societal level it hinders scientific innovation, industrial developments and economic growth. These may also widen educational inequalities, particularly for students in rural & under-resourced area of Taraba state

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who are already disadvantage. Therefore, there is an urgent need for effective instructional strategies that can simultaneously enhance students interest and improve their academic performance in chemistry, context-based learning strategy as the way forward.

Context-based learning has positive views regarding its impact on chemistry learning, considering that the 21st century demands students to master many fields, one of which is 21st century skills which include critical thinking skills, problem solving, creative thinking, communication, and collaboration. (Redhana, 2019). Many research results explain that context-based learning can assist students in improving the quality of chemistry learning. (Baydere, 2021; Pursitasari *et al.,* 2020). Furthermore, the conditions of a supportive learning environment and the use of appropriate learning strategies or models in context-based chemistry learning can help teachers or researchers to improve learning effectiveness. Context-based learning strategy involve teaching chemistry concept using real-life context drawn from student's everyday experience, local environment, culture and societal issues (King, 2019). By linking abstract chemical concept to familiar situation such as food processing, agriculture, health, water purification and environmental challenges. Context-based learning makes chemistry learning more meaningful, relevant and engaging for learners (Gilert, 2016). Context-based learning has the potentials to bridge the gap between classroom instruction and real-world application (Holbrook & Rannikmae, 2018). Through active participation, discussion, problem-solving etc. students are more likely to develop positive interest deeper conceptual understanding and improve academic performance in chemistry. Some studies emphasize the use of context as a powerful tool for constructing and understanding concepts (De Putter, Taconis, & Jochem, 2016**).** Onasanya and Omosewa (2020) argued that, no matter how well trained or qualified a teacher is, if the teacher lacks a good teaching method, he/she will fail to put his ideas into practice. However, it has been observed that the use of conventional modes of teaching chemistry is still prevalent in our secondary schools.

Conventional methods of teaching: refers to universally common method of teaching use by teachers, Conventional method portrays the instructor as a facilitator of learning activities, a source of information, and a subject matter expert. The instructor would be responsible for all classroom instruction and ensures that all course ideas are comprehended by the pupils (Adanikin & Omojemite, 2021). The conventional method of teaching chemistry does not meet the requirement of the 21st century of teaching and learning as it does not promote deep and meaningful learning among students. Though this method guarantees the completion of task on time, it encourages learners to memorize and regurgitate content of learning experiences instead of digesting and assimilating them. Hence, this method does not allow students to be actively involved in the learning process. Nnamani and Oyiba,(2016), noted that classroom instruction should among other things create the desired and equal opportunity for understanding in students' gender.

Statement of the problem

Despite the central role of chemistry in scientific advancement, technological development, and career preparation in science–related field, academic performance in chemistry at the post-basic level in Taraba state, remain persistently low. Evidence from external examination such as the West African Examination Council (WAEC) report on the percentage grade at credit-pass in chemistry as follows: 2018 (19.8%), 2019 (43.71%),2020 (32.60%), 2021 (11.68%), 2022 (16.25%), and 2023 (10.50%) in Taraba state as shown in appendix 1, indicate fluctuation and generally unsatisfactory level of credit pass in chemistry, suggesting persistent difficulties in students conceptual

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understanding and problem solving abilities. These challenges are closely associated with student's negative attitude towards the subject, often arising from the abstract nature of chemistry concept.

Ideally, chemistry instruction at the post-basic school level should be learner-centered, engaging and closely connected to student's real-life experiences. Students should demonstrate strong interest, active participation, sound conceptual understanding and improve academic performance, achieving at-least credit level passes required for further studies in science related discipline. The persistence of poor academic performance in chemistry in Taraba state can be attributed to several factors including the abstract presentation of chemistry concepts, dominance of teacher centered instructional method, shortages of qualified chemistry teachers and student's inability to relate classroom content to their everyday environment. These factors collectively contribute to negative attitude towards chemistry and weak academic performance. There is a need to adopt instructional strategies that connect classroom learning with students lived experiences. Context-based learning strategy, offers viable solution to these problems bridging the gaps between classroom instruction and real-life application. By teaching chemistry concept through familiar context drawn from student's environment, culture, and daily activities. However, due to limited empirical evidence on the effectiveness of this strategy among post-basic school students in Taraba state. This gap necessitates the present study, which seeks to investigate the effect of context-based learning strategy on academic performance in chemistry with a view to improving chemistry teaching and learning in Taraba state, Nigeria.

Purpose of the Study

The purpose of the study was to investigate the effects of context-based learning on academic performance of post-basic school's students in chemistry in Taraba state, Nigeria. The specific objectives are to determine the:

1. Effects of context-based learning strategy on post-basic school students' academic performance in chemistry.
2. Effects of gender on the academic performance of secondary schools students when taught chemistry using a context-based learning approach.

Research questions

The study was guided by the following research questions;

1. What are the mean gains in academic performance scores of students when taught chemistry using context-based learning and those taught using conventional method?
2. What are the pre-test and post-test academic performance scores of male and female Secondary school students when taught chemistry using a context-based learning strategy?

Hypotheses

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

H_{O1} There is no significant difference in the academic performance of students taught chemistry using context-based learning and those taught using conventional method.

H_{O2} There is no significant difference in the academic performance score of male and female students when taught chemistry using context-based learning.

Literature Review

The theoretical framework of context-based learning in chemistry is anchored on Lev Vygotsky's theory of social constructivism, (1978) which state that learning is a socially mediated process, where individuals construct knowledge through interactions with others and their cultural environment.

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Methodology

The Quasi-experimental research design of pretest-posttest, non-equivalent, control group, was adopted for the study. The quasi-experimental research design was adopted for the study because it allows the researcher to examine the effect of an instructional intervention in a classroom setting where random assignment of participants to group is not feasible, it also enable the comparison of an experimental group and a control group while still maintaining the normal school structure. The researcher gathers participants in a group that cannot or should not be distributed, such as intact classes. Common characteristic of quasi-experimental design is that it tries to categorize the effect of a variable (independent variable) on another variable (dependent variable) in which an intervention is introduced to one group and the other is treated as control group.

Population, Sample and Sampling

The total number population of 14,495 S.S II students offering chemistry in the state for the 2023/2024 academic session which comprised 8,395 male and 6,100 female students from public post basic school in the sixteen (16) local government areas of the state. Multi-stage sampling technique were employed for the study where Jalingo Educational Zone was selected out of the ten educational zones in the state using simple random sampling. Targeted population of the study was 3,259 S.SII students offering chemistry in Jalingo education zone. The reason for choosing SS2 chemistry students is because of their relative stability compared to SS3, which is an exam class, and SS1 being an introductory class, some school authorities do not allow such classes to be used for research purpose. The Sample size of 174 SS2 students was drawn from secondary schools offering chemistry in Jalingo Education Zone was used for the study. The sample was obtained using hat and draw simple random sampling technique and intact sampling technique also. The hat and draw method of simple random sampling technique involves putting names in a hat and drawing a certain number of names out. Relating the techniques in the study, names of secondary schools each in the local government areas were inscribed, put into a hat, reshuffled and one school picked only. The procedure was repeated to select one school each from the secondary schools in the local government areas that constitute Jalingo education zone. Subsequently, intact class sampling technique applied to select the experimental groups and the control group.

Instrumentation, Validation and Reliability

Chemistry performance test (CPT) was the instrument used in this study. The Chemistry Performance Test (CPT) consists of 40 items adapted from past question papers of West Africa Examination Council (WAEC) 2014-2024 chemistry paper two (II) objectives questions. relevant to the topics under study. The chemistry performance test items (CPT) adapted from WAEC past question papers of different years, which is considered to be standardized and was subjected to face and content validation by one expert from Chemistry Department Modibbo Adama University, Yola. The 40 items of Chemistry Performance Test (CPT) was given a pilot test by administering it to 50 students (30 males and 20 females) SS II chemistry students of Government Day Secondary School Lankaviri, Lau local government area, Taraba State, which is outside the study sample schools but it has similar characteristics with sample schools for the study Kuder Richardson formula 20 was also used Since the items on the questionnaire are uniformly scaled. The results yielded co-efficient of reliability values of 0.85 for CPT. This reliability coefficient shows that the instruments are reliable.

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Data Analysis

The data collected for the study were subjected to analysis at two different statistical levels: descriptive and inferential statistics. At the descriptive level, the descriptive statistics of mean and standard deviation were used in order to respond to the research questions. At the inferential level, the Analysis of Covariance (ANCOVA) was used to test the hypotheses and the Covariate pre-test. All hypotheses were tested at a=0.05 level of significance. The inferential statistics permit decision making whether or not to reject null hypotheses after being tested. ANCOVA is appropriate in taking care of initial group differences statistically to compare in experimental research, effectiveness of pedagogical instructions where intact classes may differ in intelligence as it is similar to the current study.

Presentation of Results

Research Question One: What are the pretest and posttest mean academic performance score of students when taught chemistry using context-based learning and those taught using conventional method?

Table 1: Comparison of Pre-test and Post-test Mean academic performance Scores of students when taught chemistry using context-based learning strategy and those taught using conventional method.

Group	n	Pretest		Posttest		Mean gain
		Mean	S.D	Mean	S.D	
Experimental Group	52	29.20	9.07	71.48	9.89	42.28
Control Group	122	33.21	10.45	55.26	18.94	22.05
Mean difference				16.22		

Table 1 illustrates the academic performance of students in both the experimental and control groups before and after the instructional period. The experimental group displayed a mean difference of 16.22, along with a mean gain of 42.28, favoring the experimental group. A significant difference was observed between the average academic performance scores of students who were taught chemistry through context-based learning strategy and those who were instructed using the traditional method. This difference favors the experimental group. Consequently, the null hypothesis, which asserts that there is no significant difference between the average academic performance scores of students taught chemistry via context-based learning and those taught through the conventional method, is rejected.

Research Question Two: What are the pre-test and post-test mean academic performance scores of male and female Secondary school students when taught chemistry using a context-based learning strategy?

Table 2: Gender-Based Comparison of Pre-test and Post-test Mean academic performance scores of post-basic school Students in the Experimental Group

	n	Pretest		Posttest		Mean Gain
		Mean	S.D	Mean	S.D	
Male	27	28.63	9.40	70.56	9.50	41.93
Female	25	29.87	8.82	72.57	10.44	42.7
Mean Difference				2.01		

Table 2. presents the gender-based comparison of students in the experimental group. Male students had a posttest mean difference of 2.01 (SD = 9.50). Female students a posttest mean gain of 42.7 (SD = 10.44). While both male and female students showed notable academic improvement using

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context-based learning, female student's notable academic improvement using context-based learning, female students had a slightly higher mean gain of 42.7, in favor of the female students.

Results of hypotheses testing

H_{O1}: There is no significant difference on the academic performance of students taught chemistry using context-based learning and those taught using conventional method.

Table 3: Summary of ANCOVA of Difference in the Mean Academic Performance of Students in the Experimental and Control Groups

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	13813.812[a]	2	6906.906	26.564	.000	.237
Intercept	36131.181	1	36131.181	138.963	.000	.448
Pre-interest	4437.160	1	4437.160	17.066	.000	.091
Teaching methods	11482.544	1	11482.544	44.163	.000	.205
Error	44461.062	171	260.006			
Total	682996.000	174				
Corrected Total	58274.874	173				

a. R Squared = .237 (Adjusted R Squared = .228)

Table 3 shows the results of an ANCOVA to test the difference in the mean academic performance of students in the experimental and control groups. The teaching method had a statistically significant effect on students' academic performance $F(1, 171) = 44.163$, $p < 0.05$, partial $\eta^2 = 0.205$). The null hypothesis is rejected; this indicates that the context-based learning approach significantly improved students' academic performance compared to the conventional method. The partial eta squared value (0.205) represents a moderate effect size, showing that 20.5% of the variance in academic performance is explained by the teaching method., and it can be concluded that the context-based learning approach was more effective in enhancing students' academic performance than the conventional method.

H_{O2}: There is no significant difference on the academic performance score of male and female students when taught chemistry using context-based learning strategy.

Table 4: Summary of ANCOVA of Difference in the Mean Academic Performance of Male and Female Students in the Experimental group.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	169.698[a]	2	84.849	.862	.429	.035
Intercept	18941.329	1	18941.329	192.494	.000	.804
Pre-test	119.537	1	119.537	1.215	.276	.025
Gender	39.852	1	39.852	.405	.528	.009
Error	4624.782	47	98.400			
Total	260264.000	50				
Corrected Total	4794.480	49				

a. R Squared = .035 (Adjusted R Squared = -.006)

Table 4 provides the results of the ANCOVA for gender differences in the academic performance of students in the experimental group. The effect of gender on academic performance was not statistically significant $F(1, 49) = 0.405$, $p > 0.05$, partial $\eta^2 = 0.009$). There is no significance difference when taught using the context-based learning approach. The partial eta squared value (0.009) suggests a very small effect size, with gender accounting for less than 1% of the variance in academic performance. Therefore, the null hypothesis is retained, confirming that gender does not significantly influence students' academic performance when exposed to context-based learning.

Discussion

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Findings arrived at in this study are discussed in this section. The study examined the effects of context-based learning strategy on academic performance of post-basic school students in chemistry in Taraba state, Nigeria. The sample comprised male and female students therefore gender was incorporated as a moderator variable. Discussion of findings was tailored along the variables in the study as guided by the results of research questions and hypotheses.

Finding number one revealed that Students taught chemistry concept using context based learning strategy performed academically better than their counterparts exposed to conventional method. This is so because, context based learning engages, informs and allows for practice within each lesson. This finding is also in agreement with the findings of Githae (2015), Musa (2015) Tariq and saeed (2020), Samuel, obikizie and Maxwell (2020), Bacay and Herrera (2020), Magwilang (2016) who in their separate studies all reported that Context Based method enhanced students' academic achievement. However, Ugama (2016), Nwanekezi and Cheta (2018) reported on contrary to this finding that practical learning fosters students' achievement in basic science than context based learning approach. The finding number two on the effect of gender on academic performance revealed that male and female students in the experimental group improved significantly, the difference in academic performance between genders was not statistically significant $F(1,49) = 0.405$, $p > .05$, $\eta^2 = 0.009$). This finding aligns with which shows only a marginal difference in mean gain favoring females. This finding agrees with the result of Ngozi (2020), who found that context-based learning had more effects on students ISPS in chemistry, Oladejo et al. (2023) also found that there was a statistically significant main effect of treatment on students' performance.

Conclusion

The study has established that the findings strongly support the effectiveness of context-based learning in improving both academic performance in chemistry among post-basic school students in Taraba state, Nigeria. Significantly, these benefits do not vary by gender, encouraging the approach's broad applicability and inclusivity. The results indicated that students taught chemistry concept such as water solubility, hardness of water, periodic table and periodicity of element using context-based learning approach performed better than those taught using conventional method. These finding suggest that context-based learning approach are equally effective across different gender. therefore, incorporating context-based learning approach into the curriculum can bridge educational gaps.

Recommendation:

1. Teachers should be encouraged to use Context based learning strategy in teaching in order to improve students' academic performance irrespective of gender because Context based learning is a gender friendly teaching technique with regards to academic performance.
2. In-service training programs, seminars, work-shops and symposia should be organized by the state and federal governments to train chemistry teachers in the use of context-based strategies in teaching chemistry.

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Comparative Assessment of challenges and improvement strategies in Agricultural Science Teaching Between Public Schools in Sabon Gari and Zaria LGAs of Kaduna State, Nigeria

ONWUNALI, Martin Royal Okechukwu[1]
martinroyal2002@yahoo.com,
https://orcid.org/0009-0005-3653-8819

LADAN, Shamsudeen[1]
Ladanshamsu90@gmail.com

MUHAMMAD, Hashiru Bello[1]
Muhammadashir51@gmail.com

[1]Department of Agricultural Education, Faculty of Vocational and Technical Education
Federal University of Education, Zaria, Nigeria.

Abstract

This study evaluated teachers' perceptions of the challenges in teaching and learning Agricultural Science in public secondary schools within the Zaria Educational Zone, which includes the Zaria and Sabon Gari Local Government Areas. Data were collected using a validated structured questionnaire (Cronbach's a = 0.88), distributed to 84 teachers across 41 registered public schools in the area. Descriptive statistics revealed demographic differences: the workforce is young (ages 30–40), married males (>70%), although Sabon Gari has a higher proportion of females (60.87%). Teachers hold bachelor's degrees (>50%) in Agricultural Education and possess 6–10 years of experience. Key challenges identified were deteriorating infrastructure, insufficient instructional materials (Zaria = 3.11; Sabon Gari = 3.03), and limited ICT resources (Zaria = 3.11; Sabon Gari = 3.03). A lack of funding severely impacted resources and motivation. Student interest was notably low, especially in Zaria (2.98), due to inadequate practical exposure, limited career counselling, and negative perceptions of agriculture. Statistical tests ($p \leq 0.05$) indicated no significant differences between zones in terms of infrastructure, ICT, funding, or student attitudes, although support for improvement strategies varied. High standard deviations (except for Sabon Gari interest and strategies) suggested a lack of consensus. Teachers, particularly in Zaria, advocated for increased funding, facility upgrades, ongoing training, better salaries, and enhanced career guidance to improve Agricultural Science education.

Keywords: Teacher Perception, instructional challenges, Agricultural Science, resource availability, practical skills

Introduction

Agricultural Science education plays a crucial role in equipping students with the knowledge and skills needed for national development, particularly in agrarian regions like Zaria and Sabon Gari, situated in the northern part of Kaduna State, referred to as Zone A. However, the teaching and learning of Agricultural Science face numerous challenges, many of which are shaped by teachers' perceptions, instructional strategies, and systemic issues (Onwunali *et al.*, 2025). Research indicates a persistent decline in Agricultural Science instruction in Nigeria secondary schools, with Zaria and Sabon Gari being no exceptions. Eya and Chukwu (2012) observed a downward trend in instructional quality, associated with obsolete teaching strategies and a lack of students' interest. Furthermore,

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poor student enrolment and engagement in agricultural education programs have been linked to uninspiring instructional approaches (Amadi and Adejoh, 2020; Oluwatosin & Olatoye,2022), suggesting that teachers often lack motivation and innovative teaching methods. However, a strong and positive correlation has been established between age and teachers' attitude and academic success of agricultural science students (Amao, 2025) These issues are particularly pronounced in Zaria, where the need for enhanced instructional strategies to stimulate student interest is critical. Akinmade (2002) reported low interest among teachers and students in Sabon Gari, attributing this to the traditional, theory-heavy approach to a subject that ideally requires practical engagement. This lack of practical orientation diminishes the subject's appeal and effectiveness, resulting in poor student performance and increased dropout rates (Egun, 2007; Onwunali *et al.,* 2022). Teachers frequently report difficulties in delivering complex agricultural science topics, especially those integrating concepts from biology, chemistry, and geography. Egun (2007) reported that many teachers experience "phobia" toward teaching challenging scientific concepts such as chemical reactions, plant physiology, and genetics, which are integral to the Agricultural Science curriculum. The curriculum and content difficulty cause discomfort, lead to misconceptions and inadequate coverage of key topics, ultimately contributing to students' poor understanding and performance in external examinations.

A significant barrier identified across studies is the lack of adequate facilities and resources for practical Agricultural Science teaching. Reports have shown that insufficiently trained teachers, inadequate infrastructure, and poorly specified curricula hinder effective teaching and learning (Ohadiugha, 2020; Onwunali, 2020). In Zaria, where most families are resource-poor subsistence farmers, these challenges are compounded by socioeconomic factors, including cultural norms such as early marriage, which restrict female participation in agricultural education. Earlier, studies comparing Zaria and Sabon Gari reported that while students in Sabon Gari often perform better (Onwunali *et al.*, 2022), overall results remain sub-optimal, with average grades falling below expectations (Omodara *et al.*, 2024). Factors influencing these outcomes include school type, location, and the availability of qualified teachers. The interaction between these variables underscores the importance of context-specific interventions to address the unique challenges faced by teachers and students in each locality. Therefore, the need to enhance teacher training and professional development to build confidence in teaching complex scientific concepts remains *sine qua non* to facilitate the adoption of innovative, student-centered instructional strategies. Such foster greater interest and engagement (Eya and Chukwu., 2012). Studies have also shown that supply of modern and improved teaching facilities and practical resources supports experiential learning when adequate policies that clarify curriculum specifications and promote gender equity in agricultural education are put in place (Amadi & Okagwa, 2020).

Statement of the Problem

Despite the immense importance of Agricultural Science, its teaching and learning have been plagued by several challenges, including inadequate infrastructure, lack of qualified teachers, and poor learning resources, *inter alia.* These challenges have resulted in poor students' performances, and lack of interest in the subject. Previously, it has been demonstrated that inadequate infrastructure, incompetent teachers, poor application of ICT facilities and insufficient power supply mostly in rural environments were responsible for poor students' achievement in secondary schools (Onwunali *et al.*, 2024b; Omodara *et al.*, 2024). Hence the need to identify the basic challenges for sustainable

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teaching and learning of the subject in Zaria and Sabon Gari Local Government Areas of Kaduna State. The necessity is based on speculations and findings on students' performance and interest in Kaduna (Onwunali et al., 2024a), as well as the resent government policies on teachers' development and rehabilitation of secondary school to enhance effectiveness and performance.

Objectives of the Study

The specific objectives of this study are to:

1. Identify the socioeconomic characteristics of Agricultural Science teachers in secondary schools in Kaduna State,
2. examine the infrastructural and instructional materials challenges in teaching and learning Agricultural Science,
3. evaluate the Information and Communication Technology (ICT) challenges in teaching and learning Agricultural Science,
4. access challenges of school funding on teaching and learning of Agricultural Science,
5. determine challenges of students' interest and attitude towards Agricultural Science, and
6. identify strategies for improving the teaching and learning of Agricultural Science in Zaria and Sabon Gari Local Government, Kaduna State.

Research Questions

The following questions guided the study:

1. What are the demographic differences between Agricultural Science teachers in Public Secondary Schools that influence teaching in Zaria and Sabon Gari areas?
2. Does the availability of infrastructure and instructional materials depict modern and skillful teaching and learning of Agricultural Science in the study areas?
3. Is the level of application of Information and Communication Technology (ICT) suitable for global experience in teaching and learning Agricultural Science in Zaria and Sabon Gari areas?
4. What are the challenges of school funding on teaching and learning Agricultural Science in Zaria and Sabon Gari areas?
5. What are the factors responsible for students' lack of interest and poor attitude towards learning Agricultural Science in Zaria and Sabon Gari areas? and
6. What are the possible strategies to improve the teaching and learning of Agricultural Science in Zaria and Sabon Gari Local Government Areas of Kaduna State?

Research Hypotheses

The study tested the following null hypotheses at 5% level of significance.

Ho_1: There are no significant differences between infrastructure and instructional materials in Zaria and Sabon Gari.

Ho_2: There are no significant differences between level and application of Information and Communication Technology in Zaria and Sabon Gari.

Ho_3: There are no significant differences between funding challenges in Zaria and Sabon Gari.

Ho_4: There are no significant differences between factors responsible for lack of interest and poor attitude of students to agricultural science in Zaria and Sabon Gari.

Ho_5: There are no significant differences between the strategies used to improve teaching and learning of Agricultural Science in Zaria and Sabon Gari.

Materials and Methods

Description of the Study Area

Zamfara International Journal of Sci. Tech. Educ. & Mathematics
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des@fugusau.edu.ng
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The investigation was carried out in Zaria metropolitan city which comprised both Zaria and Sabon Gari Local Government Areas (LGAs) in Kaduna North Senatorial District. Zaria lies between latitude 11.07^0 and 12^0 North and longitude 07.44^0 and 8^0 East with land area of 300 square kilometers (Nwanosike, 2013; Ubandoma *et al.*, 2021), and an estimated population of approximately 736,000 according to 2006 census. Sabon Gari lies between longitude 7° and 8° East and latitude 10° and 12° North with average altitude of 675m above sea level (*masl*), with a land area of approximately 600km^2 (Kaduna Agricultural Development Agency, 2018). In 2018, it had a projected population of 725,069 at an annual growth rate of 3.2% (National Population Commission, NPC and National Bureau of Statistics, NBS, 2016). Inhabitants of both areas are mostly farmers and traders. The cosmopolitan nature attracts a lot of civil servants from various ethnic groups in Nigeria and beyond, due presence of several primary, secondary and tertiary institutions

Research Design

The study adopted a descriptive survey of research design. The population of the study compromised that of the 84 Agricultural Science teachers in the 41 registered public secondary schools. Of the population, Zaria had 17 registered public schools and 15 agricultural teachers while Sabon Gari had 24 registered schools and 69 teachers. The entire population of schools and teachers were used for data collection, considering the limited and negligible numbers, hence sampling was not done. The instrument used for data collection was close structured questionnaire, comprising three sections: the demographic information (sex, age, marital status, qualification and years of teaching experience) and perceived challenges affecting teaching and learning of Agricultural Science (Infrastructure and instructional materials, use of ICT, funding, interests and attitudes) and strategies. The challenges and strategies were designed in a 4-point rating scale of Strongly Agree (SA), Agree (A), Disagree (D) and Strongly Disagree (SD), and assigned values of 4, 3, 2 and 1, respectively. The instrument was validated by three experts from Federal University of Education, Zaria. Observations of the experts in terms of Language, sentence and spelling were incorporated before the pretest that yielded reliability coefficient value of 0.88 using Cronbach Alpha.

Data Analysis

Data on the demographic information of the teachers was subjected to simple descriptive statistics of mean and percentage while challenges and strategies of teaching and learning were analyzed using mathematical technique. Standard deviation was used to determine teachers' consensus agreement on their perception on the items. Standard deviation values 0 to 0.49 implied high common agreement on the significance of the challenge and strategy while values ≥ 0.5 depicted diverging opinions. Mean benchmark of ≥ 2.5 determined the decision for the significance of challenges and strategies, while < 2.5 indicated not significant and as such, the item in the challenges and strategies was assumed not to have strong influence (Onwunali *et al.*, 2024b). t-test independent ($p \leq 0.05$) was used to test hypotheses of the study. All the analyses were carried out using Statistical Package for Social Science (SPSS) version 23.

Presentation of Results

Socioeconomic Characteristics of the Teachers

Results in table 1 revealed that male teachers (73.33%) dominated in Zaria while female teachers were more in Sabon Gari. (60.87%). Majority of the teachers were young and energetic within the ages of 31 and 40 years and married, 73.33% and 71.01% for Zaria and Sabon Gari, respectively. Results also showed that Bachelor of Science in education (B.Sc. Ed) dominated teachers' qualification, however Sabon Gari had relatively a greater number of graduates teachers (55.07%) compared to Zaria (53.33%). Teacher's years of teaching experience was between 6 to 10 corresponding to 46.67% and 31.88 in Zaria and Sabo Gari, respectively.

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Table 1: Socioeconomic Characteristics of Agricultural Science Teachers in Zaria Education Zone

Variable	ZRX (%)	SBG (%)
Sex		
Male	73.33	39.13
Female	26.67	60.87
Age (in years)		
20 – 25	-	5.80
26 – 30	6.67	15.94
31 – 35	26.67	27.54
36 – 40	46.67	23.19
41 – 45	13.33	14.50
46 – 50	6.67	11.59
> 50	-	1.45
Marital Status		
Single	20.00	27.54
Married	73.33	71.01
Widowed	6.67	1.45
Qualification		
NCE	6.67	8.70
B.Sc.	13.33	20.29
B.Sc. Ed.	53.33	55.07
M.Sc.	-	10.14
M.Sc. Ed.	6.67	5.80
Others	13.33	-
Years of Teaching Experience		
1 – 5	20.00	30.43
6 – 10	46.67	31.88
11 – 15	20.00	14.50
16 – 20	-	13.04
21 – 25	6.67	8.70
26 – 30	6.67	-
> 30	-	1.45
Total	**100**	**100**

ZRX = Zaria, SBG = Sabon Gari, % = Percentage

Infrastructure and Instructional Materials Challenges

Results (Table 2) revealed significant infrastructural decay in both Zaria and Sabon Gari, with grand means and standard deviation of 3.11±0.76 and 3.03±0.32, respectively. Results also showed prominent levels of inadequacy in farm tools, equipment and chemicals, teaching materials and power supply for supporting teaching facilities in both locations, however such challenges were highly inadequate in Zaria with 3.93, 3.87 and 3.87, respectively. Contrarily, in Sabon Gari inadequate power supply for supporting teaching facilities (3.39), inadequate equipment and chemicals (3.29) and dilapidated laboratories (3.26) were more serious challenges, implying that location, school and teachers' activities influence the availability of infrastructures. Results also revealed significant standard deviation values in Zaria 0.76 and low value in Sabon Gari (0.32).

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Despite the variation in means, t-test value of t = 0.29 < 0.05 indicated no significant difference in infrastructural challenges of the two locations, hence Ho_1 was accepted.

Table 2: Challenges in Infrastructure and Instructional Materials in Zaria and Sabon Gari Educational Zone

ZRX= Zaria, SBG= Sabon Gari, $\bar{x}$= mean, SD= Standard Deviation, Df= 28, t-cal. = 0.29, t-crit. = 2.048^{NS}

S/N	Items	ZRX ($\bar{x}$)	SD	SBG ($\bar{x}$)	SD
1	Dilapidated laboratories	3.37	0.59	3.26	0.81
2	Inadequate equipment and chemicals	3.67	0.80	3.29	0.71
3	Dilapidated and poorly equipped libraries	3.73	0.74	3.20	0.85
4	Inadequate number of classrooms	2.07	0.88	2.58	0.99
5	Small-sized classrooms	1.53	0.64	2.35	1.03
6	Inadequate teaching materials (specimen, charts, posters)	3.87	0.35	3.09	0.84
7	Inadequate school garden for farm practical	2.53	1.06	3.14	1.07
8	Inadequate farm tools, equipment, and machines	3.93	0.26	3.35	0.84
9	Inadequate power supply for supporting teaching facilities	3.27	1.03	3.39	0.83
10	Lack of storage for safekeep of instructional materials	2.60	0.91	3.17	0.89
11	Lack of farm for practical	3.40	0.74	2.94	1.01
12	Lack of government monitoring to assess infrastructural decay	3.40	0.74	3.09	0.90
13	Lack of security for farms and other facilities	3.87	0.35	3.17	0.91
14	Inadequate maintenance of facilities for teaching	3.13	0.99	2.93	0.86
15	Lack of maintenance culture by the staff	2.07	0.88	2.48	0.98
	Grand Mean	**3.11**	**0.76**	**3.03**	**0.32**

Challenges in the use of ICT

The grand mean and standard deviation in Table 3 showed that ICT challenges were high both locations however, it was significantly higher in Zaria (3.03±0.73) compared to Sabon Gari (2.28±0.53). Standard deviation values implied diverging opinions of teachers at both locations. In Zaria could be due to availability of computer laboratories in some schools and absence in others. Different in Sabon Gari where majority of schools do not have computer laboratories, hence confirming relatively low diverging consensus in their perception. Mean results varied significantly from 1.60 to 3.87 in Zaria to 2.13 to 3.52 in Sabon Gari. However, teachers disagreed with incompetence in internet browsing (< 2.49) was a strong challenge, probably due the fact that most of them are conversant with mobile browsing and may not be efficient using computers. Comparatively, the t-test value of t = 0.55 < 0.05 between ICT challenges in Zaria and Sabon Gari, was not significant, therefore the hypothesis there is no significance between the two locations was accepted. The use of ICT and digital devices in teaching agriculture in Kaduna North Senatorial Zone is grossly inadequate and jeopardizes youths' participation in global digital communication. Specifically, inadequate computers and accessories, inadequate ICT facilities, and inadequate power supply dominated challenges in both LGAs. Subsequently, location of schools also influenced ICT availability and application, while inadequate number ICT skilled teachers, teachers' incompetent skills in ICT applications and inadequate experience of teachers in application of power point were

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major challenges in Zaria, poor internet facilities, network and service and lack of ICT laboratory dominated in Sabon Gari. Despite variation in means, there was no significant difference between ICT challenges in Zaria and Sabon Gari. Hence the hypothesis was accepted. Previous reports have shown that inadequate computers and accessories, inadequate ICT facilities, and inadequate power supply dominated challenges in secondary schools (Onwunali *et al.*, 2024b; Omodara *et al.*, 2025).

Table 3: Challenges in the use of ICT in Zaria and Sabon Gari Educational Zone

S/N	Items	ZRX ($\bar{x}$)	SD	SBG ($\bar{x}$)	SD
1	Inadequate computers, printers, scanners, photocopiers	3.87	0.52	3.52	0.74
2	Inadequate power supply	3.73	0.80	3.46	0.85
3	Teachers' incompetent skills in ICT application	3.47	0.52	2.29	0.96
4	Inadequate number of ICT skilled teachers	3.93	0.26	2.59	0.97
5	Poor internet facilities, network, and service	2.53	0.92	3.32	0.76
6	Incompetence in word processing (typing & printing)	2.73	1.03	2.78	0.95
7	Low experience of teachers in use of excel for calculation	2.93	1.16	2.43	0.95
8	Inadequate experience of teachers in power point usage	3.00	0.65	2.36	0.87
9	Incompetence of teacher's internet browsing	1.60	0.74	2.13	0.95
10	Lack of ICT laboratory	2.60	1.12	3.30	0.99
	Grand Mean	**3.04**	**0.73**	**2.28**	**0.53**

ZRX= Zaria, SBG= Sabon Gari, $\bar{x}$= mean, SD= Standard Deviation, Df= 18, t-cal. = 0.55, t-crit. = 2.10 NS

Challenges in Funding

Results (Table 4) revealed that both Zaria 3.03 and Sabon Gari 3.22 were underfunded. However, the uniform (±0.12) agreement on funding barriers were slightly high in Sabon Gari and diverging (±0.76) in Zaria. By indication, school funding experiences vary significantly among teachers in Zaria, due to additional funds by politicians and Alumni interventions, creating variation in funding of schools. Consequently, insufficient financial motivation for teachers (3.38), inadequate funds for instructional materials (3.80) and shortage of funds for chemicals and specimens (3.80) significantly dominated funding barriers in Zaria. But they were not in administrative impress, young farmers club activities and school inspection and monitoring. In Sabon Gari, inadequate funds for regular farm exhibitions and shows (3.39), lack of money to buy farm tools and machinery (3.32) and insufficient financial motivation for teachers' (3.30) were prominent. Despite disparities in perception, t- value of -0.68 < 0.05 indicated no significant difference between funding challenges in the two locations, as such the Ho_3 was accepted.

Table 4: Challenges on the funding Agricultural Science in Zaria and Sabon Gari Educational Zone

S/N	Items	ZRX ($\bar{x}$)	SD	SBG ($\bar{x}$)	SD
1	Inadequate funds to purchase instructional materials	3.80	0.56	3.30	0.75
2	Lack of administrative impress for Agricultural Science	2.27	1.10	3.09	0.76
3	Unsuitable teachers' salaries and wages	3.00	1.07	3.07	0.94
4	Shortage of funds for chemicals & Agricultural Science specimen	3.80	0.41	3.25	0.76
5	Lack of support for young farmers club activities	2.27	1.10	3.14	0.79

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6	Insufficient financial motivation of teachers	3.87	0.35	3.30	0.75
7	Inadequate funds for regular farm exhibition & show	3.47	0.92	3.39	0.69
8	Inadequate funds to organize field trips/excursion	3.47	0.91	3.28	0.66
9	Inadequate funds for school inspection and monitoring	1.73	0.80	3.03	0.80
10	Lack of money to buy farm tools and machinery	2.67	0.98	3.32	0.74
	Grand Mean	**3.03**	**0.76**	**3.22**	**0.12**

ZRX= Zaria, SBG= Sabon Gari, $\bar{x}$= mean, SD= Standard Deviation, Df = 18, t-cal. = -0.68, t-crit. = 2.101^{NS}

Poor Interest and Attitudes of Students

Results in Table 5 revealed significantly poor interest and attitude in Zaria and Sabo Gari, however Zaria recorded a higher mean (2.98) than Sabon Gari (2.67). The standard deviation value of ±0.67 and ±0.33 for Zaria and Sabo Gari respectively diverge perception in Zaria and uniform opinion in Sabon Gari, reflecting differing experiences among teachers. Unwilling attitude of students to Agricultural Science (3.87) due to lack of career counseling (3.80) and poor attitude to farm work and practice (3.67) were main barriers in Zaria, despite having competent Agricultural Science teachers (1.93). In Sabon Gari, poor attitude to farm work and practice (2.93), lack of counseling (2.91), home background and parental perception in Agricultural Science (2.86) and unwilling attitude of students to Agricultural Science (2.86) were prominent to poor student's interest. Field observation revealed and confirmed that limited land for farm practical encouraged theoretical teaching in Sabon Gari, contrary to Zaria, where majority of schools have land that are used for farm practical mostly during cropping season, however not in all possibly why Zaria have high diverging opinion. The t-test value of 1.01 < 0.05 indicated no significant, hence the hypothesis that there is no significant difference in student's interest and attitude in the two locations was accepted.

Table 5: Poor Interest and Attitudes of Students to Agricultural Science in Zaria and Sabon Gari Education Zone

S/N	Items	ZRX(⁻)	SD	SBG(⁻)	SD
1	Low interest in classroom teaching (theory)	3.40	0.83	2.80	0.90
2	Lack of interest in young farmers club activities	2.67	0.98	2.70	0.77
3	Poor attitudes to farm work and practical	3.67	0.72	2.93	0.83
4	Unwilling attitude of students to Agric. Science	3.87	0.35	2.65	0.89
5	Teachers' preference for male students to females in Agricultural Science	2.47	0.99	2.57	1.05
6	Home background and parental perception in Agric. Science	2.67	0.98	2.87	0.73
7	Poor students' performance in Agric. Science examinations	3.27	0.88	2.61	0.83
8	Unwillingness of students to accept careers in Agriculture	2.93	0.88	2.86	0.79
9	Students' Truancy to Agricultural Science classes	2.13	0.83	2.70	0.77
10	Lack of students counseling for careers in Agricultural Science	3.80	0.56	2.91	0.84
11	Incompetent Agricultural Science teachers	1.93	1.16	1.75	0.91

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Grand Mean	**2.98**	**0.67**	**2.67**	**0.33**

ZRX= Zaria, SBG= Sabon Gari, $\bar{x}$= mean, SD= Standard Deviation, Df *= 20, t-calculated = 1.01, t-critical. = 2.086^{NS}*

Strategies for Improvement of teaching and leaning Agricultural Science

In table 6, the grand mean of 3.70 and 3.34 for Zaria and Sabon Gari, respectively indicated support for the seventeen identified strategies to improve the teaching and learning of Agricultural Science. Similarly, the low standard deviations values of 0.31 and 0.14 in the two locations confirmed teachers' collective agreement on the strategies. Although the 17 perceived strategies were significant (≥2.5), results showed that sustainable salary structure and regular payment were major strategies of improvement in both Zaria and Sabon Gari. Teachers also emphasized the need for financial motivation, adequate funding of schools, recruitment of qualified Agricultural Science teachers, sufficient administrative fund for agriculture, and training and retraining of teachers to enhance knowledge. The t-test value of t = 3.30 > 0.05 showed a significant difference between the strategic approaches in Zaria and Sabon Gari, suggesting stronger support for improvement of strategies in Zaria. Therefore, the hypothesis that there is no significant difference in the strategic approaches in each location was rejected

Table 6: Strategies for Improvement of Teaching Agricultural Science in Secondary Schools in Zaria Education Zone

S/N	Items	ZRX ($\bar{x}$)	SD	SBG ($\bar{x}$)	SD
1	Regular school inspection by the ministry of education	3.87	0.35	3.29	0.84
2	Provision of well-equipped Agric. Science laboratory	3.53	0.61	3.29	0.93
3	Availability of well-equipped and spacious classroom	3.93	0.26	3.28	0.96
4	Required teacher student class ratio	3.93	0.26	2.97	0.91
5	Functional and convenient Agric. Science farm for practical	3.73	0.59	3.36	0.91
6	Adequate farm tools and machines to ease students work	3.87	0.35	3.35	0.89
7	Sufficient administrative fund for agriculture	3.93	0.26	3.30	0.83
8	Sustainable salary structure and regular payment	4.00	0.00	3.57	0.70
9	Financial motivation of teachers	3.87	0.35	3.49	0.80
10	Recruitment of enough and qualified Agric. Science teachers	3.80	0.41	3.39	0.81
11	Training and retraining of teachers to enhance knowledge	3.47	0.92	3.48	0.74
12	Regular Agricultural workshop and conferences for teachers	3.80	0.41	3.42	0.79
13	ICT training on Agric. Science packages and program	3.73	0.59	3.20	0.92
14	Regular supply of electricity	3.87	0.35	3.28	0.84
15	Availability of ICT facilities in the secondary schools	3.67	0.88	3.26	0.87
16	Regular agricultural exhibition, farm show, quiz, competition and seminars for students	2.93	1.16	3.48	0.72
17	Effective career guidance and counselor for students	3.00	0.93	3.39	0.73
	Grand Mean	**3.70**	**0.31**	**3.34**	**0.14**

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*ZRX= Zaria, SBG= Sabon Gari, $\bar{x}$= mean, SD= Standard Deviation, Df= 32, t-calculated value. = 3.30, t-critical value. = 2.042**

Discussions

The variation in gender and marriage was associated with parental reservations towards the girl child education, early marriage and the usual cultural kulle system that prevents exposure of young ladies to the society in Zaria as against Sabon Gari more cosmopolitan nature, attracting people from different ethnic groups. Teachers' academic qualifications in both locations revealed availability of qualified teachers, as majority held B.Sc. Ed. which is by national policy the required teaching qualification. However, field experience revealed that while majority were Agricultural Education trained graduates, others were graduates of related disciplines such as Biology, Geography, and Integrated Science *inter alia,* confirming earlier report that shortage of trained teachers and poor application of pedagogical skills negatively influenced students' performance in agriculture (Onwunali and Muhammad, 2025). The optimum qualification of teachers was associated with the locations proximity to Ahmadu Bello University and Federal University of Education in Zaria, that float Agricultural Education as a course, and the current Kaduna State policy in education, ensuring minimum qualification of a degree to teach in Secondary Schools. Although teaching experience in both LGAs was within 6-10 years, the variation in percentage favour Zaria (46.67%) probably due to their teacher's conservative nature preventing them from migration until retirement while majority in Sabon Gari explores opportunities even outside teaching. Similarly, Ayinde *et al.* (2023) reported high percentage of married female Agricultural Science teachers in metropolitan areas of Ogun State. Eck *et al.* (2019) emphasized the need for effective Agricultural Science teachers through balanced program, personal life, reduced extra working hours and limiting their community leadership involvement. The high infrastructural decay in Zaria was confirmed by the standard deviation of 0.76, compared to a relatively low standard deviation of 0.32 in Sabon Gari. This implied diverged opinion among Zaria teachers and uniformly agreed among teachers in Sabon Gari on the scarcity of infrastructure and instructional materials. In practice, government takes absolute responsibility for school sponsorship in Sabon Gari as against Zaria where schools' alumni supplement in certain schools. Therefore, variation in school standards because of alumni activity may have created a diverged opinion. This is because while some were equipped, others lack infrastructures, resulting in teachers' inconsistent experiences. For instance, Barewa College and Alhudahuda College among others where alumni activities strongly support their Alma Mata' as way of giving back to society, perceived availability of infrastructure differently compared to where such does not exist. Field observation revealed periodic activities like construction and renovation of classrooms and Science Laboratory, supply of computers, road construction and student hostels by alumni in Zaria. However, in Sabon Gari, most public schools have limited land space making it difficult for expansion and additional infrastructural development. Comparatively, the t-test value of t = 0.29 < 0.05 indicated that there is no significant difference in infrastructural challenges of the two locations, hence Ho_1 was accepted. Earlier, information on secondary school Agricultural Science infrastructure and instructional materials revealed severe deficiency in physical and digital facilities, such as inadequate and non-functional laboratories, farms, and processing areas. These limitations, compounded by chronic under-funding, poor electricity, and a lack of modern equipment, hinder practical training and the use of ICT (Onwunali *et al.*, 2025). Following the findings, funding of Agricultural Science activities in Northern Senatorial secondary school zone of Kaduna State was confirmed inadequate, because of poor teachers' motivation, inadequate supply of instructional materials and poor experiential teaching. Earlier, reports have shown that poor financial incentive

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negatively influences socioeconomic and work attitude of teachers. For instance, Ayinde *et al.* (2023) reported that, work attitude affected teachers socioeconomic and work-related issues like inadequate incentive and poorly equipped laboratories. Studies have also confirmed the persistent underfunding and variations in teacher perceptions, in Nigerian schools, particularly in the Northern regions (Isa & Alao, 2022; Anyanwu, 2026). This highlights ongoing teacher shortages and funding priorities among the acknowledged budget challenges. The study results further highlighted location-specific barriers to students' interest and attitudes toward Agricultural Science in Zaria and Sabon Gari, Nigeria. These results indicated consistently low student engagement in Agricultural Science across both locations, aligning with recent studies showing parental disinterest, inadequate career guidance, and negative perceptions of farming as key barriers in Kaduna State particularly in Zaria. The higher variability in Zaria's attitudes, linked to seasonal farm access, underscores how inconsistent practical resources foster divergent teacher and student experiences, a pattern reported on infrastructural and pedagogical challenges in the region (Olutosin *et al.*, 2017). Despite no statistical difference ($p \leq 0.05$), Sabon Gari's uniform low means and land constraints highlight the need for targeted interventions like enhanced counselling and school farms, as recommended in contemporary Nigerian agricultural education analyses. Obaruyi *et al.* (2024) reported that, ease or difficulty perception of students in accepting Agricultural Science influences their attitude to the subject, while Agbidi *et al.* (2022) reported a negative attitude of students towards Agricultural Science. Perception and attitude significantly shape students' choices and is influenced by parental advice (Adebayo & Oloyede 2020; Adejoh *et al.*, 2016), peer influence (Eze & Onyemeh, 2022), and career aspirations Onwunali *et al.*, 2022). The statistical results from Table 6 reveal strong teacher consensus on 17 strategies for enhancing Agricultural Science teaching and learning, evidenced by grand means of 3.70 in Zaria and 3.34 in Sabon Gari, with low standard deviations (0.31 and 0.14), indicating uniform agreement, and a significant t-test value of 3.30 > 0.05 that favoured Zaria. Key priorities like sustainable salary structures, regular payments, financial motivation, adequate school funding, qualified teacher recruitment, administrative funds, and ongoing training align with recent Nigerian studies emphasizing remuneration improvements and professional development to boost morale and curriculum delivery (Onwunali *et al.*, 2026). These findings rejected the null hypothesis of no locational differences, underscoring the need for targeted interventions in Sabon Gari while supporting Zaria's stronger endorsement, consistent with broader calls for policy reforms in teacher preparation and resource allocation. Earlier, reports have shown that inadequate funding of Agricultural Science affected provision of facilities and resulted in students' poor academic performance (Adams *et al.*, 2018; Akatwijuka & Arinaitwe, 2024). Similarly, Tajudeen *et al.* (2023) revealed the significance of conducive or unconducive learning environment to students' academic achievement in Agricultural Science, while Amao (2025) reported positive correlation between teachers' attitude and students' academic performance in Agricultural Science.

Conclusion

There are persistent challenges in teaching and learning Agricultural Science at the secondary schools within the Zaria and Sabon Gari Local Governments, both in Zaria Educational Zone. The studies collectively revealed that the current instructional strategies employed in teaching the subject in both LGAs are insufficient to motivate students or equip them with digital and practical skills, to match global practice and standards. Therefore, there is a clear need for more innovative, student centered, and practical approaches to teaching, as well as systemic support to address resource and perception challenges. Implementing recommendations below can significantly enhance students' interest and performance in Agricultural Science, contributing to the development of a new generation of skilled and motivated agricultural professionals in Nigeria.

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Recommendations

Based on the findings, the following recommendations were made to enhance the teaching and learning of Agricultural Science in public secondary schools in Zaria and Sabon Gari:

1. Schools should adopt learner centered and practical approaches by integrating a more hands-on and experiential learning activities like school farms, field trips, and demonstration projects to make Agricultural Science more engaging and relevant to students' lives as well as organize regular agricultural exhibitions, farm shows, and competitions to stimulate student interest.
2. Stakeholders, both governments, non-governmental (NGOs) and private partnerships should ensure employment of qualified Agricultural Science teachers and continuous professional development of those in the system. Such will regularly update teachers on use and application of modern instructional materials and the use of ICT infrastructures like computer laboratories and reliable internet access, thereby improving teachers' competences in digital teaching methods. This is because training and retraining of teachers in inquiry-based learning, and problem-solving methods overcomes instructional difficulties and improve content delivery.
3. Government and other educational stakeholders must invest in adequate teaching materials such as laboratory equipment and chemicals, and farm tools to support practical learning experiences, as well as prioritize the renovation of libraries, and classrooms. Increased budgetary allocation for Agricultural Science education will facilitate the provision of instructional materials, practical activities, and teachers' incentives by ensuring timely and adequate payment of teachers' salaries.
4. School administrators should strengthen career guidance and counseling, as effective implementation will expose students to career opportunities in agriculture, addressing cultural and parental biases that discourage student participation in Agricultural Science. In addition, the perceptive challenges are discouraged through regular awareness campaigns, career talks, and displaying successful agricultural entrepreneurs to inspire students.
5. The dynamic nature of Agricultural Science demands that the curriculum should be periodically reviewed to ensure it reflects current agricultural practices, technologies, and career opportunities, to enhance its relevance and appeal. The review should involve collaboration with stakeholders such as the teachers, industrial professionals, and entrepreneurs to facilitate schools' partnership with local farms, agricultural agencies, and NGOs who provide mentorship, internships, and exposure students to real world agricultural practices.
6. State Ministry of Education, local communities, and alumni associations should intensify efforts in monitoring schools to ascertain their level of progress, since regular inspections and monitoring of schools by educational authorities and other stakeholders ensure compliance with standards and identify areas of improvement need and intervention.

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Influence of Science and Technology Education Research-Driven Economy on the Implementation of Renewed Hope Agenda of the Federal Government of Nigeria

ANKELI, Gabriel Odeh
gabrielodehankeli@gmail.com

Department of Physics, College of Education, Oju, Otukpo, Benue State, Nigeria

Abstract

Science and technology education research plays a fundamental role in real economic growth and transformation, wealth creation and improvement of quality of life in any nation. Based on this premise this study examines the concept of science and technology education; research driven economy and its role in accelerating the implementation of the Federal Government Renewed Hope Agenda at the different segments of economy such as, healthcare delivery, water supply, environmental management, transportation, security and safety, poverty alleviation, agriculture, rural development, food security, clean and affordable energy and education. The study observed that the gap between developed and underdeveloped countries can largely be attributed to differences in science and technology education, research and development and the difficulty in their application. When properly harnessed, education, research and development synchronously represent a triple helix for advancing the frontiers of sub-national and national development. The study recommends that concrete steps could be taken to create the needed environment for research activities in the country by government. The provision of basic infrastructure and facilities, which goes hand in hand with increased budgetary allocation to the educational sector and research specifically, has become imperative.

Key Words: *Renewed Hope Agenda, Science and Technology Research*

Introduction

There is absolutely no doubt that humanity and society have made tremendous progress since the introduction and adoption of education as a catalyst for developing and harnessing the human capital input. History is replete with the actions, struggles and the efforts made by man to improve his well-being through constant enquiry into phenomena, exploration of the environment and the exploitation of natural resources contained therein. The transition from the stone age to the iron age, the invention of agriculture, the advent of traditional and modern technology, developments in natural and health sciences, communication and energy have all been attributed to knowledge and to education (Alhassan and Abdullahi, 2013). From age to age, man has sought to improve his living condition by ordering and mastering his environment and has succeeded due mainly to improvements in the methods and scale of the acquisition of knowledge and its application. This paper examines the concept of science and technology education research driven economy and its role in accelerating the implementation of the Federal Government Renewed Hope Agenda at the different segments of economy.

Concept of Science and Technology Education Research

Nwakaire and Nnorom (2015), described research as a process of steps used to collect and analyze information to increase our understanding of a topic or issue. The three steps include posing a question, collecting data to answer the question, and presenting an answer to the question. Research is an information tool about the behaviour of phenomena in any sector of the economy. In particular, it is the process by which we seek to observe and describe, explain, predict and control the behaviour of phenomena. Science research therefore is a special type of research that can provide scientific communities and decision-makers with useful recommendations and possible actions for resolving

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fundamental problems (Rosowsky, 2022). Such research provides policy-makers with pragmatic, action-oriented recommendations for addressing an issue, question, or problem. Research especially science and technology research could be define as a way of going about finding answers to scientific questions, collection of methods people use to produce knowledge, an exciting process of discovery. It therefore requires persistence, accuracy, generalization, personal integrity, tolerance for ambiguity, interactions with others and pride in doing quality work. Echono (2023), defined research as an ongoing process and the end of one study often stimulates new thinking and fresh research questions. Although much important research occurs in colleges, universities and research institutions, however research is being conducted in many other places for many purposes. In private industry, people in market, personnel, public relations and management conduct research as for many government agencies to help them better plan or deliver services. Research at any level is undertaken to: explore an idea, probe an issue and solve a problem. According to Anaeto, et al (2016), research, in its broadest sense, includes any gathering of data, information and facts for the advancement of knowledge.

Federal Government Renewed Hope Agenda

The current government of President Bola Ahmed Tinubu rolled out the renewed hope agenda of his government to address issues on the following sectors; national security, economy, agriculture, power, oil and gas, transportation, education, healthcare, sport, youth and women empowerment among others, to enable it develop the nation. Over the last few decades Nigeria as a nation has gone through several development agenda to reform the economy. Before the 1980s, the reforms were purely in the form of extended national perspective plans that attempted to mobilize human, material and natural resources of the nation to achieve goals of national life. These national plans were the 1962-1968 Plan, the 1970-1974 Plan, the 1975-1980 Plan, and the 1981-1985 Plan. Often, these Plans went beyond mere economic prescriptions to address social, human and political goals with short-comings which necessitated reform through stabilisation/austerity measures. Due to the short- comings of the previous development plans/programmes, Babangida administration in 1986 introduced Structural Adjustment Programme (SAP) to address the fundamental and structural imbalance in the economy, diversify the economy, strengthen the currency, and build a viable, sustainable industrial infrastructure upon which real economic growth and development can be founded. The reform exercise rested on a tripod of measures: *Liberalization* of foreign exchange transactions, *Rationalization* of public sector agencies and parastatals, and *Optimization* of the capacity for domestic production and stimulation of non-oil exports.

After, the Structural Adjustment Programme (SAP), is the Vision 2010 which was introduced by Abacha administration in 1998. The aim was to “develop a blueprint that will transform the country and place it firmly on the route to becoming a developed nation by the year 2010" (Vision 2010 Report, 1998). The general objective was to transform the country into “a united, industrious, caring and God-fearing democratic society, committed to making the basic needs of life affordable for everyone, and creating Africa’s leading economy”. In 2004, the Obasanjo administration introduced NEEDS - National Economic Empowerment and Development Strategy. The NEEDS reform programme rested on four key strategies (NEEDS, 2004): Reforming Government and Institutions, Growing the Private Sector, Implementing a Social Charter, Value Re-Orientation. After the NEEDS, there was an introduction of 7 point Agenda of Yar’Adua administration, vision 20:2020, transformation agenda of the Jonathan administration, the government of change by the Buhari administration. As good as some of these development agenda were, there was little emphasis on research and development which is very necessary both at the formulation, implementation as well

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as at the monitoring and evaluation stage. Nigeria Vision 20:2020 (p. 102) recognizes Research and Development (R & D) as key to global competitiveness. Similarly, the first N.I.P. Volume I, pp.2) identifies weak R & D culture in public and private institutions as one of the major constraints to economic growth and development.

Objectives of the Study

The objectives of this study are:

1. To explore the concept of science and technology education and its impact on national economic development: This objective aims to define the role of science and technology education in driving economic growth, particularly in the context of Nigeria.
2. To analyze the relationship between a science and technology education-driven economy and Nigeria's economic strategies: This objective seeks to examine how a robust science and technology education system contributes to achieving broader economic goals, as outlined in Nigeria's Renewed Hope Agenda.
3. To evaluate the potential contributions of science and technology education research in addressing key sectors within the Renewed Hope Agenda: This involves identifying how research and innovation in science and technology education can directly influence areas such as infrastructure, agriculture, healthcare, and industry in line with the Renewed Hope Agenda.
4. To assess the current state of science and technology education in Nigeria and its alignment with the Federal Government's strategic goals: This objective investigates the existing gaps in the education system and how they hinder or promote the achievement of the Renewed Hope Agenda.
5. To propose policy recommendations for enhancing the integration of science and technology education research into Nigeria's economic development plans: This aims to offer concrete suggestions for policymakers on how to better integrate science and technology education in the national agenda for faster socio-economic development.
6. To identify challenges and opportunities for leveraging science and technology education to promote innovation and entrepreneurship in Nigeria: This objective addresses the barriers to and potential for fostering an innovation-driven economy through education.

Concept of Science and Technology Education

Science is a branch of knowledge that is concerned with the observation and classification of facts and formulation of general truth. Science suggests ideas and technology operationalizes them. Science clarifies and justifies how an objective may be achieved. The "how" is translated into practical realization and from here, technology takes over and complements science (Rosowsky, 2022). This therefore shows that there is a symbolic relationship between science and technology. Science which is a systematic search for truth provides the basis for technology. Without technology, science becomes impotent, and without science, technology does not exist. However, it is the technology, the application of techniques and not science that leads to increase in production. In the past, science and technology constituted distinct traditions, maintaining separate identity paths of process and activities. But around the 19th century, there was a development of closer relationship between the two. The narrowing of that gap of separate identities culminated in the birth of the concept of science and technology. Technology simply put is a means of harnessing and exploiting our understanding of nature for our own benefit. It is an application of knowledge for practical purpose. It is used to improve human condition, natural environment or to carry out other socio-economic activities. It could also be defined or refers to all processes dealing with materials and their end products. One important attribute of technology is that it does not just happen; it is developed and learned whether in the farm of manual skills or as an applied science. It is the systematic application of collective human rationality to the solution of human problems through the assertion of control over nature;

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technology is the engine of growth. Technology can be traced historically to the beginning of time to be man's quest to improve his way and quality of life. According to Anaeto (2016), Technology is the total and complete application of man's knowledge, skills, tools and materials. It is the use of scientific knowledge to develop and produce goods and services useful to man. It is practical problem-solving enterprise, which is propelled by scientific discovery or by societal needs. Technology therefore, can be broadly classified into two major categories namely: (a) Material Technology- where knowledge is embedded into technological products such as tools, equipment, agro-chemicals, improved plant varieties or hybrids, improved breeds of animals and vaccines. (b) Knowledge-Based Technology- such as technical knowledge, management skills and other processes which are needed to successfully produce products or grow crops. A technology may be appropriate or inappropriate depending on the nature and capable of use of such technology. An appropriate technology is a form of technology which makes use of available resources in a given economic environment. It concentrates on tools and techniques which are carefully tailored to their needs, for a technology to be appropriate; it must show the following features: (i) Simple and easy to understand; (ii) Manageable; (iii) Inexpensive; (iv) Flexible; (v) Adaptable to changing needs; (vi) Technically feasible (vii) Locally serviceable; (viii) Employment generation potential; (ix) Infrastructural compatible and compatible with the people's cultural practices. Therefore, a technology well suited to one environment may not transfer well to another very different environment.

Impact of Science and Technology Education Research-Driven Economy

Science and technology have been central in the progress and development of virtually all the nations of the world. It has contributed immensely in all sector of the economy. Science and technology are intimately connected with development because; they have historical record of bringing advances that have led to healthier, longer, wealthier and more productive lives and they are key ingredients to solutions to the most serious poverty alleviation and economic development challenges that we currently face and are likely to face in the future. The many ways in which science and technology education research impact on the renewed hope agenda is discussed as follows:

1. Agriculture and Food Security

Advances in science and technology have facilitated higher yields, greater efficiency and greater nutritional content in the worlds food supply. Food production, however, must double in the coming decades to meet rising demand and meet the challenges entailed in inter-alia improving resistance to drought, pests, salinity and temperature extremes, raising the nutritional content and reducing post-harvest loss all in an environmentally and socially sustainable manner. At the same time, the regulatory challenges of assuring safety in food production and consumption will increase exponentially. Although, the necessary technology for increasing the agricultural output is available in many developing countries including Nigeria but certain requisites must be met. They according to Barnabas and Salami (2021) include: a) The will to advance economically; b) Opportunity and organization to use the technology. (c) Elimination of political, social and economic obstacles to development as was inherited from early colonial history. d) Ability first, to incorporate the technology into overall development, and then to continue using it. In the domain of food security, advances in science and technology provided the foundation for Green Revolution, and have allowed food prices to remain at historical lows for the past decades. Improved knowledge of plant biology and breeding techniques led to better seeds and cultivation practices that drastically increased yields. Rapid advances in the understanding of plant biology and related areas (especially via genomics) hold hope for solutions to problems as varied as increased productivity, nutritional content of food, food as a carrier of vaccines, soil/land degradation, post-harvest loss, and drought and pest resistance.

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2. Power Sector

Access to affordable energy is essential for people currently living without electricity and is a pre-requisite for economic growth. Further advancement and application of research is needed to find new environmentally and socially sustainable technology that can meet the energy needs of developing countries (Bryan, 2021). Other problem, such as the needs of people who live without access to adequate fresh water, or whose health and livelihood are endangered by environmental degradation call for development of new technologies (along with appropriate policy frame works)to mitigate these problems and their effects on poor people. Timely local adoption often requires significant indigenous technological capacity. Modern clean, renewable energy technologies such as; solar, wind, modern biomass need to be developed further and there needs to be an increase in the efficiency and sustainability of energy use in transportation, industry, and housing.

3. Economic Growth and Rural Development

Science and technology are tragically important to economic opportunity and growth. For many years policymakers have suspected a close link between economic growth and productive investment in science and technology and now mounting evidence supports this, in three principle ways (Fathi *et al.*, 2020). First, since the industrial revolution, rich (developed) countries have had the most science and technology capacity and have grown fastest. From 1870 to the present, scientifically and technologically-advanced countries have become increasing wealthy and their rates of growth have not diminished as this occurred. Second, returns to rural and development have been shown to be consistently positive and high in countries where science and technology are properly established. In such case, there is always a correlation between innovation and growth.

4. Water Supply

Water is another vital but scarce resources for which, in the absence of technological innovation, current and projected use patterns can only lead to severe crises. Today, about, 1.3 billion people lack access to an adequate supply of safe- water, two billion people do not have access to adequate sanitation, and water pollution causes millions of preventable deaths each year, especially among children. Water pollution is expected to continue to degrade freshwater and marine ecosystems, with a significant loss of biodiversity. The challenge is to leverage new technologies to provide an adequate supply of "safe" water in urban and rural areas to all users in a growing-wealthier population: households, agriculture and industrial sectors for instance; inexpensive desalination.

5. Healthcare Delivery, Sanitation and Environmental Management

Advances in scientific knowledge and its application have helped slow the trend of high fertility, high mortality and led to increasingly better health for many people world over. Nonetheless, vector and water borne diseases, Aids, inadequate pre-natal and maternal/child create a tremendous burden in the developing countries. Nigeria and indeed countries will be unable to correctly identify public health needs and choose cost-effective package of health service if they lack science and technology capacity. Ill-health is both a cause and a consequence of poverty. Over the past century, science and technology provided the basis for the largest ever aggregate improvements in human health. Certain scourge diseases have been eliminated, for example, smallpox, whiles the morbidity and mortality associated with everyday health related events like childbirth and routine infectious disease have declines sharply. Indoor air pollution, dysentery, water-borne disease, for instance, cholera, vector borne disease, for example malaria, dengue and so on. AIDS account for millions of deaths annually and are hitting hardest the countries that are least prepared and can least afford to deal with them.

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Some of these issues can be addressed using current knowledge, for example, dysentery while still others require scientific breakthroughs in science and technology such as AIDS, malaria and even Ebola. Environmental degradation at the local, regional and global scale adversely affects the livelihoods, health and vulnerability of poor people. Local issues include indoor and outdoor air pollution and water pollution, regional issues include acid deposition, and global issues include climate change, stratospheric ozone depletion, and loss of biological diversity, land degradation and desertification. These changes in the environment can adversely affect the incomes of poor people who depend on natural resources for their livelihood. These changes may also adversely affect human health through air and water pollution, an increase in the exposure to vector borne disease such as malaria and dengue, and an increase the vulnerability of poor people to extreme weather phenomena, such as floods and droughts and sea level rise due to climate changes. Hence, environment degradation threatens poverty alleviation and long-term sustainable development. The key challenge is to recognize that local, regional global environmental issues are inextricable linked and affect sustainable development. Therefore, there are synergetic opportunities to develop more effective response options to these environmental issues that enhance benefits, reduce cost and more sustainably meet human needs. The capacity of countries to adapt and mitigate can be enhanced when environmental policies are integrated with national development policies.

6. Social Investments and Poverty Alleviation

Science and technology have been central in the progress made to date in the fight against poverty and in stimulating economic growth. Advances in science and technology are, in many ways, the ultimate Global Public Good: once discovered, their benefits can be extended to additional users at little or no marginal costs, the social investment programme of the renewed hope agenda is completely driven by technology, right from the data gathering and capturing to the point of payment and utilization of beneficiaries personal information. In most basic and critical areas of human need, science and technology have made possible significant progress to date, and they hold the best prospects for continued progress, particularly with respect to agriculture, health, energy, water, and environmental concerns.

7. Education

No economy has ever becomes developed with this skew in their system of education and training for national manpower supply and/or human capital development. The utter disregard for science and technology education as an instrument of development has caused incalculable damage to our corporate existence. The problems of mismanaged economy, mass unemployment, collapse of health and educational services, insecurity, inflation, collapsed infrastructure and so on can all be traced to the inadequate attention paid to science and technology in Nigeria. It is the lack of science and technology initiative by Nigerians that has led people to turn their energy to the lust for power, greed and self destruction. Sadly enough, every Nigerian finds every other person guilty as charged, except himself or herself. Government's policy on education has among other issues emphasized but not driven the following objectives:

a) The training of the mind and the acquisition of appropriate skills, abilities and competencies-both mental and physical as equipment for the individual to live and contribute to the development of the society.
b) Ensuring that all schools are properly equipped to promote sound and effective teaching, and in particular, that suitable textbooks and libraries are provided for school. Secondary education should be six-year duration and be given in two stages, a junior secondary school stage and a senior secondary school stage. The junior secondary school (3-year duration) will be both

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prevocational and academic. It would be free. The senior secondary school would be for those *able* and willing to have a complete six-year secondary education (Chien, 2023).

A greater proportion of education expenditure would be devoted to science and technology and a greater attention paid to the development of scientific orientation. However, it is common knowledge that three decades after these objectives were set out to improve the standard of education in the country, not only have none of the objectives been realized, but also the standard of education has fallen far below what it was before (Kings, 2019).

8. Societal and National Development

Science and technology hold the key to the present and future development of Nigeria or any other country for that matter. Technology plays a fundamental role in wealth creation, improvement of the quality of life and real economic growth and transformation in any society. The sooner Nigeria realizes that her escape from poverty is predicated on her investment in science and technology education, the better for her. There is a technological power vacuum in Nigeria waiting to be filled by which ever geo-political zone that cares to mobilize its people through dedicated and selfless services. Essentially, technology is the primary engine of economic growth (Manoar, 2020). It is the key and fundamental requirement for value addition to raw materials and people. It provides the key to unlocking any country's potential in terms of decreasing over-head costs associated with out sourcing and creating employment opportunities. Science and technology education will not only prepare the Youths of Nigeria and indeed any other nation, for fulfilling career prospects, but also train their minds to address social problems with scientific mind. Youths equipped with science and technology education are also endowed with high employment opportunities. Many developed and advanced countries did progress much because of their heavy investments on science and technology. Examples: The United Kingdom and France benefited immensely from the industrial revolution in the 19th century.

Similarly, the United States emerged from an agrarian economy in the 19th century into an industrial superpower in the 20th century. More recently, Taiwan and Korea have exploited advances in silicon microelectronics from the early 1960s. China and India have emerged as industrial leaders in manufacturing and information technology respectively. Malaysia has also followed in the footsteps of these later Asian successes. It is necessary to emphasize here that in recorded achievements all these countries invested heavily in people, factories and infrastructure that provided the foundation for today's industries. These successes were all based on carefully designed roadmaps of plans and strategies. Unfortunately, however in many if not all the non-development or yet to develop countries, technology is seen or viewed as a consumable- item, and not something that can be produced or created. Analysis of technologically advanced economics shows that at each level of the economy, science and technology provide the engine for economic growth. For example, in the case of primary products, application of science and technology significantly increase the yield from agricultural production and mineral beneficiation. Similarly, new and existing industries do stimulate economic growth at the intermediate level, while the overall volume of activity at the tertiary level is amplified by increased use of science and technology associated with information technology and improved distribution/marketing networks. Therefore, the need for countries with the intention to grow, to invest significantly in science and technology cannot be overemphasized. This is achieved by developing the talent, the human capacity required to compete in a globally competitive world of today.

Conclusion

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Technology is achieved through a combination of knowledge, methods, tools and skills. This four-element definition of technology offers the details and clarity required for technology enhancement planning that must necessarily include knowledge and skills upgrade (training) and acquisition of human elements (knowledge and skills) and the tangible elements (methods and tools) of technology form the basis for our thinking and working processes. We must ensure adequate development of man power in science and technology to guarantee the efficient utilization of abundant natural resources and reduce the drain on our treasury and independence on outside sources for industrialization. The nation should be technologically self-reliant in the production of capital and consumer goods and raw materials. The educational system shall emphasize science at all levels and re-orient the entire society towards scientific thinking in order to develop new technologies and adapt existing ones to improve societal well being and security. Technology based developments can occur only with concerted efforts to revitalize education, develop personnel and create integrated industries that will involve close collaboration between government, industry and academia. Considering the roles of science and technology in national development, it become important to stimulate demand for technology from private sector, renew emphasis on the creation of linkages between firms and knowledge institutions, reform enabling environments for better use of knowledge, setting priority and evaluation right, promoting transparency, objectivity, selectivity and international best practices in science and technology funding, increasing access to Information and Communication Technologies (ICTs) and Government as a consumer of knowledge.

Recommendations

Based on the findings the following recommendations were provided:

1. Policies for science and technology in human resources development aim to provide science education at the basic secondary and tertiary level, prepare young people enter a diverse labour force that requires various levels of science and technology sophistication and encourage the conduct of research and advanced training.
2. "Implicit" policies for science and technology create an enabling environment that stimulates demand for knowledge in the private sector through, inter alia, a stable macroeconomic environment.
3. Appropriate climate for trade and investment, credit policies and adequate intellectual property rights regime. "Explicit" policies for science and technology in the private sector aim to further break down barriers to the use of knowledge. These policies may include support for firm-based training to encourage technology deepening, increase industry-academia linkage and public private partnerships, establish protection for indigenous knowledge provide tax incentives for firm engaged in rural development, and stimulate "clusters" of knowledge based industries.
4. Policies for public support of science and technology must address the various aspect of the public role in the national innovation system, including: setting priorities for funding and research, providing financing, instituting open, transparent peer-review selection processes establishing governance regulatory and management mechanism, incorporating the results of research in public policy decision, and monitoring and evaluating the system.
5. Policies for information and communication technology should seek to maximize the access to and flow of knowledge by, inter alia, extending access of available ICT to a wider range of user, improving the regulatory framework to facilitate a conductive environment for ICT growth, and providing training and education to facilities broader use of ICT.

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Correlation Between Pedagogical Content Knowledge and Attitudes towards Inquiry-Based Learning on Science Teaching Effectiveness among Pre-service Teachers in Niger State, Nigeria

MUSA, Asmau[1]
asmaumusa1100@gmail.com
ABDULLAHI, Mohammed[2]
abmoh24@gmail.com
BAWA, Swafiyah[3]
bawaswafiyah@gmail.com
MADU, Peter Chijioke[4]
chijiokemadu06@gmail.com
IDIRISU, Jibril Limangba[5]
chemistlimangba@gmail.com
EKUNKE, Unyime-Abasi Raphael[6]
eyounyimeraphael@gmail.com
SHEHU, Mohammed[7]
muhammadsgini@gmail.com
ABDULMALIK, Mohammed Katun[8]
mohammedkatunabdulmalik@gmail.com

[1]Department of Physics, Dr Umaru Sanda Ahmadu College of Education Minna, Niger State, Nigeria
[2]Department of Physics, Federal University of Education, Kontagora Niger State, Nigeria
[3]Department of Chemistry, Federal University of Education Zara, Kaduna State, Nigeria
[4]Department Of Educational Foundation, University of Cross River State, Nigeria
[5]Department of Chemistry, Baze University, Abuja, Nigeria
[6]Department of Basic Science and Technology, Federal College of Freshwater Fisheries Technology, New Bussa Niger State, Nigeria
[7]Department of General and Allied Studies, College of Health Technology Minna, Niger State, Nigeria
[8]College of Agriculture, Mokwa, Niger State, Nigeria

Abstract

In order to produce science literate citizens, science must be taught and effectively taught in schools. Unfortunately, quality of science teaching continues to be an area of concern within the Nigerian education system. This study investigated how pedagogical content knowledge (PCK) and attitudes towards inquiry-based learning (IBL) predict science teaching effectiveness among pre-service science teachers in Niger State, Nigeria. The study employed a correlational research design. A sample of 100 final year pre-service science teachers was randomly selected from two Colleges of Education in Niger State. Data were collected using three instruments which were validated: the Pedagogical Content Knowledge Questionnaire (PCKQ), Attitudes towards Inquiry-Based Learning Scale (AIBLS), and Science Teaching Effectiveness Scale (STES) with a Cronbach alpha coefficient ranging from 0.78 to 0.88. Data were analysed using simple linear regression and multiple linear regression analysis with 0.05 level of significance. Significant positive correlation was found between PCK and science teaching effectiveness (r=.541, p<.05) and also between attitudes towards IBL and science teaching effectiveness (r=.495, p<.05). Multiple regression analysis shows that PCK and attitudes toward IBL together predicted 41.3% variance in the predictor of science teaching effectiveness F(2,97)=34.218, p<.05). The variables are found to be stronger predictors of science teaching effectiveness in order: PCK (r=.441), attitude towards IBL (r=.341). The study recommends that teaching subject specific pedagogies as well as providing pre-service teachers with practical exposure to inquiry-based learning would best prepare pre-service science teachers in Niger State Colleges of Education for effective science teaching.

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Keywords: Pedagogical Content Knowledge, Inquiry-Based Learning, Teaching Effectiveness, Pre-service Teachers

Introduction

In today's world, science education has become the propelling force for innovation of technology, economic viability and the accomplishment of the Sustainable Development Goals (SDGs). The pivotal element that affects any science curriculum is teachers' effectiveness which is a multifaceted construct and it strongly correlates with student learning, science literacy and long-term retention of science talent (Ashiwere et al., 2024). World-wide, there is a paradigm shift in discussions on reform in education from focus on infrastructure to that of teacher training quality, arguing that no education system can ever be greater than the quality of its teachers. But in Sub-Saharan Africa and most especially in Nigeria, efforts to achieving teacher effectiveness have been hampered by limitations of old-fashioned methods of teaching, paucity of teaching resources and an old tradition of rote learning (Abiodun and Oduali, 2026). Although the National Policy on Education laid emphasis on the importance of science education functioning appropriately in Nigeria, it has been observed that students' performance in external examinations continues to be unimpressive, which can largely be explained by teachers' in ability to conceptualize and concretize abstract scientific concepts and turn them into learner-centred situations (Adam et al., 2025). A foundational concept in the study of instructional quality is Pedagogical Content Knowledge (PCK). Coined by Shulman (1986) and refined by Magnusson et al. (1999), PCK is the amalgam of subject matter expertise and pedagogical understanding. Specifically, PCK refers to the teacher's skill to transform the disciplinary knowledge to pedagogically potent but contextually sensitive ways of knowing. Within science education, this may include an understanding of representations of science, typical student conceptions, or particular pedagogical strategies effective in making seemingly daunting topics like genetics or thermodynamics comprehensible. Following in close suit to PCK is Inquiry-Based Learning (IBL). IBL is a constructivist instructional approach based on the practice of science inquiry. It encourages students to ask questions, develop designs, and build explanations based on evidence (National Research Council, 2012). While IBL is internationally celebrated for its promotion of higher order thinking skills, teachers' disposition towards this approach has a great impact on its effectiveness. The training of pre-service teachers in Nigeria, especially in North-Central region (Niger State) cannot be undermined. Niger State has a concentration of high-calibre colleges of education and universities; hence it's considered an important region in the training of teachers. Nevertheless, there is a problem with the transition between actual class delivery and the theoretical training received; more so when they are to join a labour force that expects scientific competence from its teachers. It is therefore crucial to identify the cognitive and affective variables that influence pre-service teachers' readiness to teach and teaching effectiveness.

There seems to be an argument that effective teaching of science depends on teaching being a cognitive and an affective experience. Theoretically this work is based on the Teacher Cognition Theory and Social Cognitive Theory (Bandura, 1997; Borg, 2015) where a teacher's knowing (PCK) combined with what he or she believes (attitudes) influences his or her teaching behaviour. It is therefore being argued that PCK is the foundational cognitive requirement for teaching effectiveness; that teachers need to understand ways in which science phenomena could be represented to bring about conceptual change in students. There are researches that show that teachers with higher PCK are better at identifying students' misconceptions and at utilizing analogies to build bridges from abstract to concrete concepts (Kind, 2019; Mapulanga and Jita, 2025). Nevertheless, cognitive competency alone is insufficient. It is hypothesized in this study that attitudes toward IBL is the

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catalyst that ignites PCK. A teacher might have an abundance of PCK, yet ineffective if he or she holds a negative attitude toward student-led inquiry and prefers the security of teacher-centred lecturing. It is a basic tenet of constructivist thought that learning is an active process, thus, alignment of the teacher's beliefs and the principles of inquiry-based instruction which treats students as active knowledge constructors not passive receptors of information is prerequisite to effective instruction (Vygotsky, 1978). Recent scholarship posits a synergistic relationship; a positive attitude toward inquiry motivates teachers to more readily use pedagogical knowledge in creative ways, whereas robust PCK is necessary to prevent teachers from "floundering" amid the "chaos" that a successful inquiry-based science classroom can entail (Ogegbo, 2021). As such, teaching effectiveness in science cannot be explained through a study of variables operating in isolation, but is the product of the interplay between what the teacher knows and what the teacher values.

Despite the theoretical importance of the above construct and their attendant relationships, gaps continue to exist in the current literature. Firstly, while considerable attention has been paid to PCK and instructional attitudes both individually and jointly as predictors of effective teaching, there is a paucity of research utilizing predictive modelling of these two variables. Most of the studies within the Nigerian context are descriptive, establishing the presence of teacher knowledge without delineating its specific weight and significance to teaching effectiveness (Aina et al., 2021). Secondly, there is a significant cultural and geographic bias within Nigeria research on teacher effectiveness. Most high impact research tends to be found within the southern geopolitical zones, ignoring entirely the cultural specificities of northern Nigeria, Niger State included. Information about northern Nigerian classroom practices, teacher-training curriculum, and resource limitations can significantly influence PCK and attitudes. Finally, much of the previous research relies on self-report rather than empirically valid, multidimensional measurement of pre-service teachers' actual instruction. Methodological simplicity through the use of simple correlation, rather than predictive modelling that considers cognitive and affective antecedents as predictors of teaching effectiveness, has prevented a comprehensive examination of factors contributing to science teaching effectiveness in Nigerian classroom environments. Addressing the above gaps can allow for refined pre-service teacher training and ensure that future science teachers are adequately prepared not only with subject matter knowledge but also with the appropriate pedagogical content knowledge and positive affect toward student-centred approaches.

Objectives of The Study

To address these gaps, the present study investigates the extent to which Pedagogical Content Knowledge and attitudes toward Inquiry-Based Learning predict the science teaching effectiveness of pre-service teachers in Niger State, Nigeria. The study is guided by three primary objectives to:

1. Assess the levels of PCK and attitudes toward IBL among pre-service science teachers;
2. Determine the relationship between these constructs and teaching effectiveness; and
3. Evaluate the relative and joint contribution of PCK and IBL attitudes to the variance in teaching effectiveness.

Null Hypothesis

In line with the predictive framework of this study, the following null hypotheses were formulated and tested at a 0.05 level of significance:

H_{01}: There is no significant relationship between pre-service teachers' Pedagogical Content Knowledge (PCK) and their science teaching effectiveness in Niger State.

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H_{02}: Attitudes toward Inquiry-Based Learning (IBL) do not significantly predict the science teaching effectiveness of pre-service teachers in Niger State.

H_{03}: Pedagogical Content Knowledge and attitudes toward Inquiry-Based Learning do not jointly explain a significant proportion of the variance in the science teaching effectiveness of pre-service teachers.

Methodology

This study used a correlational research design where a non-experimental predictive approach was employed to examine the relationships between cognitive and affective teacher variables and the teaching effectiveness of pre-service science teachers. It was adopted in order to establish the predictive ability of PCK and attitude towards IBL on the science teaching effectiveness of pre-service science teachers. With this design, individual and collective contributions of independent variables to the variation in dependent variable can be accounted for, without altering the participants' situation hence providing good ecological validity (Creswell and Guetterman, 2019). The study was conducted in Niger State of Nigeria. The state is characterized by large land area and is educationally central to the Northern part of the country. It is identified as one of the pivotal areas for teacher education with some Colleges of Education that provide science teachers for Northern schools. The population of the study was all final year pre-service science teachers of the Colleges of Education within the state. Final year pre-service teachers were used as their pedagogical, subject content and teaching practice courses have been concluded, hence ready for an evaluation of teaching effectiveness.

The sample size used for this study was 100 pre-service science teachers. Participants were drawn from Dr Umaru Sanda Ahmadu College of Education Minna and Federal College of Education Kontagora using a simple random sampling technique, which gave each final year science teacher an equal and independent chance of being selected. This size of 100 was chosen because it is adequate for a multiple regression with 2 predictors. As is well established in statistics, based on certain heuristic measures for power analysis, this sample size is enough to enable the study detect a medium effect size and provide stable regression coefficients, reducing over-fitting. Data collection was achieved through three purposefully designed instruments. Firstly, the Pedagogical Content Knowledge Questionnaire (PCKQ) contained 25 items, designed to assess the teachers' capacity for transforming science subject matter to learnable forms. Using a 4-point likert scale, PCKQ measures covered knowledge of content, of pedagogy and of students' misconception. An example of a question on the questionnaire reads as: 'I know how to translate abstract scientific information into useful teachable units for junior secondary school science teaching, e.g. by explaining atomic structure using analogies'. Secondly, was the Attitudes toward Inquiry-Based Learning Scale (AIBLS), a 25-item questionnaire on a 4-point Likert scale, measuring the teachers' attitudes in the affective realm (i.e. Perceived usefulness of IBL, interests in IBL and self-efficacy to do IBL). An example item on AIBLS reads: 'I think students will learn science better if allowed to design their own science experiments as opposed to follow rigidly guided ones found in manuals'. Thirdly, the STES contained 25-items and it was used to measure teachers' quality of teaching (the domain of observable behaviour: clarity of instruction, learner engagement and quality of assessment) through its 3 sub-scales: Instructional Clarity, Learner Engagement and Quality of Assessment. A sample item for STES is: 'The teacher used an open-ended question to assess the understanding of the learner' in the course of the lesson. The instruments were validated both face and content-wise by three experienced lecturers in the subject of science Education and Measurement and Evaluation from the Federal University of Technology, Minna, Niger State before they were administrated on the teachers.

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These teachers critiqued each item in relation to relevance and clarity of language and the validity of the items were refined accordingly.

A pilot study with 30 pre-service teachers, studying at an institution similar to the research institution but not included in the main sample, was conducted to validate the instruments. The data obtained from the pilot test were analysed for internal consistency using Cronbach's alpha coefficient. The findings showed high reliability indices as it resulted to alpha=0.80 for PCKQ, alpha=0.78 for AIBLS and alpha =0.88 for STES. This means that the instruments used are highly reliable for collecting the same results throughout the samples of interest. Data collection was spread over a period of six weeks. The first two weeks of data collection were used to seek permission, expert validation and pilot testing. The rest of four weeks were used to administer the instruments. Researchers visited colleges selected, gave out questionnaires to the selected sample, administered and collected them in a face-to-face, personally monitored and highly supervised context to ensure 100% return and clarify all directions on questionnaires. Ethical procedures were adhered to strictly such as consent from the participants, voluntary participation, and assurance of not linking participants to their responses. The participants were not required to write their personal identifiable information on the instruments to ensure confidentiality and anonymity.

Statistical analysis was carried out using SPSS (2020) version 26.0. Inferential statistics, including simple linear regression and multiple linear regression were used to test the null hypotheses at significance level 0.05. Multiple linear regression was utilized to assess the combined predictive ability of PCK and attitude towards IBL on teaching effectiveness. Several key assumptions related to multiple linear regression were tested prior to the actual analysis. They were; normalcy tested using p-p plot and shapiro-wilk test, linearity tested through scatterplots, multicollinearity examined using VIF and Tolerance scores. It revealed that VIF was within tolerance (VIF <10). This indicated that predictors are distinct concepts. These statistics confirmed that all assumptions about the use of the model have been satisfied.

Presentation Of Results

The results of the statistical analyses are presented in this section, organized according to the research objectives and hypotheses. The data were analysed using descriptive statistics (Mean and Standard Deviation), Pearson Product-Moment Correlation, and Multiple Linear Regression analysis. All hypotheses were tested at a 0.05 level of significance.

Descriptive Statistics

The descriptive statistics for the variables of Pedagogical Content Knowledge (PCK), Attitudes toward Inquiry-Based Learning (IBL), and Science Teaching Effectiveness (STE) are summarized in Table 1. The data represent the responses of 100 pre-service science teachers in Niger State.

Table 1: *Descriptive Statistics of PCK, Attitudes toward IBL, and Science Teaching Effectiveness*

Variables	Mean (M)	Std. Deviation (SD)
Pedagogical Content Knowledge (PCK)	2.84	0.52
Attitudes toward IBL	3.02	0.47
Science Teaching Effectiveness (STE)	2.76	0.58

The results in Table 1 show that pre-service teachers attained a mean score of 2.84 (SD = 0.52) in Pedagogical Content Knowledge and a mean score of 3.02 (SD = 0.47) for their attitudes toward Inquiry-Based Learning. The dependent variable, Science Teaching Effectiveness, recorded a mean score of 2.76 (SD = 0.58).

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Correlation Analysis

To determine the direction and strength of the relationships between the variables, a Pearson Product-Moment Correlation (PPMC) was conducted. The correlation matrix is presented in Table 2.

Table 2: *Correlation Matrix for PCK, Attitudes toward IBL, and Science Teaching Effectiveness*

Variables	PCK	Attitudes toward IBL	Science Teaching Effectiveness
PCK	1	.382**	.541**
Attitudes toward IBL		1	.495**
Science Teaching Effectiveness			1

Note: p < .00 (2-tailed)

As shown in Table 2, there was a significant moderate positive correlation between Pedagogical Content Knowledge and Science Teaching Effectiveness (r = .541, n = 100, p < .01). Similarly, a significant positive relationship was observed between attitudes toward Inquiry-Based Learning and Science Teaching Effectiveness (r = .495, n = 100, p < .01). Furthermore, a positive correlation existed between the two independent variables (r = .382), suggesting they are related but distinct constructs.

Test of Research Hypotheses

Hypothesis One

H_{01}: There is no significant relationship between pre-service teachers' Pedagogical Content Knowledge (PCK) and their science teaching effectiveness in Niger State. The correlation analysis in Table 2 reveals a significant positive relationship (r = .541, p < .05). Consequently, the null hypothesis (H_{01}) is rejected. The result indicates that higher levels of PCK are associated with increased science teaching effectiveness among pre-service teachers.

Hypothesis Two

H_{02}: Attitudes toward Inquiry-Based Learning (IBL) do not significantly predict the science teaching effectiveness of pre-service teachers in Niger State. Based on the regression coefficients (see Table 5), attitudes toward IBL significantly predicted science teaching effectiveness (β = .341, t = 4.162, p < .05). Therefore, the null hypothesis (H_{02}) is rejected. This finding suggests that a positive disposition toward inquiry-based methods is a significant individual predictor of instructional quality.

Hypothesis Three

H_{03}: Pedagogical Content Knowledge and attitudes toward Inquiry-Based Learning do not jointly explain a significant proportion of the variance in the science teaching effectiveness of pre-service teachers.

To test this hypothesis, multiple linear regression analysis was performed. The model summary, ANOVA, and coefficients are presented in Tables 3, 4, and 5, respectively.

Table 3: *Model Summary of the Predictive Relationship*

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.643	.413	.401	.452

Predictors: (Constant), Attitudes toward IBL, PCK

Table 3 shows a multiple correlation coefficient R = .643, indicating a strong overall relationship between the combined predictors and the dependent variable. The coefficient of determination (R^2) of

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.413 indicates that Pedagogical Content Knowledge and attitudes toward IBL jointly explain 41.3% of the variance in science teaching effectiveness.

Table 4: *ANOVA for the Regression Model*

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	13.982	2	6.991	34.218	.000
Residual	19.818	97	.204		
Total	33.800	99			

Predictors: (Constant), Attitudes toward IBL, PCK
Dependent Variable: STE

The ANOVA regression results indicate that the regression model is statistically significant ($F(2, 97) = 34.218$, $p < .05$). This confirms that the joint contribution of the independent variables is not due to chance.

Table 5: *Regression Coefficients*

Model	Unstandardized B	Std. Error	Standardized Beta (β)	t	Sig.
(Constant)	0.842	.245		3.437	.001
PCK	0.458	.085	.441	5.388	.000
Attitudes toward IBL	0.421	.101	.341	4.162	.000

As presented in Table 5, both PCK ($\beta = .441$, $p < .05$) and attitudes toward IBL ($\beta = .341$, $p < .05$) are significant contributors to the model. PCK emerged as the stronger predictor of science teaching effectiveness compared to attitudes toward IBL. H_{03} is rejected: PCK and attitudes toward IBL jointly and significantly predict science teaching effectiveness among pre-service teachers in Niger State ($p < .05$).

Discussion of Results

The findings of this study provide empirical evidence for the multi-dimensional nature of science teaching effectiveness, highlighting the critical roles played by both cognitive and affective variables. The results demonstrated that Pedagogical Content Knowledge (PCK) and attitudes toward Inquiry-Based Learning (IBL) are significant positive predictors of instructional quality among pre-service science teachers in Niger State. Notably, the correlation analysis revealed that as pre-service teachers' grasp of pedagogical transformations and their disposition toward inquiry-oriented instruction improved, their overall teaching effectiveness increased. Furthermore, the regression model established that these two constructs jointly account for a substantial proportion of the variance in teaching effectiveness, suggesting that neither content-specific pedagogical skill nor instructional belief is sufficient in isolation to produce high-quality science instruction.

The significant relationship found between PCK and science teaching effectiveness aligns with the foundational theoretical frameworks of Shulman (1986) and Magnusson et al. (1999), which posit that effective teaching resides at the intersection of content expertise and pedagogical transformation. This finding is consistent with the work of Mapulanga and Jita, (2025), who argued that the ability to identify student misconceptions and employ context-specific analogies is the hallmark of a competent science educator. In the context of Niger State, this result suggests that pre-service teachers who possess a sophisticated understanding of how to represent scientific concepts such as utilizing local examples to explain biological diversity or chemical bonding exhibit

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higher instructional clarity and engagement. In contrast to studies that emphasize general pedagogical skills or pure subject-matter knowledge as the primary drivers of effectiveness, this result underscores that transformed knowledge is the most potent cognitive predictor. This finding partially aligns with the observations of Kind (2019), who noted that while content knowledge is a prerequisite, it is the pedagogical packaging of that knowledge that directly influences student learning outcomes. The strength of PCK as a predictor in this study likely stems from the fact that pre-service teachers in Nigerian Colleges of Education are increasingly exposed to micro-teaching exercises and teaching practice requirements that emphasize the translation of theory into practice, a trend highlighted in recent Nigerian educational reforms (Adam et al., 2025).

The results also established that pre-service teachers' attitudes toward IBL significantly predict their teaching effectiveness. This finding is consistent with Teacher Cognition Theory (Borg, 2015) and Social Cognitive Theory (Bandura, 1997), which suggest that teachers' internal belief systems act as filters for their classroom behaviours. In this study, a positive attitude toward inquiry characterized by high perceived usefulness and self-efficacy translated into more effective, student-cantered instructional practices. This result mirrors the findings of Ogegbo (2021), who established that teachers with a constructivist orientation are more likely to create a learning environment where students pose questions and design investigations. However, this finding stands in contrast to the historical reliance on rote memorization and teacher-centric lectures often documented in Sub-Saharan African contexts (Zoupidis et al., 2023). While traditional Nigerian science education has frequently been criticized for its talk-and-chalk approach, the current results suggest a generational shift among pre-service teachers in Niger State. This positive disposition toward IBL indicates an emerging alignment with international standards for science instruction, such as those advocated by the National Research Council (2012). The significant predictive power of these attitudes implies that when pre-service teachers value the inquiry process, they are more resilient in navigating the logistical challenges such as large class sizes or limited laboratory equipment prevalent in many Nigerian secondary schools.

The multiple regression analysis revealed that PCK and attitudes toward IBL jointly explained 41.3% of the variance in science teaching effectiveness. This finding addresses a critical gap identified by Aina et al. (2021), who noted that many Nigerian studies fail to account for the simultaneous influence of cognitive and affective domains. The results demonstrate that the synergy between "what a teacher knows" and "what a teacher values" creates a more robust predictor of performance than either variable alone. This supports the argument that instructional quality is a holistic construct where cognitive competence (PCK) provides the tools for teaching, while affective disposition (attitudes toward IBL) provides the motivation to use them. Interestingly, the standardized beta coefficients showed that PCK was a slightly stronger predictor (β=.441) than attitudes toward IBL (β=.341). This suggests that while beliefs are vital, they cannot compensate for a lack of pedagogical depth. In the challenging educational landscape of Northern Nigeria, a teacher may passionately believe in student-led inquiry, but without the PCK necessary to manage student misconceptions or simplify abstract scientific phenomena, their classroom effectiveness remains constrained. This finding reinforces the notion that PCK is the "gatekeeper" of effective science instruction (Kind, 2019). Situating these findings within the global science education discourse reveals a convergence between the realities in Niger State and international trends. The shift toward recognizing teacher quality as a function of specific pedagogical knowledge rather than general intelligence is a universal theme in contemporary educational research (Yilmaz and Sahin, 2025). The results from Niger State echo

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findings from both developed and developing countries, suggesting that the components of effective science teaching are, to a large extent, culturally transcendent. However, the specific highlight of the Nigerian context such as the urgent need for scientific literacy to drive national development give these findings a unique regional importance.

The study confirms that the challenges faced in Sub-Saharan Africa regarding teacher preparation are not insurmountable. By focusing on the dual development of PCK and inquiry-based attitudes, teacher education programs in Niger State can bridge the gap between theoretical knowledge and classroom practice. This is particularly relevant in Northern Nigeria, where educational outcomes have historically lagged behind other regions; these findings provide an evidence-based pathway for narrowing that disparity through targeted teacher preparation.

Conclusion

This study examined the relative effectiveness of Pedagogical Content Knowledge (PCK) and attitudes toward Inquiry-Based Learning (IBL) as predictors of effective science teaching among pre-service teachers in Niger State of Nigeria. This study confirmed both PCK and attitudes toward IBL to be a viable set of both unique and combined predictors of instructional quality. While PCK was confirmed as the most powerful cognitive determinant of teacher effectiveness, teachers' attitudes toward inquiry served as the most salient affective factor influencing teacher effectiveness. Conceptually, the present study confirmed that the separation of cognitive and affective components of teacher cognition is not sufficient. Practically, this study contributes a statistically valid measurement of teacher preparedness for the task in North-Central Nigeria and helps fill a gaping geographic hole in the literature, while the practical implication of the study confirms that the existing bifurcated approach to teacher training is an impediment to a successful practice.

Recommendation

To be pragmatic, teacher-training institutions in Niger State should embrace the integration of PCK modules and offer pre-service teachers (PST) with direct experiences on inquiry-based learning in the early stages of their education. Future researches need to adopt longitudinal study designs to trace the impact of these PST-predictors on long-term student outcomes in secondary schools. By equipping the Nigerian pre-service science teachers with not only subject specific knowledge but also with strong professional commitment towards inquiry-based instruction, the future Nigerian nation will have its future science teachers who will lead science literacy and innovation.

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A Multi-Index Reliability Examination of the ISPTEQ Instrument among Private Secondary School Teachers in Gusau, Zamfara State, Nigeria

MUHAMMAD, Bala Maradun[1]
mbmaradun@fugusau.edu.ng
balamaradun@gmail.com
NA ALLAH, Nasiru[2]
[1]University Health Services Department, Federal University Gusau
[2]Department of Mathematics and Statistics, Abdu Gusau Polytechnic Talata Mafara

Abstract

Scale reliability is a necessary condition for valid score interpretation. Yet, most educational research conducted in Nigerian private schools reports only Cronbach's alpha, thereby neglecting complementary indices that reveal distinct facets of measurement consistency. The present study systematically evaluated the psychometric reliability of the three-subscale ISPTEQ instrument (N = 386 teachers) using five independent reliability indices: Cronbach's alpha with Feldt, Woodruff, and Salih (1987) 95% confidence intervals; McDonald's omega-hierarchical; Spearman–Brown corrected split-half reliability; item-total discrimination coefficients; and item difficulty proportions. Alpha values were: S1 = .724 (95% CI [.679, .760]), S2 = .621 (95% CI [.560, .671]), and S3 = .620 (95% CI [.558, .671]). McDonald's omega was uniformly lower than alpha (S1 = .652; S2 = .522; S3 = .502), indicating that alpha systematically overestimates reliability when the essential tau-equivalence assumption is violated. Spearman–Brown values were S1 = .725, S2 = .613, and S3 = .644. Mean inter-item correlations fell below the .15 target for all three scales (ISPS: .127; TES: .093; TQS: .119), and 67–88% of item pairs did not attain r = .15. No item exceeded a discrimination index of .36. Item difficulty proportions ranged from .78 to .84, confirming a systematic ceiling effect. Collectively, the multi-index profile characterises the instrument's reliability as marginally acceptable for research purposes but in need of targeted item revision. These findings highlight the limitations of relying solely on Cronbach's alpha and provide a roadmap for strengthening the ISPTEQ instrument in future research.

Keywords: Cronbach's alpha, McDonald's omega, split-half reliability, item discrimination, item difficulty, reliability confidence interval, ISPTEQ, psychometrics

Introduction

Cronbach's (1951) coefficient alpha remains the most widely reported reliability statistic in educational and social science research; yet it is frequently misunderstood and over-relied upon. Zakariya (2022) demonstrated that the indiscriminate use of alpha — without attention to the essential tau-equivalence assumption — is pervasive across leading educational journals. Hussey et al. (2025) further revealed a statistically anomalous clustering of alpha values around .70, consistent with researcher reporting biases. McNeish (2018) argued that, when item factor loadings differ substantially, alpha underestimate's true reliability; conversely, when a scale is heterogeneous or multidimensional, alpha may paradoxically overestimate reliability. McDonald's (1999) omega-hierarchical (ω^h) provides a more defensible estimate because it is derived directly from the factor structure of the items and does not require tau-equivalence. In the Nigerian private-school context, the ISPTEQ instrument has been employed to measure internal supervision practices (ISPS, 18 items), teachers' effectiveness (TES, 16 items), and teaching quality (TQS, 12 items) amongst 386 teachers in Gusau, Zamfara State. Prior publications from this dataset have reported alpha values of .724, .621, and .620, respectively, which have been interpreted variously as 'acceptable' or 'good'. What has not been examined is whether these alpha values accurately reflect the scores' reliability and whether complementary indices would yield a substantially different reliability story. The present paper directly addresses this gap.

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Statement of the Problem

A significant methodological gap persists in Nigerian educational research: instruments such as the ISPTEQ are routinely validated using Cronbach's alpha alone, without corroborating indices. This practice obscures violations of the tau-equivalence assumption, ignores ceiling effects induced by positively keyed Likert items, and presents inflated reliability estimates that may mislead subsequent score interpretations. The absence of omega-hierarchical estimates, split-half checks, and item-level diagnostics from published ISPTEQ studies means that consumers of this research cannot judge the true precision of measurement.

Aim and Objectives

The overarching aim of this study is to provide a comprehensive, multi-index reliability characterisation of the ISPTEQ instrument as administered to private secondary school teachers in Gusau, Zamfara State. Specifically, the objectives are to:

(i) estimate Cronbach's alpha with 95% exact confidence intervals for each ISPTEQ subscale;
(ii) compute McDonald's omega-hierarchical and quantify the magnitude of alpha overestimation;
(iii) derive Spearman–Brown corrected split-half estimates as an independent reliability check;
(iv) examine inter-item correlation distributions to evaluate subscale homogeneity;
(v) calculate corrected item-total discrimination indices and identify underperforming items; and
(vi) Compute item difficulty proportions and standard errors of measurement.

Literature Review

The scholarly literature on scale reliability has evolved considerably since Cronbach (1951) formalised the coefficient alpha framework. Early validity and reliability studies in Nigerian educational settings largely confined themselves to single-index alpha reporting (Nunnally, 1978), a pattern that has persisted despite mounting evidence of its limitations. Clark and Watson (1995) established inter-item correlation benchmarks of .15 to .50 as necessary conditions for subscale homogeneity, whilst Ebel and Frisbie (1991) provided widely used discrimination thresholds. More recent scholarship has challenged the hegemony of alpha: McNeish (2018) provided an accessible treatment of omega-hierarchical as a preferred alternative, and Revelle and Zinbarg (2009) formalised the mathematical relationship between factor structure and reliability estimation. Kalkbrenner (2023) offered practical guidance on choosing between alpha, omega, and coefficient H, noting that the choice of index materially affects conclusions. In the specific domain of teacher evaluation instruments, Xiao and Hau (2022) demonstrated that non-normal response distributions — common on positively keyed Likert scales — attenuate inter-item covariance and depress true reliability below the alpha estimate. Doval, Viladrich, and Angulo-Brunet (2023) found that alpha's resistance to replacement in the applied literature stems partly from inertia and partly from journal reporting conventions that have not kept pace with psychometric advances. The ISPTEQ instrument, developed to capture internal supervision practices, teacher effectiveness, and teaching quality in Nigerian secondary schools, has to date been evaluated solely using alpha, a gap the present study aims to remedy.

Research Gap

Despite growing international recognition that multi-index reliability profiling yields more defensible psychometric conclusions, no published study has applied such a framework to the ISPTEQ

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instrument. Existing research on private schools in Zamfara State has not reported omega-hierarchical estimates, split-half coefficients, or item difficulty proportions, making it impossible to evaluate whether the commonly cited alpha values reflect genuine measurement consistency or artefacts of scale construction. The present study fills this gap by applying five complementary reliability indices to the full 46-item ISPTEQ, thereby providing the most comprehensive psychometric evaluation of this instrument to date.

Materials and Methods

Participants and Instrument

Participants were N = 386 qualified teachers employed in private secondary schools in Gusau, Zamfara State, Nigeria. All data were collected via the 46-item ISPTEQ questionnaire using a four-point Likert scale (1 = Strongly Disagree to 4 = Strongly Agree). Subscales are: ISPS (items 1–18, internal supervision practices), TES (items 19–34, teachers' effectiveness), and TQS (items 35–46, teaching quality).

Analytical Procedures

Five reliability indices were computed: (1) Cronbach's alpha with Feldt, Woodruff, and Salih (1987) exact F-distribution 95% confidence intervals; (2) McDonald's ω^h derived from single-factor exploratory factor analysis loadings; (3) Spearman–Brown corrected split-half reliability using odd/even item splits; (4) corrected item-total discrimination indices; and (5) item difficulty proportions (p = item mean / maximum score). Alpha-if-item-deleted analysis was conducted for all 46 items. Standard errors of measurement were computed according to Equation (2). All analyses employed Python 3.12 (scipy, numpy, sklearn), with computations verified against IBM SPSS 25.

Key Formulae

Cronbach's alpha (α) is defined as:

$$\alpha = (k / (k - 1)) \times (1 - \Sigma\sigma^2_i / \sigma^{2T}) \quad (1)$$

where k is the number of items, $\Sigma\sigma^2_i$ is the sum of item variances, and σ^{2T} is the total score variance. The standard error of measurement is:

$$SEM = SD \times \sqrt{(1 - \alpha)} \quad (2)$$

McDonald's omega-hierarchical (ω^h) is:

$$\omega^h = (\Sigma\lambda_i)^2 / [(\Sigma\lambda_i)^2 + \Sigma\delta_i] \quad (3)$$

where λ_i are standardised loadings on the general factor and $\delta_i = 1 - \lambda_i^2$ are the uniquenesses. The Spearman–Brown corrected split-half coefficient is:

$$r_SB = 2r_{12} / (1 + r_{12}) \quad (4)$$

Presentation of Results

Cronbach's Alpha with 95% Confidence Intervals

Table 1 presents Cronbach's alpha alongside 95% exact confidence intervals for each ISPTEQ subscale. The ISPS subscale (α = .724; 95% CI [.679, .760]) is the only subscale that meets the conventional .70 research-grade threshold. TES (α = .621; 95% CI [.560, .671]) and TQS (α = .620; 95% CI [.558, .671]) fall below that threshold, and their lower confidence interval bounds approach .56, meaning that at the lower limit of sampling uncertainty these two subscales verge on 'poor' reliability (α < .50). The ISPS confidence interval is notably narrower (width = .081) compared with TES and TQS (widths ≈ .111–.113), a consequence of the stabilising effect of the larger 18-item pool on estimation precision. These results indicate that, even by the comparatively lenient single-index

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criterion, two of the three ISPTEQ subscales do not meet minimum standards for research use without additional qualification.

Table 1

Cronbach's Alpha with 95% Confidence Intervals for ISPTEQ Subscales

Subscale	k	α	95% CI Lower	95% CI Upper	Interpretation
ISPS (Supervision)	18	.724	.679	.760	Acceptable (≥ .70)
TES (Effectiveness)	16	.621	.560	.671	Below .70 threshold
TQS (Teaching Quality)	12	.620	.558	.671	Below .70 threshold

Note. 95% CI computed via Feldt, Woodruff, and Salih (1987) exact F-distribution method. k = number of items. Alpha threshold: ≥ .70 = acceptable for research purposes (Nunnally, 1978). N = 386.

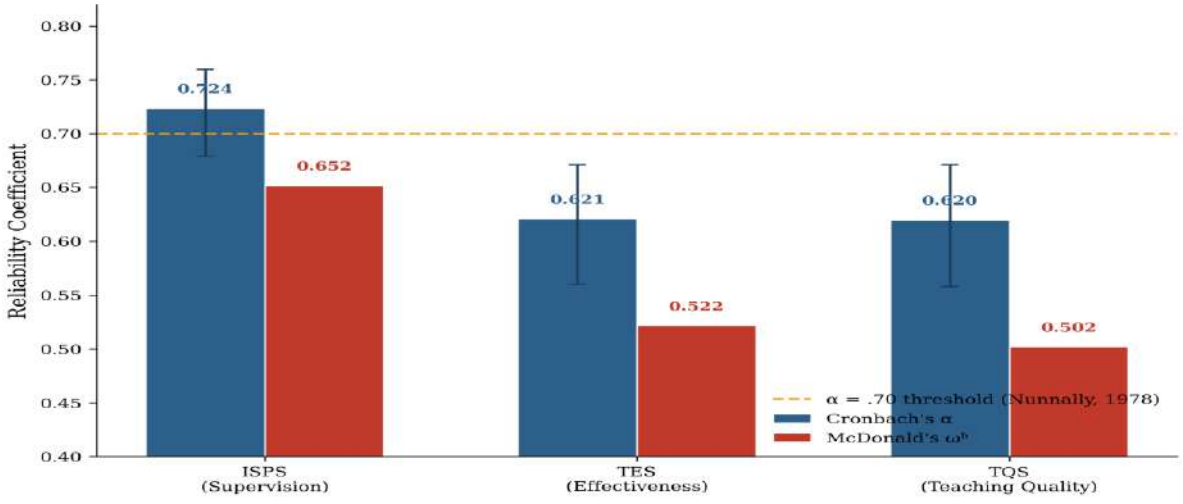


Figure 1

Comparison of Cronbach's Alpha (with 95% Exact Confidence Intervals) and McDonald's Omega-Hierarchical Across the Three ISPTEQ Subscales

Figure 1 displays the magnitude of each reliability coefficient side by side for the ISPS, TES, and TQS subscales. The blue bars represent Cronbach's alpha, and the red bars represent McDonald's omega-hierarchical (ω^h). The error bars attached to the blue bars show the 95% exact F-distribution confidence intervals computed following Feldt, Woodruff, and Salih (1987). The dashed horizontal line marks the conventional research-grade threshold of α = .70 (Nunnally, 1978). Three patterns are immediately apparent. First, ISPS is the only subscale whose alpha bar clears the .70 threshold, whilst TES and TQS fall clearly below it. Second, the red omega bar is consistently shorter than the corresponding blue alpha bar across all three subscales, confirming the systematic $\alpha > \omega^h$ overestimation gap that ranges from +.072 (ISPS) to +.118 (TQS). Third, the confidence interval for ISPS is noticeably narrower than those of TES and TQS, reflecting the greater estimation precision

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conferred by the larger 18-item pool. At the omega level, TQS reliability (.502) effectively falls below the minimum acceptable threshold for any research application.

McDonald's Omega Versus Cronbach's Alpha

Table 2 presents a comparison between Cronbach's alpha and McDonald's hierarchical omega, together with factor loading statistics that explain the divergence. The systematic $\alpha > \omega^h$ gaps demonstrate that essential tau-equivalence is violated across all three subscales, and that alpha has overstated the true reliability of TES and TQS by 19% and 24%, respectively. This overestimation is directly traceable to the heterogeneity of factor loadings within each subscale: in ISPS, for instance, the minimum loading (.236) is only 66% of the maximum (.355), indicating that items contribute unevenly to the latent supervision practices factor. The overestimation is most severe for TQS (+.118), where omega (.502) falls below the absolute floor of .50 for any research application — a considerably more alarming picture than the alpha value of .620 would suggest on its own.

Table 2

Comparison of Cronbach's Alpha and McDonald's Omega-Hierarchical Across ISPTEQ Subscales

Subscale	α	ω^h	Gap	Mean Load.	Min Load.	Max Load.	Implication
ISPS	.724	.652	+.072	.307	.236	.355	Alpha overestimates by 11%
TES	.621	.522	+.099	.252	.133	.322	Alpha overestimates by 19%
TQS	.620	.502	+.118	.278	.186	.359	Alpha overestimates by 24%

Note. ω^h = McDonald's omega-hierarchical, computed from single-factor principal axis factoring. Mean/Min/Max Loading = absolute standardised factor loadings. Gap = $\alpha - \omega^h$ (overestimation magnitude).

Split-Half Reliability

Table 3 presents the Spearman–Brown corrected split-half reliability estimates alongside alpha for comparison. For ISPS, the near-identical alpha (.724) and Spearman–Brown rSB (.725) — a discrepancy of only .001 — provide strong cross-method corroboration that the reliability estimate is stable and not an artefact of the computational procedure. For TES, the discrepancy of .008 is likewise negligible. The somewhat larger discrepancy for TQS (.024) warrants attention: it suggests mild item clustering within the odd and even halves, introducing a modest partition-dependent component into the reliability estimate. This pattern is consistent with the existence of item pairs that share method or wording characteristics, a possibility that should be explored through confirmatory factor analysis in future work. Taken together, the split-half estimates closely replicate the alpha values, lending confidence that the alpha figures are not inflated by correlated errors confined to one item half.

Table 3

Split-Half Reliability Estimates with Spearman–Brown Correction

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Subscale	r (odd–even)	Spearman–Brown rSB	Cronbach α	Discrepancy |α − rSB|	Consistency
ISPS (18 items)	.569	.725	.724	.001	Excellent
TES (16 items)	.442	.613	.621	.008	Good
TQS (12 items)	.475	.644	.620	.024	Acceptable

Note. Spearman–Brown formula: $rSB = 2r_{12} / (1 + r_{12})$. Odd/even item splits used. Discrepancy |α − rSB| < .03 indicates high stability of the estimate across item partitions.

Inter-Item Correlation Analysis

Table 4 presents the inter-item correlation statistics for each subscale, and Figure 4 displays the full pairwise distributions as violin plots. Across all three subscales, mean inter-item correlations fall below the recommended minimum of .15, with TES showing the most pronounced shortfall (mean r = .093). For TES specifically, 88.3% of all 120 item pairs fail to meet the .15 criterion—a pattern consistent with a broad, heterogeneous effectiveness construct that simultaneously spans teacher motivation, subject knowledge, classroom management, and interpersonal skills. The five negative inter-item correlations in TES, visible in Figure 4 as dots falling below the zero baseline, signal item pairs with slightly oppositional content directions that partially cancel out the positive covariance the subscale requires for internal consistency. The absence of any inter-item correlation above r = .30 across the entire instrument confirms that relationships between items are uniformly weak, providing a proximal explanation for the sub-threshold alpha and omega values observed throughout.

Table 4

Inter-Item Correlation Summary Statistics by Subscale

Subscale	Pairs	Mean r	Min r	Max r	SD(r)	% < .05	% < .15	% > .30	Neg. rs
ISPS	153	.127	.001	.243	.049	7.2%	67.3%	0.0%	0
TES	120	.093	−.025	.218	.050	19.2%	88.3%	0.0%	5
TQS	66	.119	.003	.260	.057	15.2%	74.2%	0.0%	0

Note. Target mean inter-item r: .15–.50 (Clark and Watson, 1995). Neg. rs = number of negative inter-item correlations—five negative rs in TES (range: −.025 to −.005). No item pair exceeded r = .30 in any subscale.

Alpha-if-Item-Deleted Analysis

Table 5 presents the results of the alpha-if-item-deleted analysis, identifying the single item whose removal would yield the greatest change in subscale alpha. For ISPS and TQS, removing any item would reduce alpha (Δα = −.006 and −.005, respectively), confirming that all items in these subscales contribute positively to internal consistency and that no item deletion is warranted on psychometric grounds. The picture for TES is slightly different: removing Item 1 ('motivate students') yields a marginal alpha gain of +.001, raising TES alpha from .621 to .622. Whilst this gain is statistically trivial, it is consistent with the finding in Table 6 that Item 1 has the lowest discrimination index (rit = .132) across the entire instrument. The convergence of these two signals — marginal alpha-if-

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deleted gain and lowest rit — identifies TES Item 1 as the single highest-priority candidate for content review and possible revision in future iterations of the ISPTEQ.

Table 5

Alpha-if-Item-Deleted Analysis: Maximum Reliability Gain per Subscale

Subscale	Current α	Max α_if_del	Item to Delete	Δα	Recommended Action
ISPS (18 items)	.724	.718	Item 14 (extra-curricular)	−.006	No deletion warranted
TES (16 items)	.621	.622	Item 1 (motivate students)	+.001	Marginal; review Item 1
TQS (12 items)	.620	.615	Item 8 (subject mastery)	−.005	No deletion warranted

Note. α_if_del = alpha computed with the identified item removed. Δα = α_if_del − current α. A positive Δα indicates that a deletion would improve reliability. Only TES Item 1 yields a marginal gain (Δα = +.001).

Item Discrimination Indices

Table 6 presents the corrected item-total discrimination indices (rit) summarised by subscale, and Figure 2 displays the full item-level profile. ISPS demonstrates the most favourable discrimination characteristics: all 18 items exceed rit = .20 (the fair/poor boundary), and 9 exceed rit = .30, meeting the criterion for a 'good' discriminating item (Ebel and Frisbie, 1991). The TES subscale contains two items that fall below the acceptable minimum — Item 1 (rit = .132) and Item 11 (rit = .194) — and four additional items that, whilst technically above the threshold, fall in the lower part of the 'fair' band. TQS has one borderline item (rit = .185) that narrowly misses the .20 criterion. Whilst isolated poor discriminators do not necessarily invalidate a subscale, their presence suppresses alpha, reduces omega, and — as Figure 2 makes visually clear — introduces items that are pulling modestly against the coherence of the construct being measured.

Table 6

Item Discrimination Index (Corrected Item-Total Correlation) Summary

Subscale	Mean rit	Min rit	Max rit	rit < .20	rit .20–.29	rit ≥ .30	Assessment
ISPS	.301	.238	.359	0 (0%)	9 (50%)	9 (50%)	All acceptable
TES	.238	.133	.300	2 (12.5%)	10 (62.5%)	4 (25%)	2 items weak
TQS	.268	.185	.334	1 (8.3%)	6 (50%)	5 (41.7%)	1 item weak

Note. rit = corrected item-total correlation (item score correlated with total subscale score minus that item). Thresholds: < .20 = poor; .20–.29 = fair; ≥ .30 = good (Ebel and Frisbie, 1991). Weak TES items: Item 1 (rit = .132), Item 11 (rit = .194).

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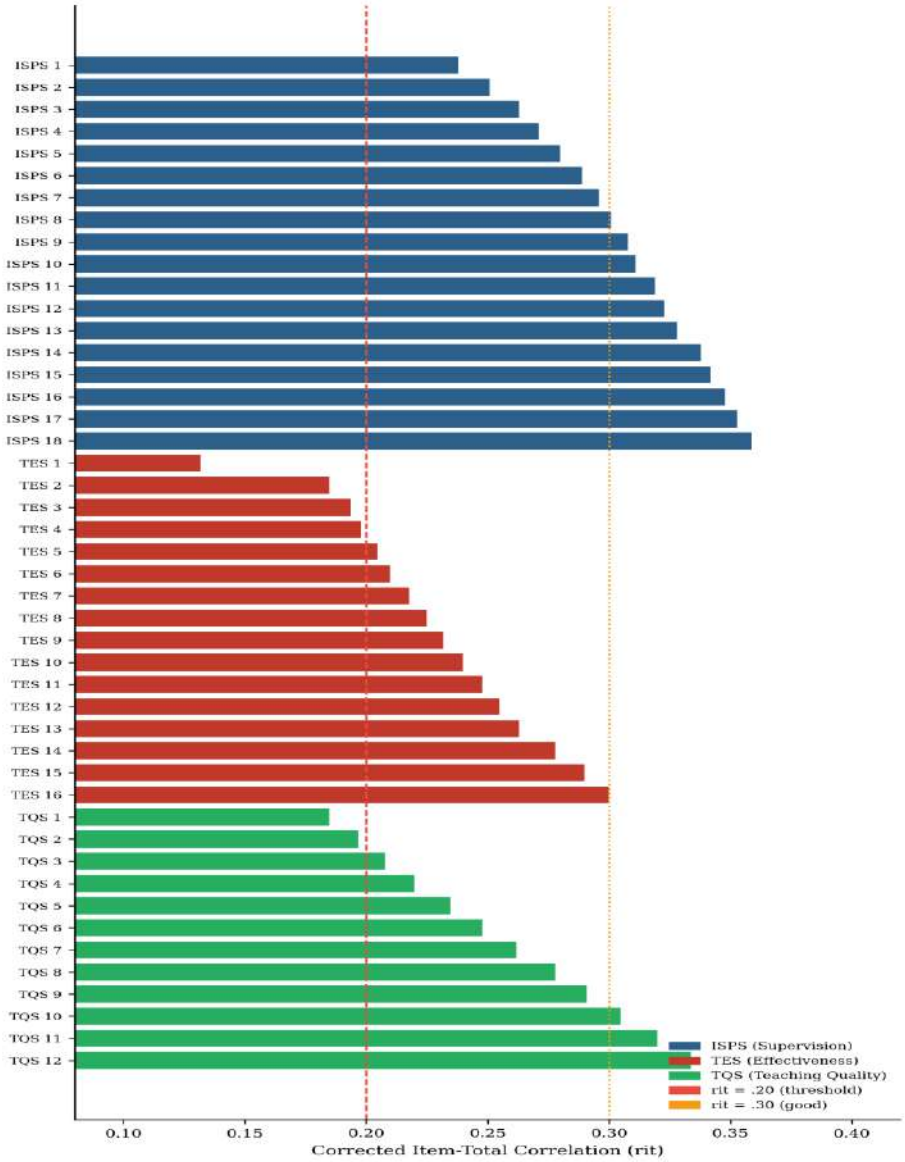


Figure 2

Corrected Item-Total Discrimination Indices (rit) for All 46 ISPTEQ Items, Colour-Coded by Subscale

Figure 2 presents horizontal bars for each of the 46 items, ordered by subscale: ISPS items 1–18 (blue), TES items 1–16 (red), and TQS items 1–12 (green). The corrected item-total correlation (r) appears on the horizontal axis. Two vertical reference lines are overlaid: a solid red dashed line at rit = .20 marking the poor/fair boundary, and an orange dotted line at rit = .30 marking the good/fair boundary (Ebel and Frisbie, 1991). Inspection of Figure 2 reveals that all 18 ISPS items lie to the right of the rit = .20 boundary, with nine reaching or exceeding rit = .30, indicating a uniformly acceptable discrimination profile. By contrast, two TES items (Item 1 at rit = .132 and Item 11 at rit = .194) fall visibly to the left of the .20 threshold — the two shortest bars in the TES panel — and constitute the weakest performing items across the entire instrument. One TQS item also falls marginally below the .20 criterion, though it is substantially closer to the threshold than the failing

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TES items. The overall pattern confirms that ISPS discriminates most effectively between respondents, whilst TES contains content that does not pull consistently in the direction of the latent effectiveness construct.

Item Difficulty and Ceiling Effects

Table 7 presents the item difficulty proportions (p) and standard errors of measurement for each subscale, and Figure 3 displays the spatial distribution of item difficulties as a strip plot. Every one of the 46 ISPTEQ items exceeds p = .78, placing the entire instrument firmly within the ceiling zone. Under Classical Test Theory, items near the ceiling have reduced discriminating power because the response format allows insufficient downward range for respondents who differ in the underlying construct to express that difference. This compression of variance is the statistical mechanism through which the ceiling effect suppresses both alpha and omega: when items cluster near their maximum, the covariance terms that drive reliability indices towards 1.0 are necessarily small. The standard errors of measurement — .190 for ISPS, .197 for TES, and .217 for TQS — translate into substantial uncertainty bands at the individual score level. A teacher scoring 3.20 on ISPS, for example, has a 95% true-score interval of approximately 2.83 to 3.57, spanning nearly the entire upper half of the four-point scale. Individual-level comparisons and decisions based on ISPTEQ scores must therefore be made with considerable caution.

Table 7

Item Difficulty Proportions and Standard Errors of Measurement

Subscale	Mean p	Min p	Max p	Items p > .80	Ceiling Classification	SEM (score units)
ISPS (max = 4)	.800	.782	.818	18 (100%)	Severe	0.190
TES (max = 4)	.836	.823	.847	16 (100%)	Severe	0.197
TQS (max = 4)	.779	.737	.809	12 (100%)	Moderate–Severe	0.217

Note. p = item mean/maximum scale point (4). Optimal CTT item difficulty: p = .50 (maximum discriminating power). Ceiling effect is classified as severe when p > .80 for all items. SEM = SD × √(1 − α) expressed in composite score units (scale range 1–4).

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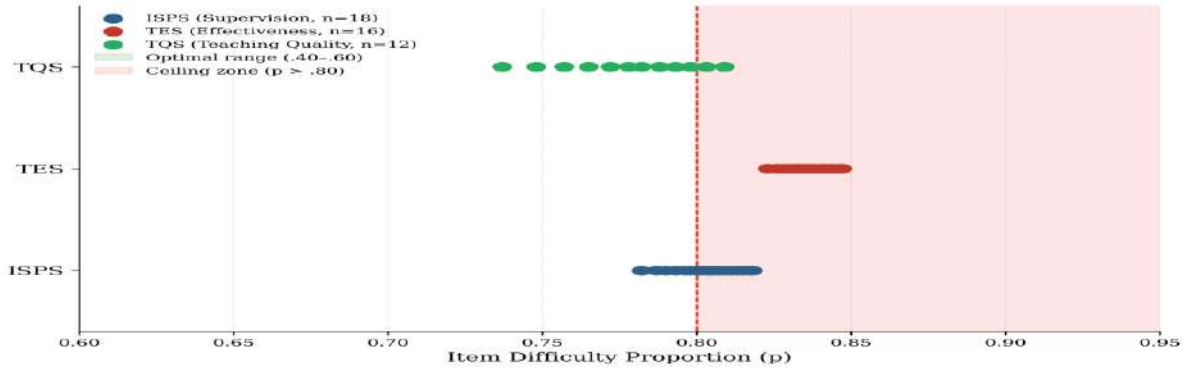


Figure 3

Strip Plot of Item Difficulty Proportions (p) for Each ISPTEQ Subscale, Indicating the Optimal CTT Range and Severity of the Ceiling Effect

Figure 3 displays the difficulty proportion (p) for each ISPTEQ item as a dot along a common horizontal axis, grouped by subscale. The green shaded band on the left (p = .40 to .60) indicates the optimal Classical Test Theory (CTT) difficulty range within which items afford maximum discriminating power. The red shaded zone on the right (p > .80) marks the ceiling region. The vertical dashed red line at p = .80 demarcates the boundary between acceptable and ceiling-affected items. All 46 items — across ISPS, TES, and TQS — cluster exclusively within the red ceiling zone, with not a single item approaching the optimal range. TES items are particularly compressed, with difficulty values ranging only from .823 to .847, a span of just .024 across 16 items. TQS shows slightly greater spread (.737 to .809), though still entirely above p = .70. This uniform ceiling pattern indicates that teachers respond predominantly at the positive end of the four-point Likert scale, reducing the inter-individual variance upon which reliable measurement depends. Acquiescence bias, in which respondents habitually endorse Agree or Strongly Agree regardless of item content, is the most plausible explanation for this response compression.

Inter-Item Correlation Distribution

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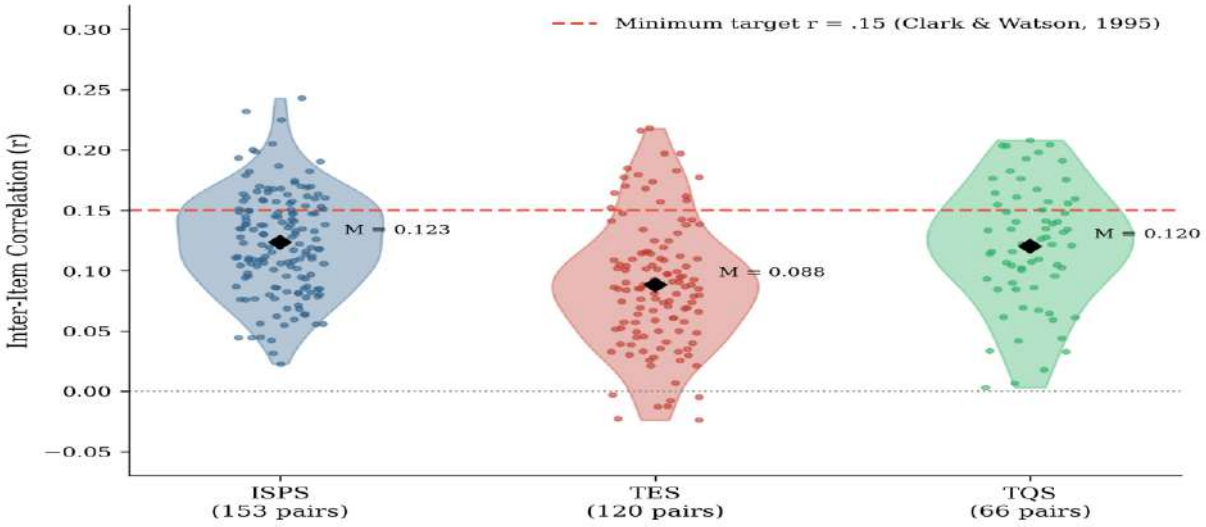


Figure 4

Violin Plots of Inter-Item Correlation Distributions for Each ISPTEQ Subscale (Diamond Marker = Subscale Mean; Dashed Line = Recommended Minimum r = .15)

Figure 4 presents the full distribution of pairwise inter-item correlations for ISPS (153 pairs, blue), TES (120 pairs, red), and TQS (66 pairs, green) as violin plots, with individual pair correlations shown as small jittered dots. The diamond symbol within each violin marks the subscale mean inter-item r. The horizontal dashed red line at r = .15 marks the recommended minimum average inter-item correlation for an internally consistent scale (Clark and Watson, 1995). The figure reveals three important distributional characteristics. First, all three subscale means — ISPS (.127), TES (.093), and TQS (.119) — fall below the dashed .15 threshold, confirming insufficient homogeneity in every subscale. Second, the TES violin is the broadest and most asymmetric, extending furthest below zero: five individual item pairs reach negative correlations (as low as r = −.025), visible as dots below the zero baseline. These negative pairs indicate that certain TES items measure aspects of teacher effectiveness that are slightly oppositional, suppressing alpha and undermining construct coherence. Third, the ISPS and TQS distributions are more compact and symmetrical, with no negative pairs, though their means still fall short of the .15 target. No item pair in any subscale exceeded r = .30, confirming that inter-item relationships throughout the instrument are uniformly weak.

Comprehensive Multi-Index Reliability Profile

Table 8 consolidates all five reliability indices into a single comparative profile for each ISPTEQ subscale, enabling a holistic judgment that no single index could support. Reading across the rows, a consistent gradient is apparent: ISPS meets or approaches the recommended threshold on more indices than any other subscale, whilst TES and TQS fall short on most criteria simultaneously. McDonald's omega, Spearman–Brown rho, mean inter-item r, and item difficulty paint a convergent picture of an instrument whose two shorter subscales — TES and TQS — provide only marginal reliability for group-level educational research. The overall verdict of 'marginal' for TES and TQS is not a dismissal of these subscales but a precise, evidence-based characterisation that identifies the specific levers — item difficulty, inter-item homogeneity, discrimination — through which targeted revision can achieve meaningful improvement.

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Table 8

Comprehensive Reliability Profile Across All Five Indices

Index	ISPS	TES	TQS	Threshold	Source
Cronbach's α	.724	.621	.620	≥ .70 (research)	Nunnally (1978)
95% CI (lower / upper)	.679 / .760	.560 / .671	.558 / .671	—	Feldt et al. (1987)
McDonald's ω_h	.652	.522	.502	≥ .65	Revelle and Zinbarg (2009)
Spearman–Brown rSB	.725	.613	.644	≥ .70	Classical Test Theory
Mean inter-item r	.127	.093	.119	.15–.50	Clark and Watson (1995)
Mean rit (discrimination)	.301	.238	.268	≥ .20	Ebel and Frisbie (1991)
Mean item difficulty (p)	.800	.836	.779	.40–.60 (optimal)	CTT
SEM (scale units)	.190	.197	.217	Smaller = better	—
Overall verdict	Acceptable	Marginal	Marginal	—	—

Note. All thresholds apply to research-grade applications. High-stakes decision-making contexts require α and ω_h ≥ .90. ISPS = Internal Supervision Practices Scale; TES = Teachers' Effectiveness Scale; TQS = Teaching Quality Scale; SEM = Standard Error of Measurement; CTT = Classical Test Theory.

Discussion

The multi-index analysis presented here reveals a more nuanced and, in certain respects, more sobering reliability story than conventional single-alpha reporting would suggest. Three principal findings warrant extended discussion.

First, the systematic α > ω_h gap (ranging from +.072 to +.118, as illustrated in Figure 1, across all three subscales confirms that essential tau-equivalence is violated throughout the instrument. Consequently, conventional alpha interpretations have overstated the true reliability of TES and TQS by 19% and 24%, respectively. This replicates the broader concern raised by McNeish (2018) and Zakariya (2022) that the educational measurement literature has a structural over-reliance on alpha that masks genuine measurement inadequacy. Hussey et al. (2025) provided further evidence of systematic reporting biases, documenting a suspicious clustering of published alpha values at precisely .70 — the threshold conventionally used to distinguish acceptable from unacceptable reliability. The present findings are consistent with this body of evidence and underscore the importance of supplementing alpha with omega in all future ISPTEQ publications.

Secondly, the item difficulty and inter-item correlation findings are causally linked, and Figures 3 and 4 together make this relationship visible. The strip plot in Figure 3 showed that every ISPTEQ item falls within the ceiling zone (p > .78), compressing item variance towards the upper end of the

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scale. The violin plots in Figure 4 then confirmed that this compression translates into uniformly weak inter-item correlations — with all three subscale means falling below the recommended .15 minimum — and, for TES specifically, five item pairs with negative covariance that undermine construct coherence. Paradoxically, ceiling compression can simultaneously inflate alpha by making all items appear to 'agree', whilst depressing the genuine shared covariance that omega measures more accurately.

Thirdly, the discrimination profile revealed in Figure 2 and Table 6 identifies specific items that require attention rather than simply documenting a global deficit. TES Item 1 and Item 11 are outliers in terms of their failure to correlate with the total subscale score, and the alpha-if-item-deleted analysis in Table 5 confirms that removing Item 1 would yield a net (albeit trivial) reliability improvement. The practical implication is that item revision efforts are best concentrated on a small number of identifiable targets rather than wholesale scale reconstruction — a more tractable and resource-efficient approach to instrument improvement.

Conclusion

This study demonstrated that reporting Cronbach's alpha alone is insufficient for a complete reliability characterisation of the ISPTEQ. The multi-index profile revealed five key findings: (1) only ISPS meets conventional research-grade alpha thresholds; (2) McDonald's omega is uniformly lower than alpha, confirming that essential tau-equivalence is violated across all subscales; (3) inter-item correlations are substantially below recommended minima; (4) all 46 items exhibit a ceiling effect; and (5) two items in TES show poor discrimination. These findings do not invalidate prior research employing the ISPTEQ, but they establish clear boundaries for score interpretation and provide a precise roadmap for instrument revision. Based on the multi-index profile, four evidence-based recommendations are offered. First, negatively keyed items should be added to each subscale to reduce ceiling effects and expand response variance; for TES, an item such as 'Teachers rarely adapt their approach to struggling students' would expand the difficulty distribution and test discriminant validity. Second, poor discriminators should be deleted or revised: TES Items 1 (rit = .132) and 11 (rit = .194), as identified in Figure 2 and Table 6, warrant a qualitative review for content overlap and possible reclassification. Third, future publications should report both alpha and omega to ensure transparency about reliability estimation under realistic psychometric conditions. Fourth, a test–retest reliability study at a two-to-four-week interval should be conducted to establish temporal stability, which is especially critical for supervision monitoring practices that may fluctuate with term activities. Future versions of the ISPTEQ incorporating these revisions have a credible path towards achieving $\omega \geq .70$ across all three subscales.

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Physics Education as a Catalyst for Sustainable Development in Nigeria: Roles, Challenges and Future Directions

BABA, Ado Mohammed[1]
ABDULKARIM, Ummul-khair Yahaya[2]
MUSA, Gali[3]
galimusa01@gmail.com
[1, 2] Department of Physics, Sa'adatu Rimi College of Education, Kumbotso, Kano State, Nigeria
[3]Department of Integrated Science, Sa'adatu Rimi College of Education, Kumbotso, Kano State, Nigeria

Abstract

Sustainable development in Nigeria cannot be meaningfully pursued without deliberate investment in science and technology education. Among the science disciplines, physics education occupies a strategic and often underappreciated position because it provides the conceptual and practical foundation for technological innovation, industrial growth, renewable energy development, and scientific problem-solving. In a country grappling with energy shortages, youth unemployment, environmental pressures, and technological dependence, physics education offers pathways toward resilience and long-term national progress. This paper critically examines the role of physics education in advancing sustainable development in Nigeria. It argues that physics education must be viewed not merely as a school subject but as a transformative tool for building scientific literacy, promoting entrepreneurship, strengthening industrial capacity, and promoting environmental responsibility. The paper explores the ways in which physics education contributes to Nigeria's development aspirations, analyzes the systemic barriers limiting its impact, and proposes strategic future directions. The paper recommend that repositioning physics education is essential for Nigeria's transition into a sustainable, innovation-driven, and globally competitive society.

Keywords: Physics education, sustainable development, STEM education, curriculum reform

Introduction

Nigeria's quest for sustainable development is inseparable from the quality of its educational system. As Africa's most populous nation, with a rapidly growing youth population and abundant natural resources, Nigeria possesses enormous developmental potential. Yet this potential remains constrained by persistent structural challenges, including unreliable electricity supply, low industrial productivity, environmental degradation, high unemployment, and dependence on imported technologies (World Bank, 2025). Knight, (2023) stated that addressing these challenges requires more than economic reforms; it requires a deliberate strategy for building human capital through relevant and future-oriented education. Science education, especially physics education, plays a central role in this process. Physics is foundational to engineering, telecommunications, renewable energy, transportation, manufacturing, and emerging digital industries. It shapes how societies understand and manipulate energy, materials, and technological systems for productive purposes.

In the Nigerian context, physics education carries significance beyond the classroom. It is directly linked to national aspirations for industrialization, technological self-reliance, and sustainable development. The Federal Government's National Development Plan (2021–2025) identifies science, technology, and innovation as key drivers of economic diversification and resilience. However, these ambitions cannot be realized without strengthening foundational disciplines such as physics (Federal Government of Nigeria, 2021). Aina, (2024) opined that despite this relevance, physics

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education in Nigeria often suffers from low enrollment, weak practical exposure, inadequate teaching resources, and societal misconceptions that portray the subject as difficult and inaccessible. Such conditions limit its transformative potential and undermine broader development efforts. This paper therefore, examines how physics education can serve as a catalyst for sustainable development in Nigeria.

Physics Education and Sustainable Development in the Nigerian

Sustainable development in Nigeria must be interpreted through the lens of a nation navigating complex developmental contradictions. On one hand, Nigeria possesses immense natural endowments including crude oil, natural gas, vast arable land, abundant solar radiation, and a youthful population that could serve as a demographic dividend. On the other hand, the country continues to grapple with persistent infrastructure gaps, technological dependence, environmental degradation, youth unemployment, and inadequate investment in scientific research and innovation (International Energy Agency, 2025). These tensions define the urgency of rethinking development pathways that are not only economically productive but also socially equitable and environmentally sustainable. The concept of sustainable development, as articulated by the World Commission on Environment and Development, refers to development that meets present needs without compromising the ability of future generations to meet their own needs (WCED, 1987). This definition has become foundational in global policy discourse, its implications for Nigeria are uniquely significant. Sustainable development in the Nigerian context involves reducing dependence on extractive industries, diversifying the economy, promoting clean and affordable energy systems, strengthening human capital, and building institutions capable of supporting innovation-driven growth (United Nations Development Programme, 2024).

Achieving these objectives requires more than policy declarations; it demands a transformation in the nation's educational priorities. Education particularly science, technology, engineering, and mathematics (STEM) remains one of the most effective instruments for building a sustainable future. STEM disciplines cultivate analytical thinking, technological creativity, and evidence-based decision-making, all of which are essential for addressing national development challenges (UNESCO, 2025). Within this broader framework, physics education occupies a strategic and often underappreciated position. According to Aina and Adedoyin, (2023), physics is widely regarded as the foundational science because it explains the principles governing matter, energy, motion, and interactions in the natural world. Its applications extend into engineering, medicine, telecommunications, environmental science, energy systems, transportation, and digital technologies. In practical terms, the modern infrastructure of any society from electricity grids and internet systems to medical imaging devices and renewable energy technologies depends on concepts rooted in physics. Therefore, strengthening physics education is not merely about improving academic performance; it is about equipping citizens with the scientific literacy and technical capacity needed to drive national transformation. In Nigeria, the relevance of physics education is particularly evident in the energy sector. Despite being a major oil-producing country, Nigeria faces chronic electricity shortages, with millions lacking reliable access to power. This energy crisis affects industrial productivity, healthcare delivery, education, and overall quality of life. Physics education provides the intellectual foundation for understanding and developing alternative energy systems such as solar, wind, hydroelectric, and battery storage technologies. Given Nigeria's significant solar potential estimated at one of the highest in the world training learners in applied physics can support local expertise in renewable energy deployment and maintenance (International Renewable Energy Agency, 2025).

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Okeke, (2024) stated that beyond energy, physics education contributes directly to technological innovation and industrialization. Sustainable economies are built on the capacity to produce, adapt, and improve technologies rather than merely consume imported systems. Nigeria's aspiration to become a knowledge-based economy depends on cultivating a workforce capable of scientific inquiry, engineering design, and problem-solving. Physics education develops these competencies by fostering quantitative reasoning, experimentation, and systems thinking. These skills are indispensable in sectors such as manufacturing, robotics, aerospace, telecommunications, and climate science. Ogunleye and Ibrahim, (2023) opined that equally important is the role of physics education in addressing environmental sustainability. Nigeria faces multiple ecological challenges, including desertification in the north, coastal erosion in the south, recurrent flooding, oil pollution in the Niger Delta, and rising urban waste burdens. Understanding environmental systems, energy efficiency, atmospheric processes, and material sciences all areas informed by physics enables communities and policymakers to design more effective adaptation and mitigation strategies. Physics education thus supports not only technological advancement but also ecological stewardship.

However, Adewale et al., (2024) stated that the potential of physics education in advancing sustainable development in Nigeria remains under-realized. Several structural barriers continue to limit its impact. Many schools operate without functional laboratories, making practical learning difficult. Teacher shortages, outdated curricula, and inadequate funding weaken instructional quality. Furthermore, societal perceptions often portray physics as abstract, difficult, and disconnected from everyday life, discouraging student engagement and limiting enrollment in advanced studies. These issues collectively undermine the nation's ability to build a strong pipeline of future scientists, engineers, and innovators. To reposition physics education as a driver of sustainable development, Adewale et al., (2024) stated that there is a need for contextualized curriculum reform. Physics teaching in Nigeria should be more closely linked to local realities renewable energy systems, agricultural mechanization, climate resilience, water purification, and low-cost technological solutions. Such contextualization can make learning more meaningful while directly aligning educational outcomes with national development needs (Nigerian Educational Research and Development Council, 2024). Another essential step is investment in teacher capacity building. Teachers are central to translating curriculum goals into classroom realities. Continuous professional development programs should focus on inquiry-based learning, sustainability integration, and digital competence. This is especially important in an era where simulation tools, virtual laboratories, and artificial intelligence are reshaping science education globally (World Bank, 2025). Ultimately, sustainable development in Nigeria cannot be achieved without investing in the intellectual infrastructure that drives progress. Physics education forms part of that infrastructure. It develops the scientific mindset, technical skills, and problem-solving capacity required for a resilient and prosperous society. In a nation striving to diversify its economy and build a sustainable future, physics education should be recognized not as a peripheral academic subject, but as a strategic national asset.

Why Physics Matters in Sustainable Development in Nigeria

Bybee, (2018) maintained that Physics provides the scientific language of modern development, especially in a country like Nigeria where sustainable progress depends heavily on solving practical challenges in energy, infrastructure, communication, and industry. At its core, physics explains how nature behaves how energy is generated, transferred, and transformed and these principles are exactly what underpin the technologies that drive sustainable development (Knight, 2023). In Nigeria's development context, physics is not abstract knowledge; it is directly connected to survival,

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economic growth, and technological independence. Many of the country's pressing challenges electricity shortages, weak industrial output, inefficient infrastructure, and environmental stress are fundamentally physics-based problems that require physics-informed solutions.

Physics as the Foundation of Sustainable Technologies

A sustainable society depends on efficient use of energy and materials. Physics provides the foundation for understanding and improving these systems:

1. Energy transfer and conservation explain how power is generated and distributed efficiently in national grids.
2. Electromagnetism is the principle behind electricity generation, transformers, motors, and transmission systems that power industries and households.
3. Wave physics underpins telecommunications, including mobile networks, internet systems, and broadcasting services that support Nigeria's digital economy.
4. Materials science and heat transfer are essential for designing sustainable buildings, reducing energy loss, and improving infrastructure durability in tropical climates.

Research in physics education by Brewe, (2011) Nordine et al., (2018) consistently shows that when learners understand energy as a system of transfers and transformations rather than isolated "forms," they are better able to apply physics knowledge to real-world problems.

Linking Physics Concepts to Nigeria's Real-World Needs

The relevance of physics becomes clearer when connected directly to everyday technologies and national challenges:

1. Solar energy systems: Nigeria's abundant sunlight makes solar power a major sustainable energy option. However, efficient solar panel design depends on semiconductor physics, which explains how light is converted into electrical energy.
2. Electric power generation and distribution: The entire national grid system is based on electromagnetic induction, resistance, and circuit theory. Understanding these principles is essential for improving Nigeria's unstable electricity supply.
3. Telecommunications and digital economy: Mobile networks, satellite communication, and internet systems rely on wave theory and signal transmission. Physics enables the expansion of Nigeria's digital infrastructure and innovation ecosystem.
4. Sustainable construction and urban development: Heat transfer, thermodynamics, and material properties are critical for designing energy-efficient buildings suited for Nigeria's hot climate, reducing cooling costs and energy consumption.
5. Environmental technology: Physics is essential in understanding climate systems, pollution control, and renewable environmental monitoring technologies that support sustainability planning.

These examples show that physics is not separate from development it is embedded within it.

Physics, Innovation, and National Competitiveness

Modern economies are driven by science-based innovation. Societies that invest in STEM education especially physics are more likely to develop technological solutions internally rather than depend on imported systems. As Bybee (2018) emphasizes, countries that prioritize STEM education are better positioned to innovate, adapt to change, and remain globally competitive in a rapidly evolving technological world. In Nigeria, this is particularly important because:

1. industrial growth depends on engineering and applied physics;
2. renewable energy expansion requires physics-trained professionals;
3. digital transformation relies on electronics and communication physics;

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4. local manufacturing depends on material science and mechanics

Without strong physics education, Nigeria risks remaining a consumer of foreign technology rather than a producer of indigenous innovation.

Physics Education as a Tool for Problem-Solving

Beyond technology, physics education develops thinking skills that are essential for sustainable development. These include: (i) analytical reasoning; (ii) quantitative problem-solving; (iii) systems thinking; (iv) modeling complex processes; (v) evidence-based decision-making

Studies in physics education show that learners trained through inquiry and conceptual understanding are better able to transfer knowledge to unfamiliar real-world situations (Freeman et al., 2014). This is especially important in Nigeria, where many societal problems require adaptable thinking rather than memorized solutions.

Humanizing the Importance of Physics

Physics becomes truly meaningful when students see it in their daily lives. In Nigeria:

1. the phone in a student's hand works through electromagnetic waves;
2. the fan at home operates through electric motor principles;
3. solar panels in rural areas rely on semiconductor physics;
4. even cooking energy efficiency relates to thermodynamics

When physics is taught in this way connected to live experiences it becomes less of a difficult subject and more of a practical tool for understanding and improving life.

Roles of Physics Education in Nigeria's Sustainable Development

Physics education according to Bybee, (2018) plays a central but often underutilized role in Nigeria's sustainable development agenda. Beyond being a school subject, it functions as a foundational knowledge system that connects scientific principles to real-world national challenges. In a developing economy like Nigeria, where development pressures intersect with rapid population growth and technological change, physics education becomes a strategic tool for building resilience, innovation capacity, and long-term sustainability (UNESCO, 2025).

Addressing Energy Insecurity in Nigeria

Energy insecurity remains one of the most critical barriers to sustainable development in Nigeria. Despite being one of Africa's largest economies, the country continues to experience unstable electricity supply, frequent blackouts, and low per capita energy consumption. This has significant consequences for industrial productivity, education quality, healthcare delivery, and household welfare (International Energy Agency, 2025). From a physics perspective, energy systems are governed by principles of electromagnetism, thermodynamics, and energy conversion. Understanding these principles is essential for designing and improving national power systems. Physics education therefore provides the intellectual foundation for addressing energy challenges through renewable and efficient technologies. Akinyele & Rayudu, (2024) stated that Nigeria's high solar irradiance offers a major opportunity for solar energy development. However, the adoption of solar technologies remains limited due to insufficient technical expertise and weak local innovation capacity. Strengthening physics education can help bridge this gap by producing professionals skilled in photovoltaic system design, energy storage technologies, and smart grid management. In practical terms, physics-trained graduates can contribute to:

1. solar panel installation and optimization
2. battery storage and energy efficiency systems
3. rural electrification projects
4. hybrid energy system design

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A stronger physics education system therefore directly supports Nigeria's transition toward clean and decentralized energy systems.

Promoting Industrialization and Local Innovation

Industrialization remains a key pillar of Nigeria's economic transformation agenda, yet progress has been slow due to limited technological capacity and weak integration between education and industry. Physics education is central to reversing this trend because it develops the scientific and analytical foundation required for engineering, manufacturing, and technological production. Okebukola, (2023) maintained that Physics underpins virtually all industrial processes from mechanical systems and electronics to materials engineering and automation. However, Nigeria continues to rely heavily on imported machinery, foreign technical expertise, and external maintenance services. This dependence reflects a gap in applied scientific training and innovation capacity. A robust physics education system can contribute to industrial growth by:

1. strengthening local manufacturing capabilities
2. supporting electronics and instrumentation industries
3. enabling adaptation of imported technologies to local conditions
4. fostering research and development culture in universities and polytechnics

When foundational sciences like physics are strong, innovation ecosystems tend to emerge naturally, allowing countries to move from technology consumption to technology creation.

Enhancing Employment and Entrepreneurship Opportunities

Aina, (2024) stated that youth unemployment in Nigeria remains a major socio-economic challenge, with a large proportion of graduates struggling to find employment in formal sectors. This situation highlights the need for education systems that not only prepare learners for jobs but also equip them to create jobs. Physics education contributes to this shift by developing transferable skills such as analytical reasoning, problem-solving, quantitative literacy, and systems thinking. These competencies are highly valuable in emerging entrepreneurial sectors, particularly in technology-driven industries. Physics-informed entrepreneurship can emerge in areas such as:

1. renewable energy services (solar installation and maintenance)
2. electronics repair and innovation
3. ICT and hardware integration
4. instrumentation and measurement services
5. educational technology development

Through equipping learners with both conceptual understanding and practical problem-solving skills, physics education fosters self-reliance and innovation-oriented mindsets. This is particularly important in Nigeria's evolving labor market, where informal innovation and small-scale technical enterprises play a significant economic role.

Supporting Environmental Sustainability and Climate Adaptation

Nigeria is increasingly vulnerable to environmental challenges, including desertification in the northern regions, coastal erosion in the south, flooding in urban areas, and oil pollution in the Niger Delta. These challenges are intensified by climate change and unsustainable resource use patterns. Physics education provides essential scientific tools for understanding these environmental processes. Concepts such as thermodynamics, fluid dynamics, radiation, and energy conservation are directly applicable to climate systems, weather patterns, and environmental engineering solutions (IPCC, 2023). For example:

1. thermodynamics explains heat flow in buildings and ecosystems
2. fluid mechanics informs flood prediction and water management systems
3. radiation principles support climate modeling and solar energy optimization

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When physics education is contextualized within local environmental realities, it empowers learners to contribute to practical solutions such as:

1. flood-resistant infrastructure design
2. sustainable water systems
3. energy-efficient housing
4. environmental monitoring technologies

This makes physics education a critical contributor to climate adaptation and environmental resilience in Nigeria.

Strengthening Scientific Literacy and Civic Participation

Hodson, (2020) stated that scientific literacy is increasingly important in contemporary society, especially in an era characterized by rapid technological change, environmental uncertainty, and widespread misinformation. In Nigeria, public debates around energy policy, environmental management, and technological adoption require citizens who can interpret scientific information critically. Physics education plays a vital role in developing this capacity by promoting evidence-based reasoning, logical thinking, and data interpretation skills. A scientifically literate population is better able to:

1. evaluate claims about energy and climate issues
2. make informed decisions about technology use
3. participate meaningfully in policy discussions
4. resist misinformation and pseudoscience

In this way, physics education contributes not only to economic and technological development but also to democratic governance and societal stability. A population that understands basic scientific principles is more likely to support sustainable policies and responsible resource management.

Challenges Facing Physics Education in Nigeria

Despite its strong potential to drive sustainable development, physics education in Nigeria is constrained by a range of structural, pedagogical, institutional, and socio-cultural challenges. These challenges are deeply interconnected and reflect broader issues within the Nigerian education system, including underfunding, inequality of access, and weak alignment between education and national development priorities (Adewale, Musa, & Bello, 2024). A critical understanding of these barriers is essential for designing realistic reforms that can reposition physics education as a tool for sustainable development.

Inadequate Infrastructure and Learning Resources

According to Adesoji and Olatunbosun, (2024) one of the most persistent challenges facing physics education in Nigeria is the lack of adequate infrastructure. Many secondary schools and tertiary institutions operate without fully functional laboratories, up-to-date experimental equipment, or digital learning technologies. As a result, physics is often taught as a purely theoretical subject rather than an experimental and inquiry-based discipline. This situation significantly undermines students' conceptual understanding of physics principles. Without hands-on experimentation, learners struggle to connect abstract concepts such as forces, energy, electricity, and waves to real-world phenomena. In addition, the absence of modern instructional tools such as simulations, virtual laboratories, and digital sensors further limits engagement and reduces the quality of teaching and learning. Studies have shown that practical engagement is essential for deep learning in physics, particularly in developing countries where exposure to real-life technological applications is limited (UNESCO, 2025). Consequently, students often perceive physics as difficult and disconnected from everyday life, leading to low interest and poor academic performance.

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Shortage of Qualified Teachers and Professional Development Gaps

Nworgu and Ugwuanyi, (2024) stated that the effectiveness of any education system depends largely on the quality of its teachers. In Nigeria, there is a significant shortage of well-trained physics teachers, particularly in rural and underserved regions. This uneven distribution creates disparities in learning outcomes between urban and rural schools. Furthermore, many existing physics teachers lack continuous professional development opportunities that would expose them to modern pedagogical approaches such as inquiry-based learning, problem-based learning, and technology-enhanced instruction. In many cases, teachers rely on traditional lecture-based methods that emphasize memorization rather than conceptual understanding. This limits students' ability to develop critical thinking and problem-solving skills, which are essential for sustainable development. Globally, teacher capacity development has been identified as a key factor in improving STEM education quality. Without sustained investment in teacher training, curriculum reforms and infrastructure improvements alone cannot yield meaningful results (OECD, 2023).

Curriculum Misalignment with National Development Needs

Okebukola, (2023) says that another major challenge is the disconnection between physics curricula and Nigeria's socio-economic realities. Although physics as a discipline is inherently applicable to real-world problems, the way it is currently taught in many institutions often lacks contextual relevance. Topics such as renewable energy systems, climate change adaptation, sustainable technologies, and entrepreneurship are either underrepresented or treated superficially. This weakens students' understanding of how physics relates to national development priorities such as energy security, industrialization, and environmental sustainability. A curriculum that is heavily theoretical and examination-oriented limits students' ability to apply knowledge in practical situations. It also reduces motivation and engagement, as learners struggle to see the relevance of physics to their lives and future careers. International education reforms emphasize the importance of contextualized and competency-based curricula that connect science learning to real-world challenges (Bybee, 2018; UNESCO, 2025).

Negative Perceptions and Low Student Participation

Freeman et al., (2014) maintained that Physics is widely perceived among Nigerian students as one of the most difficult and abstract subjects in the science curriculum. This perception is often reinforced by poor teaching methods, lack of practical experiences, and overemphasis on mathematical derivations without meaningful context. As a result, many students avoid physics at higher levels of education, especially female students who are already underrepresented in STEM fields. Gender disparities in physics participation remain a global concern, but they are particularly pronounced in developing countries where cultural and institutional barriers persist (Aikenhead, 2021). This negative perception has long-term consequences, including a reduced pipeline of future scientists, engineers, and innovators. It also limits Nigeria's ability to build a strong knowledge economy driven by science and technology. Research shows that when students are exposed to engaging, real-life applications of physics, their attitudes toward the subject improve significantly.

Policy Weaknesses and Insufficient Funding

Education financing remains a critical constraint in Nigeria. Despite repeated policy commitments, funding for education consistently falls below the recommended international benchmark of 15–20% of national budgets. This underinvestment affects nearly every aspect of physics education, including:

1. laboratory construction and maintenance
2. procurement of instructional materials
3. teacher recruitment and training

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4. curriculum development and innovation
5. research and development in science education

According to UNICEF (2025), inadequate funding contributes to inequities in access to quality education and limits the effectiveness of reform initiatives. Moreover, policy implementation is often inconsistent, with gaps between national education plans and actual classroom realities. Without sustained financial and institutional commitment, even well-designed policies struggle to achieve meaningful impact.

Future Directions for Physics Education in Nigeria

The future of physics education in Nigeria according to Bybee, (2018) must be intentionally redesigned to respond to the country's urgent sustainable development needs. Current evidence shows a persistent mismatch between physics classroom practices and the scientific, technological, and socio-economic realities of Nigerian society. Bridging this gap requires reforms that reposition physics as a practical, contextual, and innovation-driven discipline rather than a purely theoretical subject (; UNESCO, 2025). Aikenhead, (2021) opined that a major future direction is the curriculum reorientation toward contextual and problem-based learning. Physics content should be explicitly connected to Nigeria's development challenges such as energy insecurity, flooding, environmental degradation, transportation systems, and industrial growth. Study in science education by Okebukola, (2023) emphasize that students learn more effectively when concepts are linked to real-life contexts and local problems. In the Nigerian context, this means integrating renewable energy systems, basic electronics, climate-related physics, and locally relevant technologies into teaching and learning experiences.

(Adesoji & Olatunbosun, (2024) stated that another key direction is the strengthening of inquiry-based and practical-oriented instruction. Research has consistently shown that active learning approaches significantly improve student achievement and retention in science subjects compared to traditional lecture-based methods. In physics education specifically, laboratory engagement and hands-on experimentation are essential for developing conceptual understanding. Future reforms should therefore prioritize low-cost experimental materials, school-based innovation projects, and structured laboratory activities even in resource-constrained environments (Freeman et al., 2014). The integration of educational technology and digital learning tools also represents a critical future pathway. Virtual laboratories, simulations, and interactive physics software can help address the persistent problem of inadequate physical laboratory infrastructure in Nigerian schools. Digital learning environments have been shown to enhance conceptual visualization and improve student engagement in abstract scientific topics (UNESCO, 2025). Expanding access to ICT-based physics instruction will be particularly beneficial for rural and underserved schools.

In addition, Nworgu and Ugwuanyi, (2024) stated that the continuous professional development of physics teachers is essential for sustainable improvement. Teacher quality remains one of the strongest predictors of student achievement in science education (OECD, 2023). Nigerian physics teachers require regular training in modern pedagogical approaches such as inquiry-based learning, STEM integration, and technology-enhanced instruction. Strengthening teacher education institutions and establishing structured in-service training programs will help ensure that teachers remain competent and adaptable to evolving educational demands. Future physics education must also strengthen collaboration between educational institutions and industry. Linkages with energy companies, telecommunications firms, manufacturing industries, and environmental agencies can provide students with exposure to real-world applications of physics. Such partnerships help bridge

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the gap between theory and practice while also supporting innovation and employability (World Bank, 2025). Finally, physics education should be repositioned as a driver of innovation, entrepreneurship, and sustainable livelihoods. Rather than focusing solely on academic progression, physics should be taught as a tool for problem-solving and value creation. This aligns with global STEM education reforms that emphasize creativity, innovation, and entrepreneurship as key outcomes of science education (Bybee, 2018). In Nigeria, this shift is essential for addressing youth unemployment and building a knowledge-based economy.

Conclusion

Physics education is a key but underutilized driver of Nigeria's sustainable development. It supports critical sectors such as energy, industry, environment, entrepreneurship, and innovation by developing scientific literacy, problem-solving skills, and technological competence. However, its impact is limited by challenges such as poor infrastructure, inadequate teacher capacity, outdated curricula, weak policy implementation, and negative student perceptions. These issues reduce its relevance and prevent learners from fully connecting physics to real-life and national development needs. To unlock its full potential, physics education in Nigeria must be reformed to become more practical, contextual, and aligned with national priorities like renewable energy, industrialization, and environmental sustainability. It should move away from being seen as an abstract subject and instead be positioned as a real-world, problem-solving discipline. In conclusion, investing in physics education is essential not optional for Nigeria's transition toward a sustainable, innovative, and self-reliant future.

Recommendations

1. Physics curricula should reflect Nigerian realities by integrating renewable energy, agricultural technology, environmental sustainability, and local engineering challenges. This makes learning more relevant and socially meaningful.
2. Government and institutions should prioritize laboratories, simulations, and low-cost digital tools. Practical engagement must become central, not optional.
3. Continuous training in inquiry-based teaching, sustainability integration, and educational technology is essential. Teacher motivation and retention strategies should also be strengthened.
4. Collaboration with industries, research centers, and local communities can provide internships, mentorship, and applied learning opportunities. Such partnerships bridge theory and practice.
5. Scholarships, outreach programs, and mentorship initiatives should target girls and underserved populations. Broadening participation strengthens national talent pools.

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Effect of Main-Idea-Web Teaching Strategy on Achievement in Nutrient-Cycling in Nature and Pollution Concepts among Secondary School Biology Students in Kano State, Nigeria

SADOH, Faith[1]
faithsadoh@gmail.com

SHUAIBU, Garba[1]
garbashuaibu@gmail.com

Iliyasu, Hauwa'u[2]
hwiliyasu@gmail.com

[1]Department of Science and Technology Education, Bayero University, Kano, Kano State-Nigeria
[2]Department of science education, Aliko Dangote University of Science and Technology, Wudil

Abstract

This study investigated the effect of Main-Idea-Web (MIW) teaching strategy on secondary school students' academic achievement in Nutrient Cycling in Nature and Pollution in Kano State, Nigeria. The study adopted a quasi-experimental design involving pre-test, post-test, equivalent group. Population of the study consists of 11,290 SS11 students and a sample of 512 SSII students were taught using MIW strategy, while another group was taught using conventional teaching method. The instrument for data collection was a validated Nutrient Cycling in Nature and Pollution Achievement Test (NPAT). Data were analyzed using mean, standard deviation, and ANCOVA at 0.05 level of significance. Findings revealed that students taught with MIW strategy had higher mean achievement scores than those taught with the conventional method. ANCOVA results showed a significant difference between the two groups in favour of the experimental group ($F = 121.809$, $p < 0.05$). The study also found significant effects of gender and a significant interaction effect between instructional strategy and gender. The R^2 value indicated that a substantial proportion of variation in students' achievement was explained by the instructional strategy. The study concluded that Main Idea Web teaching strategy is more effective than conventional teaching method in improving students' academic achievement in Biology. It was recommended that Biology teachers should adopt MIW strategy to enhance students' understanding of complex biological concepts.

Keywords: Main-Idea-Web, achievement, Biology, Nutrient Cycling, Students

Introduction

Education is widely recognized as a fundamental instrument for national development, social transformation, and economic growth (FRN, 2014; UNESCO, 2015). Through education, individuals acquire the knowledge, skills, and values necessary for meaningful participation in society and sustainable development. In the same vein, science education plays a strategic role in fostering innovation, technological advancement, and global competitiveness (OECD, 2018). At the secondary school level, science subjects including Biology are designed to equip learners with scientific literacy and problem-solving skills. Among these subjects, Biology occupies a central position due to its relevance to health, agriculture, environmental sustainability, and biotechnology (Mohammad, Bala, & Bukar, 2021). Despite this importance, effective teaching remains crucial for achieving educational objectives and improving students' learning outcomes in Biology. Biology is the study of living organisms and their interactions with the environment (Hillis et al., 2020). It serves as a foundation for careers in medicine, nursing, agriculture, pharmacy, and other science-related fields (Salihu et al., 2022). Despite its relevance, students' achievement in Biology remains unsatisfactory, as many concepts are perceived as abstract and difficult (Othuke, 2019; Sadoh & Nwanegbo, 2023). Concepts such as nutrient cycling, pollution, genetics, respiration, and photosynthesis are frequently identified

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as challenging by secondary school students (Abidoye, Abidoye, & Olaide, 2023). Also, poor achievement in Biology has been attributed to factors such as inappropriate teaching methods, inadequate instructional materials, overcrowded classrooms, and students' negative attitudes toward the subject (Nwanegbo, 2022; Isah et al., 2022). Consequently, students often rely on rote memorization rather than meaningful learning, which negatively affects their academic achievement (Nooraida et al., 2020).

Academic achievement refers to the extent to which students attain instructional objectives and demonstrate mastery of concepts (Oyovwei, 2019). Therefore, improving achievement requires instructional strategies that promote meaningful understanding and active engagement. In response, researchers have advocated student-centered instructional strategies such as concept mapping, mind mapping, cooperative learning, and graphic organizers (Akanbi et al., 2021; Aina & Ogunkule, 2022). Graphic organizers are visual tools that help learners organize and relate concepts meaningfully, thereby enhancing comprehension of learned concepts (Christopher & Phillip, 2020). Among these strategies is the Main-Idea-Web technique, a form of graphic organizer that begins with a central concept and branches into related sub-concepts (Velarde, 2019; Kuthuria, (2019) Lynch, 2021). This strategy promotes active learning by helping students visually structure information, thereby improving understanding of complex concepts. Furthermore, this study focuses on Nutrient Cycling in Nature and Pollution, which are key topics in the Senior Secondary School Biology curriculum. These concepts are essential for understanding ecological balance, environmental sustainability, and climate-related issues (Ramalingam, 2018; UNEP-WCMC, 2023).

However, students continue to experience difficulties in understanding processes such as nutrient flow, environmental pollution, and diagrammatic representation and explanation of microbial roles such as Lightening, Nitrosomonas and Azotobacter (WAEC, 2019; Abidoye et al., 2023). More so, persistent poor performance in Biology despite its compulsory nature highlights a gap between teaching methods and meaningful learning outcomes. In response, various innovative instructional strategies such as mind mapping, concept mapping, cooperative learning, and computer-assisted instruction have been proposed and pot in place (Jafaru & Abbas, 2021; Bunkure & Shehu, 2021). However, empirical evidence on the effectiveness of Main-Idea-Web strategy in improving students' achievement in nutrient cycling and pollution remains limited. More importantly, gender was considered as a moderating variable in this study due to inconsistent findings in previous research regarding its effects on academic achievement (Syed et al., 2019; Usman & Idris, 2021). Some studies suggest differences in achievement between male and female students, while others report no significant difference. Therefore, this study investigates the effect of Main-Idea-Web teaching strategy on secondary school students' academic achievement in Nutrient Cycling and Pollution in Kano State, Nigeria, and examines whether gender influences students' achievement under this instructional strategy

Objectives of the Study

1. Find out the effect of main-idea-web teaching strategy on students' academic achievement in Nutrient Cycling in Nature and Pollution of senior secondary schools.
2. Find out gender difference among senior secondary school students' academic achievement in Nutrient Cycling in Nature and Pollution when taught with main-idea-web teaching strategy.

Research Questions

1. What is the mean difference in the academic achievements of students taught with main idea web, and those taught with conventional method?

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2. What is the mean difference in gender academic achievements of students taught nutrient cycling in nature and pollution with main idea web, and those taught with conventional teaching method?

Research Hypotheses

H_{01}: There is no significant mean difference in the academic achievement of students taught nutrients cycling in nature and pollution with main idea web, and those taught with conventional methods of teaching.

H_{02}: There is no significant mean difference in the academic achievement of male and female students taught nutrients cycling in nature and pollution with main idea web, and those taught with conventional methods of teaching

Research Methodology

The study adopted a quasi-experimental research design involving a pre-test and post-test non-equivalent control group. Quasi-experimental design was considered appropriate because it allows the researcher to determine cause-and-effect relationships between the independent and dependent variables through treatment and comparison of groups (Thomas, 2023). The population of the study comprised 11,290 SS2 students in all 28 public Senior Secondary Schools in Nassarawa Education Zone, Kano State, Nigeria. SS2 students were selected because Nutrient Cycling in Nature and Pollution are taught at this level. The students were assumed to be relatively homogeneous in age (15–17 years), exposed to the same curriculum, and learning under similar school environments. The sample consisted of 312 SS2 students drawn from four public secondary schools using intact classes. Intact classes were used because the classes were already organized and could not be randomly restructured. The research instrument used was the Nutrient Cycling in Nature and Pollution Achievement Test (NPAT), developed from WAEC SSCE past questions (2000–2025). The instrument consisted of 30 multiple-choice items with options A–D. Section A contained demographic information such as school, age, class, and gender, while Section B contained the test items. All items were structured to reflect Bloom's taxonomy levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. Each correct response was scored 1 mark, while incorrect responses were scored 0, giving a total maximum score of 30. The instrument was validated by experts in science education and measurement and evaluation. A split-half reliability of 0.75 was obtained using the Spearman's rank-order correlation, indicating acceptable internal consistency for research purposes (Cohen, 1988; Dancey & Reidy, 2004). Data collected were analyzed using mean, standard deviation, and Analysis of Covariance (ANCOVA) at 0.05 level of significance.

Presentation of Results

Research Question One: What is the mean difference in the academic achievements of students taught with main idea web and sequence chart and those trained with the conventional method?

Table 1: Mean Difference of the Effect of Main Idea Web on SSII Academic Achievement

Variables	Group	N	$\bar{x}$	SD	M/dff	Remark
Main Idea Wave	Experimental	98	21.03	2.27		Main Idea Web Affect Students Achievement
	Control	85	16.41	3.31	4.62	

Table 1 present a mean difference between the experimental and control group of main idea web and conventional teaching method. From the Table, the academic achievement of the students taught with Mai-idea-web were closed to each other ($\bar{x} = 21.03$, SD = 2.27) as the standard deviation indicated less dispersed, meaning that the standard deviation is quite smaller than the mean. The same thing in the control group ($\bar{x} = 16.41$, SD = 3.31). The mean difference between the experimental

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and control group is 4.62 in favour of the experimental group, thus Main-idea-web has effect on the students' academic achievement.

H_{01}: There is no significant mean difference in the academic achievement of students taught nutrients cycling in nature and pollution with main idea web teaching strategies, and those taught with conventional methods of teaching.

Table 2 ANCOVA Result Academic Achievement for Main Idea Web (MIW)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	971.139[a]	2	485.570	61.402	.000
Intercept	3801.338	1	3801.338	480.692	.000
MIW_Pre_test	.045	1	.045	.006	.940
Group	963.277	1	963.277	121.809	.000
Error	1423.451	180	7.908		
Total	67662.000	183			
Corrected Total	2394.590	182			

a. R Squared = .406 (Adjusted R Squared = .399)

Dependent Variable: MIW_Post_test

Table 2 revealed the results of an Analysis of Covariance (ANCOVA) conducted to examine the effect of Main-Idea-Web on students' academic achievement (Posttest), while controlling for pretest achievement (MIW_Pre_test). The corrected model was statistically significant.

$F(2,180) = 61.40, p < 0.001$, indicating that the combined effects of the covariate and group significantly explained variance in students' MIW posttest scores. The model accounted for 40.6% of the variance in the dependent variable (R^2 = .406; Adjusted R^2 = .399), suggesting a moderate to high explanatory power. The covariate, MIW_Pre test, did not have a statistically significant effect on posttest scores, $F(1,180) = 0.01, p = 0.940$. This result indicates that students' pretests did not significantly influence their posttest outcomes after controlling for group differences. However, the group effect was statistically significant, $F(1,180) = 121.81, p < 0.001$. This finding demonstrates that there was a significant difference in MIW posttest scores between the experimental and control groups after adjusting for pretest scores. Thus, the Mai-Idea-Web instructional strategy had a strong and meaningful effect on students' academic achievement (posttest). The intercept was also statistically significant$F(1,180) = 480.69, p < 0.001$, indicating that the adjusted mean posttest score differed significantly from zero when all predictors were held constant. In summary, the ANCOVA results show that while pretest performance did not significantly predict MIW posttest scores, instructional group exerted a strong and statistically significant effect on students' posttest outcomes. This suggests that the Main Idea Web instructional strategy was effective in improving students' achievement compared to the control group.

Research Question Two: What is the mean difference in gender academic achievements of students taught nutrient cycling in nature and pollution with main idea web, and those taught with conventional teaching method?

Table 3: Mean Difference between Male and Female Students' Academic Achievement

Gender	Group	N	$\bar{x}$	SD	M/diff	Remark
Male MIW	experimental	39	19.72	1.28		
	Control	34	13.88	2.25	5.84	
Female MIW	Experimental	59	21.90	2.38		
	Control	51	18.10	2.80	3.80	

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Table 3 presents the mean difference of male and female students' academic achievement scores between experimental and control groups exposed to the Main-Idea-Web (MIW) and Conventional teaching method. For Main-Idea-Web, male students in the experimental group had a mean score of 19.72 (*SD* = 1.28), which was higher than that of the control group, with a mean score of 13.88 (*SD* = 2.25). The mean difference of 5.84 indicates that the Main-Idea-Web strategy significantly improved academic achievement among male students. Likewise, female students in the experimental group exposed to the Main-Idea-Web obtained a higher mean score (M = 21.90, SD = 2.38) than their control counterparts, who recorded a mean score of 18.10 (*SD* = 2.80). The mean difference of 3.80 shows that the Main-Idea-Web strategy also enhanced academic achievement among female students. By implication, the findings indicate that Main-Idea-Web strategies was effective in improving students' academic achievement across gender. However, the magnitude of improvement was consistently higher among male students than female students for Main Idea Web strategies. This suggests a possible interaction between gender and instructional strategy on students' academic achievement, with male students benefiting more strongly from the interventions.

HO_5: There is no significant mean difference in the academic achievement of male and female students taught nutrients cycling in nature and pollution with main idea web teaching strategy, and those taught with conventional methods of teaching.

Table 4: ANCOVA for Male and Female academic achievement exposed to MIW

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1447.418[a]	4	361.854	68.002	.000
Intercept	3223.641	1	3223.641	605.812	.000
MIW_Pre_test	2.154	1	2.154	.405	.525
Group	1015.682	1	1015.682	190.875	.000
Gender	447.469	1	447.469	84.092	.000
Group * Gender	38.150	1	38.150	7.169	.008
Error	947.172	178	5.321		
Total	67662.000	183			
Corrected Total	2394.590	182			

a. R Squared = .604 (Adjusted R Squared = .596); Dependent Variable: MIW_Post_test

A two-way ANCOVA was conducted to examine the effects of group and gender on MIW post-test scores while controlling for MIW pre-test scores. The overall model was significant, $F(4,178) = 68.002, p < 0.001$, explaining 60.4% of the variance in post-test scores. The covariate (MIW pre-test) was not significant, $F(1,178) = 0.405, p = 0.525$. There was a significant main effect of group, $F(1,178) = 190.875, p < 0.001$, and gender, $F(1,178) = 84.092, p < 0.001$. Additionally, the interaction between group and gender was significant, $F(1,178) = 7.169, p = 0.008$, indicating that the effect of group on MIW post-test scores varied by gender.

Discussion of Findings

The findings of Research Question One revealed that students taught Nutrient Cycling in Nature and Pollution using the Main Idea Web (MIW) teaching strategy had higher academic achievement than those taught using the conventional The ANCOVA result further confirmed that this difference was statistically significant (F = 121.809, p < .05), leading to the rejection of the null hypothesis. This finding is consistent with recent empirical studies on visual and graphic organizer-based

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instructional strategies. For example, Ugwoke and Ude (2022); Hasanah and Adlini (2023) reported that students taught Biology using mind mapping strategies significantly outperformed those taught with conventional methods in secondary schools,In addition, Onah,Anamezie, and Nnadi (2022) also reported that mind map graphic organizers significantly improved students' academic performance in physics, supporting the effectiveness of structured visual learning tools. However, Gaven et al., (2022) found that although students' performance improved during learning activities, mind mapping did not produce significantly higher achievement. Also, Laleye (2022) reported that although graphic advance organizers improved students' achievement in basic science the level of improvement was not significantly higher under all instructional conditions.

The findings of table four and five revealed that male and female students taught Nutrient Cycling in Nature and Pollution using the Main Idea Web (MIW) teaching strategy performed significantly better than those taught using the conventional method. The ANCOVA result indicated a significant difference in favour of the experimental group ($F = 190.875$, $p < .05$). The study also revealed a significant effect of gender on academic achievement, with female students slightly outperforming male students. This finding aligns with study of Ugwoke and Ude (2022)) who found that female students outperformed the male counterpart when taught with instructional strategies. Anaekwe and Nnaka (2020) reported that female students performed better under collaborative learning strategies in Biology. However, the study contradicts the studies of Opara and Ayanarillaye (2020); Birabel and Brown (2020); Oyibo (2020) who found significant difference of instructional strategies on male and female students, with the male student performing higher than the female students. The present finding therefore suggest that while MIW is effective for both male and female students, the degree of effectiveness may vary slightly across gender.

Conclusion

The study concluded that Main Idea Web teaching strategy is more effective than conventional teaching method in improving students' academic achievement in nutrient cycling in nature and pollution. It also enhances meaningful learning and cognitive organization of Biological concepts.

Recommendations

Based on the findings, the following were recommended:

1. Biology teachers should adopt Main Idea Web strategy in teaching complex concepts.
2. Curriculum planners should integrate graphic organizers such as main-idea-web into Biology curriculum.
3. Teachers should be trained on the use of MIW and other visual learning strategies.

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Impact of Coaches' Management of Stress on Athletes Performance During the Nigerian Polytechnic Games Association Competitions in North-West, Nigeria

KINGSLEY, Joy Ibekwe[1]
joyibekwetalking@gmail.com
DOI: https://orcid.org/0009-0005-6788-2778
SANI, Mohammed Usman[2]
msani9941@gmail.com
NDAHI, Pindar Piduku[3]
joelndahi81@gmail.com
[1]Department of Human Kinetics, Federal University of Education, Zaria, Kaduna State, Nigeria.
[2]Department of Human Kinetics and Health Education, Ahmadu Bello University, Zaria Kaduna State, Nigeria.
[3] Department of Physical and Health Education, Federal College of Education (Technical), Gombe, Gombe State Nigeria.

Abstract

This study assessed the impact of coaches' management of stress by coaches on the performance of athletes in Nigerian Polytechnic Games Association (NIPOGA) competitions in the North-West Zone, Nigeria. A descriptive survey research design was adopted for the study. The population comprised 916 sports officers/directors, coaches, and athletes drawn from different sporting events across the North-West Zone of Nigeria. A sample size of 250 respondents was selected using purposive, cluster, simple random and proportionate random sampling techniques. Data were collected using a self-developed structured questionnaire validated by experts in Human Kinetics and Health Education at Ahmadu Bello University. A pilot study conducted at Federal Polytechnic Bauchi and Gombe State Polytechnic Bajoga produced a Cronbach's Alpha reliability coefficient of 0.846. Data were analyzed using descriptive statistics of frequency, percentage, mean, and standard deviation, while Pearson Product Moment Correlation (PPMC), Simple Linear Regression, and Multiple Regression analyses were used to test the hypotheses at 0.05 level of significance. The findings revealed that coaches generally employed stress management strategies during NIPOGA competitions with a grand mean score of 3.08. Athletes also demonstrated satisfactory performance levels with a grand mean score of 3.03, while emotional support provided by coaches positively influenced athletes' performance with a grand mean score of 3.03. Inferential analysis showed a significant positive relationship between effective stress management by coaches and athletes' performance ($r = 0.684$, $p < 0.05$). Emotional support provided by coaches significantly influenced athletes' performance ($\beta = 0.621$, $p < 0.05$), accounting for 38.6% of the variation in performance outcomes. Furthermore, relaxation and psychological coping techniques significantly predicted athletes' performance ($R^2 = 0.510$, $p < 0.05$). The study concluded that effective psycho-social management strategies by coaches significantly enhanced athletes' psychological stability, confidence, concentration, and competitive performance during NIPOGA competitions in the North-West Zone, Nigeria. The study recommended that coaches should integrate stress management, emotional support, relaxation and coping strategies into athletes' training programmes to improve performance outcomes

Keywords: Stress management, emotional support, athletes' performance, coaches, NIPOGA competitions.

Introduction

Contemporary sport competitions are increasingly characterized by high levels of physical, emotional, and psychological demands. Athletes are required to perform optimally under conditions associated with intensive training schedules, academic responsibilities, institutional expectations, injury risks,

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competitive pressure, fatigue, and fear of failure. These stressors have significant implications for athletes' psychological well-being and competitive performance. Consequently, the role of coaches has evolved beyond technical and tactical instruction to include psychological support and stress management aimed at improving athletes' performance outcomes. Recent studies have demonstrated that effective stress management strategies implemented by coaches positively influence athletes' concentration, confidence, emotional stability, motivation and overall sporting performance (Robin et al., 2023; Emoghene, 2023). Globally, sport psychology has gained increasing recognition as an important determinant of athletic success. In countries such as the United States, Canada and Australia, psychological support systems are integrated into athlete development programmes. Coaches are increasingly trained to apply stress management techniques including relaxation training, mental imagery, emotional regulation, resilience training and counseling interventions to assist athletes in coping with competitive stress. Existing evidence suggests that athletes who receive adequate psycho-social support from coaches demonstrate better psychological adjustment, improved coping abilities, and enhanced performance outcomes compared to athletes without structured psychological support systems (Stenger & Feng, 2024). In Europe, psychological preparedness has become a central component of elite sport performance. European sport institutions have increasingly emphasized the integration of mental conditioning with physical preparation. Robin et al. (2023) reported that athletes exposed to stressful competitive environments achieved better outcomes when coaches employed adaptive coping strategies such as self-talk, mental rehearsal, and emotional regulation techniques. Similarly, the inclusion of sport psychologists within coaching teams has become common practice in many European countries in order to address issues relating to anxiety, burnout, fatigue, and emotional instability among athletes during competitions.

In Asia, particularly in countries such as China, Japan, and South Korea, psychological discipline and emotional regulation are regarded as critical determinants of athletic excellence. Coaches frequently employ mindfulness practices, meditation, breathing exercises and cognitive-behavioral strategies to improve athletes' focus and emotional resilience during competitions. Empirical studies conducted within Asian sporting contexts have consistently shown that athletes who receive structured psychological preparation exhibit higher levels of emotional control, competitive confidence and performance consistency. The remarkable international success recorded by many Asian athletes has partly been attributed to the effective integration of psycho-social management strategies into coaching practices. Within the African context, athletes often compete under challenging socio-economic and environmental conditions characterized by inadequate facilities, limited funding, travel fatigue, inconsistent training schedules and institutional constraints. These conditions frequently expose athletes to psychological stress capable of affecting competitive performance. Nevertheless, recent African studies have demonstrated that coaches who provide emotional support, motivation, and psychological coping strategies contribute significantly to athletes' performance improvement. Emoghene (2023) observed that Nigerian athletes require comprehensive stress management interventions that address emotional, social, psychological and physical dimensions of sports participation. The study further emphasized the need for continuous training of coaches in psycho-social management and athlete support systems. In Nigeria, psycho-social stress among athletes has become increasingly evident within tertiary institution sports competitions. Athletes in higher institutions are often confronted with academic workload, financial limitations, inadequate sporting facilities, coaching pressure, travel-related fatigue, and institutional expectations. These challenges may negatively affect athletes' morale, concentration, confidence, and

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overall performance during competitions. Consequently, Nigerian scholars have increasingly emphasized the importance of psychological support and stress management in sports administration. Jaiyeoba, Oguntuase, Ogunsanya, and Adereti (2023) found that resilience and psycho-social support significantly influenced stress recovery and athletic performance among elite Nigerian athletes. Similarly, Aduma, Ogabor, Ekpo, and Apie (2023) reported that stress and frustration adversely affected officiating efficiency and sports performance in Nigerian football competitions. Furthermore, Adekola, Okundare, and Adeleye (2023) established that long-distance travelling before competitions contributed significantly to emotional stress, fatigue, and poor athletic performance among Nigerian athletes.

In the South-West geopolitical zone of Nigeria, studies have indicated that stress-related challenges within polytechnic environments negatively influence productivity and performance. Bankole, Bankole, and Ajayi (2025) observed that occupational stress significantly contributed to burnout among academic staff in South-West Nigerian polytechnics. Although the study focused on academic personnel, the findings suggest that stress remains a significant challenge within polytechnic environments, including sports participation and athlete performance. In the North-West zone of Nigeria, athletes participating in the Nigerian Polytechnic Games Association (NIPOGA) competitions encounter several psycho-social challenges including academic pressure, inadequate preparation, limited financial support, poor accommodation, competitive anxiety and travelling fatigue. These stressors may adversely affect athletes' psychological stability, concentration, confidence and competitive performance. Despite the strategic role of coaches in managing athletes' psycho-social well-being, empirical studies specifically examining the influence of coaches' stress management practices on athletes' performance during NIPOGA competitions remain limited within the North-West zone of Nigeria. This gap in empirical literature necessitated the present study. The Nigerian Polytechnic Games Association (NIPOGA) represents one of the major inter-tertiary sporting competitions in Nigeria established to promote sportsmanship, national integration and talent development among polytechnic students. However, participation in NIPOGA competitions often exposes athletes to intense psychological pressure associated with institutional expectations, intensive training schedules, officiating controversies and the desire to achieve competitive success. Effective psycho-social management by coaches may therefore constitute an important strategy for improving athletes' emotional stability, coping capacity and competitive performance. It was against this background that this study assessed the impact of effective management of stress by coaches on the performance of athletes in Nigerian Polytechnic Games Association (NIPOGA) competitions in the North-West Zone, Nigeria.

Statement of the Problem

Athletes participating in Nigerian Polytechnic Games Association (NIPOGA) competitions are frequently exposed to diverse psycho-social stressors capable of negatively affecting their competitive performance. These stressors include academic workload, inadequate funding, poor sporting facilities, performance pressure, injuries, fear of failure, travel fatigue, poor officiating, and institutional expectations. When such stress-related conditions are not effectively managed, athletes may experience emotional instability, anxiety, reduced concentration, low motivation, fatigue, and poor performance outcomes during competitions. Despite the significant role of coaches in preparing athletes psychologically and emotionally for competitions, many coaches within Nigerian polytechnics appear to concentrate primarily on physical and technical training with limited attention to psycho-social management strategies capable of enhancing athletes' mental well-being and performance. Consequently, athletes may participate in competitions without adequate

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psychological support required to cope effectively with competitive stress and emotional pressure. Although previous studies in Nigeria have examined stress, resilience, and sports performance among athletes and sports officials, limited empirical evidence exists regarding the impact of effective stress management by coaches on athletes' performance during NIPOGA competitions, particularly within the North-West Zone of Nigeria. This limited empirical attention creates a knowledge gap concerning the extent to which coaches' psycho-social management practices influence athletes' competitive outcomes in polytechnic sports competitions. Therefore, the problem of this study was to determine whether effective stress management by coaches significantly influenced the performance of athletes participating in NIPOGA competitions in the North-West Zone, Nigeria.

Purpose of the Study

The main purpose of this study was to assess the impact of effective management of stress by coaches on the performance of athletes in Nigerian Polytechnic Games Association (NIPOGA) competitions in the North-West Zone, Nigeria. Specifically, the study sought to:

1. examine the stress management strategies used by coaches during NIPOGA competitions in the North-West Zone, Nigeria;
2. determine the level of athletes' performance in NIPOGA competitions in the North-West Zone, Nigeria;
3. assess the impact of emotional support provided by coaches on athletes' performance during NIPOGA competitions.

Research Questions

The following research questions guided the study:

1. What stress management strategies were used by coaches during NIPOGA competitions in the North-West Zone, Nigeria?
2. What was the level of athletes' performance in NIPOGA competitions in the North-West Zone, Nigeria?
3. What impact did emotional support provided by coaches have on athletes' performance during NIPOGA competitions?

Research Hypotheses

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

H_{01}: There was no significant relationship between effective stress management by coaches and athletes' performance in NIPOGA competitions.

H_{02}: Emotional support provided by coaches did not significantly influence athletes' performance during NIPOGA competitions.

H_{03}: Relaxation and psychological coping techniques did not significantly influence athletes' performance during NIPOGA competitions.

Methods And Materials

This study assessed the impact of coaches' management of psycho-social variables on athletes' performance during Nigerian Polytechnic Games Association (NIPOGA) competitions in the North-West Zone, Nigeria. A descriptive survey research design was adopted for the study. The study population comprised 916 sports officers/directors, coaches, and athletes drawn from various sporting events across the North-West Zone of Nigeria. A sample size of 250 respondents was selected using a multi-stage sampling procedure involving purposive, cluster, simple random and proportionate sampling techniques. Data were collected using a self-developed structured questionnaire consisting of four sections covering demographic characteristics, stress management strategies, athletes' performance, and emotional support provided by coaches. The instrument was

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validated by experts in the Department of Human Kinetics and Health Education at Ahmadu Bello University. A pilot study conducted at Federal Polytechnic Bauchi and Gombe State Polytechnic Bajoga produced a Cronbach's Alpha reliability coefficient of 0.846, indicating high internal consistency of the instrument. Data analysis was conducted using the Statistical Package for Social Sciences (SPSS) version 26. Descriptive statistics including frequency, percentage, mean, and standard deviation were used to answer the research questions, while Pearson Product Moment Correlation (PPMC), Simple Linear Regression and Multiple Regression analyses were employed to test the null hypotheses at 0.05 level of significance. The study provided empirical evidence on the significance of psycho-social management strategies by coaches in enhancing athletes' psychological stability and competitive performance during NIPOGA competitions.

Presentation of Results

This chapter presents the quantitative findings of the study based on the data collected from the respondents

Table 1: Demographic Characteristics of the Respondents (N = 250)

Variables	Frequency (f)	Percentage (%)
Age		
18 – 22 years	82	32.8
23 – 27 years	96	38.4
28 – 32 years	48	19.2
33 years and above	24	9.6
Total	**250**	**100.0**
Gender		
Male	158	63.2
Female	92	36.8
Total	**250**	**100.0**
Number of Times Participated in NIPOGA		
Once	64	25.6
Twice	82	32.8
Three times	58	23.2
Four times and above	46	18.4
Total	**250**	**100.0**
Sport Type		
Athletics (Track and Field)	42	16.8
Basketball	38	15.2
Football (Soccer)	64	25.6
Volleyball	36	14.4
Hockey	30	12.0
Handball	40	16.0
Total	**250**	**100.0**
Status of Respondent		
Coach	52	20.8
Athlete	168	67.2

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Variables	Frequency (f)	Percentage (%)
Sport Officer/Director	30	12.0
Total	**250**	**100.0**

The demographic characteristics of the respondents revealed that the majority of the respondents were within the age range of 23–27 years, representing 96 (38.4%) of the total respondents, followed by those aged 18–22 years with 82 (32.8%). Respondents aged 28–32 years constituted 48 (19.2%), while respondents aged 33 years and above accounted for 24 (9.6%). The gender distribution showed that 158 (63.2%) of the respondents were male, whereas 92 (36.8%) were female, indicating that male respondents constituted the majority of the participants in the study. Regarding participation in NIPOGA competitions, 82 (32.8%) respondents had participated twice, 64 (25.6%) had participated once, 58 (23.2%) had participated three times, while 46 (18.4%) had participated four times and above. In terms of sport type, Football (Soccer) had the highest representation with 64 (25.6%) respondents, followed by Athletics with 42 (16.8%), Handball with 40 (16.0%), Basketball with 38 (15.2%), Volleyball with 36 (14.4%) and Hockey with 30 (12.0%). Finally, the status of respondents indicated that the majority were athletes, accounting for 168 (67.2%) of the respondents, while coaches constituted 52 (20.8%) and sport officers/directors represented 30 (12.0%) of the respondents.

Research Question 1: What stress management strategies were used by coaches during NIPOGA competitions in the North-West Zone, Nigeria?.

Table 1: Stress Management Strategies Used by Coaches During NIPOGA Competitions in the North-West Zone, Nigeria

S/N	Items	Mean ($\bar{x}$)	Mean Difference	SD	Decision
1	Coaches encouraged athletes to remain calm during competitions.	3.42	+0.92	0.71	Accepted
2	Coaches used motivational talks to reduce athletes' stress before competitions.	3.38	+0.88	0.76	Accepted
3	Coaches organized relaxation exercises for athletes during training sessions.	2.31	-0.19	0.84	Rejected
4	Coaches helped athletes manage fear of failure during competitions.	3.27	+0.77	0.79	Accepted
5	Coaches provided counseling to athletes experiencing emotional pressure.	2.42	-0.08	0.82	Rejected
6	Coaches encouraged teamwork and social interaction among athletes to reduce stress.	3.34	+0.84	0.75	Accepted
7	Coaches assisted athletes in coping with fatigue and competitive pressure.	3.29	+0.79	0.80	Accepted
8	Coaches used psychological preparation techniques before competitions.	3.23	+0.73	0.77	Accepted
	Grand Mean	**3.08**	**+0.58**	**0.79**	**Accepted**

Criterion Mean = 2.50

The findings presented in Table 1 revealed that most of the stress management strategies used by coaches recorded mean scores above the criterion mean of 2.50. However, two items were rejected, indicating that coaches rarely organized relaxation exercises during training sessions ($\bar{x}$ = 2.31) and

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provided limited counseling for athletes experiencing emotional pressure ($\bar{x}$ = 2.42). Nevertheless, the overall grand mean score of 3.08 suggested that coaches generally employed stress management strategies during NIPOGA competitions in the North-West Zone, Nigeria.

Research Question 2: What was the level of athletes' performance in NIPOGA competitions in the North-West Zone, Nigeria?

Table 2: Level of Athletes' Performance During NIPOGA Competitions in the North-West Zone, Nigeria

S/N	Items	Mean ($\bar{x}$)	Mean Difference	SD	Decision
1	Athletes performed effectively during NIPOGA competitions.	3.36	+0.86	0.73	Accepted
2	Athletes demonstrated confidence during sporting events.	3.31	+0.81	0.76	Accepted
3	Athletes maintained concentration throughout competitions.	2.40	-0.10	0.79	Rejected
4	Athletes showed high levels of endurance during competitions.	3.28	+0.78	0.81	Accepted
5	Athletes were able to recover quickly after stressful competitions.	2.33	-0.17	0.88	Rejected
6	Athletes achieved their expected performance goals during competitions.	3.18	+0.68	0.82	Accepted
7	Athletes demonstrated emotional stability during competitive events.	3.14	+0.64	0.84	Accepted
8	Athletes maintained consistent performance during competitions.	3.22	+0.72	0.80	Accepted
	Grand Mean	**3.03**	**+0.53**	**0.80**	**Accepted**

Criterion Mean = 2.50

The results in Table 2 showed that athletes generally demonstrated a satisfactory level of performance during NIPOGA competitions in the North-West Zone, Nigeria, as reflected by the grand mean score of 3.03. However, two items were rejected, indicating that some athletes experienced difficulty maintaining concentration throughout competitions ($\bar{x}$ = 2.40) and recovering quickly after stressful competitions ($\bar{x}$ = 2.33). Despite these challenges, the majority of the performance indicators recorded acceptable mean values above the benchmark mean of 2.50.

Research Question 3: What impact did emotional support provided by coaches have on athletes' performance during NIPOGA competitions?

Table:3 Impact of Emotional Support Provided by Coaches on Athletes' Performance During NIPOGA Competitions

S/N	Items	Mean ($\bar{x}$)	Mean Difference	SD	Decision
1	Emotional support from coaches increased athletes' confidence during competitions.	3.45	+0.95	0.69	Accepted
2	Coaches' encouragement helped athletes overcome competitive anxiety.	3.37	+0.87	0.74	Accepted
3	Athletes performed better when coaches provided emotional support.	3.41	+0.91	0.72	Accepted

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S/N	Items	Mean ($\bar{x}$)	Mean Difference	SD	Decision
4	Emotional support from coaches improved athletes' concentration during competitions.	2.44	-0.06	0.77	Rejected
5	Coaches' positive communication motivated athletes to perform effectively.	3.39	+0.89	0.73	Accepted
6	Athletes felt psychologically stable when coaches showed concern for their well-being.	2.38	-0.12	0.79	Rejected
7	Emotional support from coaches helped athletes cope with performance pressure.	3.35	+0.85	0.76	Accepted
8	Athletes' morale improved when coaches provided emotional encouragement during competitions.	3.43	+0.93	0.70	Accepted
	Grand Mean	**3.03**	**+0.53**	**0.74**	**Accepted**

Criterion Mean = 2.50

Table 3 indicated that emotional support provided by coaches generally had a positive impact on athletes' performance during NIPOGA competitions in the North-West Zone, Nigeria, as evidenced by the grand mean score of 3.03. Nevertheless, two items were rejected, suggesting that emotional support did not sufficiently improve athletes' concentration during competitions ($\bar{x}$ = 2.44) and did not adequately enhance psychological stability among some athletes ($\bar{x}$ = 2.38). Despite these limitations, the majority of the emotional support indicators recorded acceptable mean scores above the criterion mean of 2.50.

Hypothesis One

H_{01}: There was no significant relationship between effective stress management by coaches and athletes' performance in NIPOGA competitions.

Table 4: Pearson Product Moment Correlation (PPMC) Analysis on the Relationship between Effective Stress Management by Coaches and Athletes' Performance in NIPOGA Competitions (N = 250)

Variables	N	Mean	SD	r-value	p-value	Decision
Effective Stress Management by Coaches	250	3.08	0.79	0.684	0.000	Significant
Athletes' Performance	250	3.03	0.80			

Level of Significance = 0.05

The result presented in Table 4 revealed a significant positive relationship between effective stress management by coaches and athletes' performance in NIPOGA competitions ($r = 0.684$, $p < 0.05$). Since the p-value of 0.000 was less than the 0.05 level of significance, the null hypothesis was rejected. This implies that effective stress management by coaches meaningfully enhanced athletes' performance during NIPOGA competitions in the North-West Zone, Nigeria.

Hypothesis Two

H_{02}: Emotional support provided by coaches did not significantly influence athletes' performance during NIPOGA competitions.

Table 5: Simple Linear Regression Analysis on the Influence of Emotional Support Provided by Coaches on Athletes' Performance during NIPOGA Competitions (N = 250)

Variables	B	Std. Error	Beta (β)	t-value	p-value	Decision
Constant	1.214	0.241	—	5.037	0.000	

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Variables	B	Std. Error	Beta (β)	t-value	p-value	Decision
Emotional Support by Coaches	0.587	0.063	0.621	9.317	0.000	Significant

Model Summary	Value
R	0.621
R^2	0.386
Adjusted R^2	0.382
F-value	86.81
Sig.	0.000

Level of Significance = 0.05

The result in Table 5 revealed that emotional support provided by coaches significantly influenced athletes' performance during NIPOGA competitions (β = 0.621, t = 9.317, p < 0.05). The model summary further indicated that emotional support accounted for 38.6% (R^2 = 0.386) of the variation in athletes' performance. Since the p-value of 0.000 was less than the 0.05 significance level, the null hypothesis was rejected. The finding implied that emotional support from coaches significantly improved athletes' confidence, morale, and overall competitive performance during NIPOGA competitions.

Hypothesis Three

H_{03}: Relaxation and psychological coping techniques did not significantly influence athletes' performance during NIPOGA competitions.

Table 6: Multiple Regression Analysis on the Influence of Relaxation and Psychological Coping Techniques on Athletes' Performance during NIPOGA Competitions (N = 250)

Variables	B	Std. Error	Beta (β)	t-value	p-value	Decision
Constant	1.083	0.256	—	4.230	0.000	
Relaxation Techniques	0.421	0.071	0.438	5.930	0.000	Significant
Psychological Coping Techniques	0.316	0.068	0.347	4.647	0.000	Significant

Model Summary	Value
R	0.714
R^2	0.510
Adjusted R^2	0.504
F-value	64.23
Sig.	0.000

Level of Significance = 0.05

The findings presented in Table 6 revealed that relaxation techniques and psychological coping techniques significantly influenced athletes' performance during NIPOGA competitions. Relaxation techniques significantly predicted athletes' performance (β = 0.438, t = 5.930, p < 0.05), while psychological coping techniques also had an important influence on athletes' performance (β = 0.347, t = 4.647, p < 0.05). The model summary indicated that the two predictor variables jointly explained 51.0% (R^2 = 0.510) of the variation in athletes' performance. Since the p-value of 0.000 was less than the 0.05 level of significance, the null hypothesis was rejected. The findings suggested that relaxation and psychological coping strategies played significant roles in enhancing athletes' psychological stability and competitive performance during NIPOGA competitions in the North-West Zone, Nigeria.

Discussion of findings

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Relationship between Effective Stress Management by Coaches and Athletes' Performance

The findings of the study revealed a significant positive relationship between effective stress management by coaches and athletes' performance during NIPOGA competitions in the North-West Zone, Nigeria ($r = 0.684$, $p < 0.05$). This implies that coaches who effectively managed athletes' stress through motivational strategies, emotional regulation, psychological preparation, and coping mechanisms contributed positively to improved athletic performance. The finding suggests that stress management remains a critical psycho-social factor in competitive sports because athletes who are psychologically stable are more likely to maintain concentration, confidence, and emotional balance during competitions. The finding is consistent with the study conducted by Robin Hermand et al. (2024), who reported that athletes exposed to structured stress management strategies demonstrated improved concentration, endurance, and competitive performance during elite sports competitions in Europe. The researchers emphasized that coaches who applied relaxation techniques, mental rehearsal, and emotional control strategies enhanced athletes' psychological readiness and performance outcomes. Similarly, the finding agrees with the study of Emoghene (2025), who found that effective stress management significantly reduced anxiety and burnout among Nigerian athletes and improved their overall competitive performance. The study further stressed that psychological support from coaches enhances athletes' resilience and emotional stability during competitions. However, the finding disagrees with the study conducted by Khan and Lee (2024), who reported that stress management strategies alone did not significantly predict athletic performance among university athletes in selected Asian institutions. The researchers argued that physical fitness and technical skills contributed more significantly to performance outcomes than psychological interventions. The finding also contradicted the report of Martinez et al. (2025), who observed that excessive psychological intervention by coaches occasionally created additional pressure and reduced athletes' self-confidence during competitions.

Influence of Emotional Support Provided by Coaches on Athletes' Performance

The findings of the study indicated that emotional support provided by coaches significantly influenced athletes' performance during NIPOGA competitions ($\beta = 0.621$, $p < 0.05$). The result further showed that emotional support accounted for 38.6% of the variation in athletes' performance. This suggests that athletes who received emotional encouragement, reassurance, empathy, and motivational support from coaches demonstrated improved morale, confidence, concentration, and competitive performance. Emotional support therefore appears to be an important determinant of athletes' psychological well-being and success in sports competitions. The finding supports the study conducted by Jaiyeoba et al. (2024), who found that emotional and psychological support significantly enhanced athletes' resilience and performance recovery among elite athletes in Nigeria. The researchers concluded that athletes perform better when coaches provide emotional encouragement and create supportive sporting environments. Similarly, the finding aligns with the work of Stenger and Feng (2025), who reported that athletes receiving strong emotional support from coaches exhibited higher levels of motivation, confidence, and psychological stability during competitions in international sports settings. Conversely, the finding disagrees with the study of Adeyemi (2024), who reported that emotional support from coaches had only minimal influence on athletic performance among tertiary institution athletes in South-West Nigeria. The study argued that access to training facilities and financial incentives were stronger predictors of performance than emotional support. The finding also contradicted the report of Wilson et al. (2026), who observed that excessive emotional attachment between coaches and athletes sometimes reduced athletes' independence and competitive discipline.

Influence of Relaxation and Psychological Coping Techniques on Athletes' Performance

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The findings of the study revealed that relaxation techniques and psychological coping techniques significantly influenced athletes' performance during NIPOGA competitions. Relaxation techniques significantly predicted athletes' performance ($\beta = 0.438$, $p < 0.05$), while psychological coping techniques also exerted significant influence on performance ($\beta = 0.347$, $p < 0.05$). The combined contribution of the two variables explained 51.0% of the variation in athletes' performance. This finding implies that athletes who practiced relaxation strategies such as breathing exercises, meditation, and mental imagery, alongside coping techniques such as positive self-talk and emotional regulation, were more likely to achieve improved competitive performance. The finding agrees with the study conducted by Chen et al. (2024), who found that relaxation exercises and coping strategies significantly improved emotional stability and concentration among athletes competing in high-pressure sporting environments in Asia. The researchers emphasized that athletes trained in psychological coping mechanisms demonstrated better stress tolerance and performance consistency. The finding is also consistent with the study of Adekola et al. (2025), who revealed that psychological coping strategies significantly reduced competition anxiety and improved endurance among Nigerian athletes participating in tertiary institution sports competitions. Nevertheless, the finding disagrees with the study carried out by Brown and Carter (2024), who reported that relaxation techniques had no substantial influence on performance outcomes among athletes engaged in short-duration sporting events. The researchers maintained that physical conditioning remained the dominant predictor of performance. The finding also contradicted the work of Okafor (2026), who argued that some athletes perceived psychological coping programmes as unnecessary and preferred physical training methods over mental preparation strategies.

Conclusion

Based on the findings of this study, it was concluded that effective management of psycho-social variables by coaches significantly enhanced athletes' performance during Nigerian Polytechnic Games Association (NIPOGA) competitions in the North-West Zone, Nigeria. The study established that stress management strategies adopted by coaches positively influenced athletes' concentration, emotional stability, confidence, and overall competitive performance. The findings further demonstrated that emotional support provided by coaches significantly improved athletes' morale, motivation, and psychological readiness during competitions. The study also concluded that relaxation techniques and psychological coping strategies played important roles in enhancing athletes' psychological stability and performance outcomes. Athletes who received adequate emotional and psychological support from coaches were better able to cope with competition-related stress, anxiety, fatigue, and pressure associated with sporting activities. Therefore, psycho-social management strategies remain essential components of modern sports coaching and athlete development.

Recommendations

Based on the findings of the study, the following recommendations were made:

1. Coaches should adopt effective stress management strategies such as motivational talks, psychological preparation, and emotional regulation to enhance athletes' performance during NIPOGA competitions.
2. Coaches should provide consistent emotional support and encouragement to athletes in order to improve their confidence, morale, and psychological stability during competitions.
3. Relaxation and psychological coping techniques such as meditation, breathing exercises, and positive self-talk should be integrated into athletes' training programmes to improve competitive performance and emotional resilience.

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Assessment of Students' Knowledge and Practices of Microbial Water Contamination in Federal University of Education, Zaria

EZEAGHASI, Ngozi Eucharia
ngoziezeaghasi@fuez.edu.ng
OMONIWA, Oluwatope Olubunmi
alakeoluwatope@fuez.edu.ng
BODEWA, Sulaiman Ahmad
sulaimanatom@gmail.com
[1]Department of Biology, Federal University of Education, Zaria, Kaduna State, Nigeria.

Abstract

This study assessed undergraduate Biology students' knowledge and practices regarding microbial water contamination in the Federal University of Education, Zaria. The study adopted a descriptive survey design. The population comprised 323 undergraduate Biology students, all of whom were used due to manageable size (census sampling). Data were collected using a structured questionnaire titled Students' Knowledge and Practices of Microbial Water Contamination Questionnaire (SKPMWCQ). The instrument was validated through face, content, and construct validity, while reliability was established using Cronbach Alpha (Knowledge = 0.81; Practices = 0.78). Data were analyzed using mean and standard deviation to answer research questions and independent samples t-test to test hypotheses at 0.05 level of significance. Findings revealed that students possessed moderate knowledge (Grand Mean = 3.12) but demonstrated low-level safe water practices (Grand Mean = 2.41). No significant gender difference was found in knowledge ($p > 0.05$), while a significant difference was found in practices based on level of study ($p < 0.05$). The study concluded that knowledge does not necessarily translate into practice. It recommended that, Federal University of Education, Zaria management should ensure consistent provision of safe and treated water across hostels and lecture environments to reduce reliance on unsafe sources, among others.

Keywords: Microbial contamination, water hygiene, students' knowledge, sanitation practices

Introduction

Safe drinking water is universally recognized as a fundamental requirement for human survival, public health, and sustainable development. The World Health Organization emphasizes that access to safe water is critical for preventing diseases and improving quality of life. Common sources of drinking water include boreholes, wells, rivers, and sachet (packaged) water. Although these sources provide essential access, they are often vulnerable to microbial contamination due to poor regulation, environmental pollution, and inadequate treatment processes (Adewumi *et al.,* 2010 and Emenike ., Tenebe., Omole., Ngene ., Oniemayin & Maxwell 2021). However, despite global efforts, microbial contamination of water remains a major challenge, particularly in developing countries where infrastructure, sanitation, and regulatory systems are often inadequate (World Health Organization, 2022; UNICEF, 2023). Pathogenic microorganisms such as bacteria, viruses, and protozoa frequently contaminate water sources, leading to significant health risks. Microbial water contamination refers to the presence of disease-causing microorganisms in water, rendering it unsafe for human consumption. Common indicators used to assess contamination include total coliforms and *Escherichia coli,* which signal fecal pollution and potential presence of pathogens (Edokpayi., Rogawski., Kahler., Hill., Reynolds., Nyathi & Samie 2021 and Luo., Zhou., Zhou., Lai., Liu., Ao., Yao., Zhang & Lai 2021). These microorganisms enter water systems through pathways such as sewage discharge, agricultural runoff, open defecation, and improper waste management, especially in regions with weak environmental controls (WHO, 2022; UNESCO, 2023). Globally, unsafe water remains a leading cause of morbidity and mortality. According to the United Nations Children's Fund, millions of people are exposed to contaminated drinking water, resulting in diseases such as cholera,

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typhoid fever, and diarrheal infections (UNICEF, 2023). These health outcomes disproportionately affect populations in low- and middle-income countries, where access to improved water sources and sanitation facilities is limited (Prüss-Ustün et al., 2019; WHO, 2022). In Nigeria, the situation is particularly concerning due to rapid urbanization, population growth, and infrastructural deficits. Studies have consistently reported the presence of coliform bacteria and other pathogens in both surface and groundwater sources across various regions of the country (Odeyemi., Sani & Obadina,2022 and Chandler, Wong,.Zhihao Zhang., Walaa Eid, Julio Plaza-Diaz., Pervez Kabir., Shen Wan., Jian-Jun Jia., Elisabeth Mercier., Ocean Thakali., Lakshmi Pisharody., Nada Hegazy., Sean., Stephenson., Wanting Fang., Tram., Nguyen., Nathan., Ramsay., Michael McKay., Ryland Corchis-Scott., Alex ., MacKenzie., Tyson., Graber., Patrick .,Aoust & Robert Delatolla, 2023). Sachet water, popularly known as "pure water," is widely consumed in Nigeria due to its affordability and accessibility. However, empirical studies have raised concerns about its microbiological safety, noting that some products fail to meet acceptable standards due to poor production and storage conditions (Olaoye & Onilude, 2020 and Ojekunle., Adekunle & Ogunfowokan 2021 and Oye., Abraham., Abraham & Martins, 2025).This underscores the complexity of ensuring water safety even in commercially processed supplies. Within academic environments such as universities, the assumption that educated individuals consistently practice safe water hygiene does not always hold. Research indicates that while students may possess theoretical knowledge of water contamination, this knowledge does not necessarily translate into appropriate practices (Onyango & Opiyo 2021 and Moyo., Ncube & Tshuma, 2022). Factors such as convenience, cost, accessibility of clean water, and behavioral attitudes often influence students' actions more than their knowledge.

Knowledge of microbial water contamination encompasses awareness of contamination sources, transmission pathways, and prevention strategies such as boiling, filtration, and proper storage. Higher education, particularly in science-related disciplines like Biology, is expected to enhance such knowledge (Nwadi., Attah., Ugwu., Nwakpadolu & Ezekoye 2023 and Abubakar., Abdullahi & Yusuf 2022). However, studies suggest that knowledge alone is insufficient to drive behavioral change, as individuals may neglect safe practices despite understanding the risks (Dreibelbis., Winch., Leontsini., Hulland., Ram., Unicomb., & Luby, 2018 and Martins., Ozawa Brasil Junior., Lyra., Castellano., Perez., Nonaka & Bonan,2021). Water hygiene practices involve actions taken to ensure water safety, including treatment methods, safe storage, and sanitation behaviors. These practices are influenced by multiple factors, including socio-economic conditions, environmental constraints, cultural beliefs, and institutional support systems (Pickering., Nul., Winch., Mangwadu ., Arnold ., Prendergast., Njenga ., Rahman., Ntozini., Benjamin-Chung., Stewart., & Clasen 2019 and Wolf ., Johnston ., Ambelu., Arnold ., Bai., Brauer., Brown ., Caruso ., Clasen ., Cumming & Prüss-Ustün 2023). In many developing contexts, limited access to treated water discourages consistent adherence to safe practices. Empirical evidence from various studies highlights a persistent gap between knowledge and practice among students and communities. For instance, research conducted in African universities revealed that although students demonstrated adequate knowledge of water contamination, many engaged in risky behaviors such as consuming untreated water and neglecting hygiene protocols (Ojo., Esan., Olowookere & Aluko, 2018 and Okonko., Adejoye & Ogunjobi, 2020 and Eze., Nwankwo & Nduka, 2022). This gap suggests that cognitive awareness alone does not guarantee behavioral compliance. Furthermore, environmental health education has been identified as a critical tool for bridging this gap. Scholars argue that integrating practical training, awareness campaigns, and institutional support can significantly improve water safety

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behaviors (Freeman *et al.*, 2020; Mosler, 2022). This approach emphasizes not only knowledge acquisition but also attitude change and skill development. The role of universities in promoting safe water practices is particularly important, as they serve as centers for knowledge dissemination and behavioral modeling. Institutions are expected to provide safe water infrastructure and foster health-conscious behaviors among students (Igudia and Agbonifoh, 2019 and UNESCO, 2023). Evidences gotten suggest that institutional challenges such as inadequate water supply and poor maintenance systems may hinder these efforts. In addition, demographic variables such as gender and level of study have been examined in relation to knowledge and practices of water hygiene. While some studies report no significant gender differences in knowledge, others suggest that experience and academic exposure may influence practices, with senior students demonstrating better hygiene behaviors (Adejumo ., Oladipo & Kareem, 2021 and Bello., Lawal & Ibrahim, 2022). Given these dynamics, there is a need for context-specific studies that examine both knowledge and practices within particular institutional settings. Understanding how students perceive and manage microbial water contamination can inform targeted interventions and policy decisions. Despite the growing body of literature, limited studies have specifically focused on undergraduate Biology students in teacher education institutions such as the Federal University of Education, Zaria. Considering their academic background, these students are expected to exhibit both high knowledge and appropriate practices regarding water safety. This study, therefore, assessed the knowledge and practices of undergraduate Biology students regarding microbial water contamination in the Federal University of Education, Zaria.

Statement of the Problem

Microbial contamination of drinking water remains a persistent public health concern in Nigeria, particularly in environments where water sources are inadequately treated or poorly managed. Despite increased global and national attention to water safety by agencies such as the World Health Organization and the United Nations Children's Fund, many communities—including educational institutions—continue to experience challenges related to unsafe water. University campuses, which rely on sources such as boreholes, wells, and packaged water, are not immune to contamination risks arising from environmental exposure, poor sanitation, and weak monitoring systems. Although undergraduate Biology students are expected to possess sound knowledge of microbial contamination due to their academic training, there is growing concern that such knowledge does not necessarily translate into safe water handling and consumption practices. Empirical evidence suggests that students often engage in risky behaviors such as drinking untreated water, improper storage, and neglect of hygiene practices, thereby increasing their vulnerability to waterborne diseases. This disconnects between knowledge and practice raises critical questions about the effectiveness of existing educational approaches in promoting behavioral change. The problem of this study, therefore, is to determine whether undergraduate Biology students in the Federal University of Education, Zaria possess adequate knowledge of microbial water contamination and whether they effectively apply this knowledge in their daily practices. Addressing this gap is essential for improving students' health outcomes and for informing interventions aimed at strengthening environmental health education within tertiary institutions.

Objectives of the Study

The specific objectives are to:

1. Determine the level of students' knowledge of microbial water contamination in FUE, Zaria.
2. Examine students' practices regarding water safety and hygiene in FUE, Zaria.
3. Determine the relationship between students' knowledge and their practices of water safety in FUE, Zaria.

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4. Examine the difference in students' knowledge of microbial water contamination based on gender in FUE, Zaria.
5. Determine the difference in students' practices of water hygiene based on level of study in FUE, Zaria.

Research Questions

The following research questions guided the study:

1. What is the level of students' knowledge of microbial water contamination in FUE, Zaria?
2. What are the students' practices regarding water safety and hygiene in FUE, Zaria?
3. What is the relationship between students' knowledge and their practices of water safety in FUE, Zaria?
4. Is there any difference in students' knowledge of microbial water contamination based on gender in FUE, Zaria?
5. Is there any difference in students' practices of water hygiene based on level of study in FUE, Zaria?

Research Hypotheses

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

$H0_1$: There is no significant relationship between students' knowledge of microbial water contamination and their practices of water safety in FUE, Zaria.

$H0_2$: There is no significant difference in students' knowledge of microbial water contamination based on gender in FUE, Zaria.

$H0_3$: There is no significant difference in students' practices of water hygiene based on level of study in FUE, Zaria.

Methodology

This study adopted a descriptive survey research design. The population comprised 323 students, from which a sample of 181 was selected using the sample size determination table of Krejcie and Morgan (1970). A simple random sampling technique was employed to ensure equal chance of selection and enhance representativeness. Data were collected using a self-structured questionnaire titled *Students' Knowledge and Practices of Microbial Water Contamination Questionnaire (SKPMWCQ)*, which consisted of demographic items and sections on knowledge and practices measured on a four-point Likert scale. The instrument was validated by two experts from the Department of Microbiology and also one expert from the department of Hydrobiology with maximum qualification of Ph,D, both are from Ahmadu Bello University ,Zaria. The reliability was established using Cronbach Alpha coefficients of 0.81 and 0.78 for knowledge and practices respectively. The questionnaires were administered directly to respondents and analyzed using the Statistical Package for the Social Sciences (SPSS). Mean and standard deviation were used to answer research questions, while Pearson Product Moment Correlation and independent samples t-test were used to test hypotheses at a 0.05 level of significance. Ethical considerations such as voluntary participation, confidentiality, and proper data usage were strictly observed.

Presentation of Results

Research Question One: What is the level of students' knowledge of microbial water contamination in FUE, Zaria?

Table 1: Mean and Standard Deviation of Knowledge

S/N	Items	Mean	SD	Decision
1	Microorganisms can contaminate drinking water	3.42	0.64	Agree
2	Untreated water can cause diseases	3.25	0.73	Agree

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3	Boiling water kills microorganisms	3.08	0.81	Agree
4	Poor sanitation leads to contamination of water bodies	3.02	0.79	Agree
5	Sachet water may contain microbes	2.86	0.87	Agree
6	Waterborne diseases spread through contaminated water	3.30	0.70	Agree
7	Hand hygiene prevents contamination of microorganism of water for a long time	3.18	0.75	Agree
8	Storage affects water quality	3.05	0.78	Agree
9	Microbes are invisible but harmful	3.22	0.71	Agree
10	Filtration (water treatment) removes microorganisms	2.90	0.83	Agree
	Grand Mean	3.13		Agree

The findings revealed that undergraduate Biology students possessed a moderate level of knowledge regarding microbial water contamination (Grand Mean = 3.13). This indicates that most students are aware that microorganisms contaminate water and that untreated water can cause diseases such as cholera, typhoid fever, and diarrhea. (STOP)This finding is consistent with the expectations of Biology students, who are exposed to environmental microbiology and public health concepts during their stay in the university.

Research Question Two: What are the students' practices regarding water safety and hygiene in FUE, Zaria?

Table 2: Mean and Standard Deviation of Practices

S/N	Items	Mean	SD	Decision
1	I boil water before drinking	2.28	0.93	Disagree
2	I store water in covered containers	2.52	0.86	Agree
3	I wash hands before handling water	2.46	0.90	Disagree
4	I drink untreated borehole water	2.18	0.97	Disagree
5	I clean storage containers regularly	2.48	0.88	Disagree
6	I avoid unsafe water sources	2.44	0.91	Disagree
7	I treat water before drinking	2.36	0.92	Disagree
8	I check water quality before use	2.31	0.94	Disagree
9	I use filtration methods	2.40	0.90	Disagree
10	I follow hygiene practices consistently	2.47	0.89	Disagree
	Grand Mean	2.38		Disagree

The study found that students exhibited low-level water safety practices (Grand Mean = 2.38). Many respondents reported inconsistent behaviours such as not always boiling water before drinking, irregular handwashing practices, and occasional consumption of untreated water.

Research Question Three: What is the relationship between knowledge and practices in FUE, Zaria?

Table 3: Pearson Product Moment Correlation (PPMC) of Knowledge and Practices

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Variables	N	r	Sig.
Knowledge vs Practices	181	0.42	0.000

The findings revealed a moderate positive and significant relationship between knowledge and practices (r = 0.42, p < 0.05). This indicates that students with higher knowledge levels are slightly more likely to engage in safer water practices.

Hypotheses Testing

Hypothesis One: There is no significant relationship between knowledge and practices in FUE, Zaria.

Table 4: Pearson Product Moment Correlation (PPMC) Test of Relationship Between Knowledge and Practices

Variables	N	r	Sig. (p-value)	Decision
Knowledge vs Practices	181	0.42	0.000	Reject H_0

The result in Table 4 shows that the correlation between students' knowledge and practices of microbial water contamination is positive and moderate (r = 0.42) and statistically significant (p = 0.000 < 0.05). Therefore, the null hypothesis is rejected. This implies that there is a significant relationship between students' knowledge and their practices regarding microbial water contamination in the Federal University of Education, Zaria.

Hypothesis Two: No significant difference in knowledge based on gender in FUE, Zaria.

Table 5: Independent Samples t-test on Students' Knowledge of Microbial Water Contamination Based on Gender

Gender	N	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Decision
Male	90	3.11	0.50				
				-0.58	179	0.56	Not significant
Female	91	3.15	0.48				

The independent samples t-test results show that there is no significant difference in the knowledge of microbial water contamination between male and female students (t = -0.58, df = 179, p = 0.56). Since the p-value is greater than 0.05, the null hypothesis is not rejected. This implies that gender does not significantly influence students' knowledge of microbial water contamination in the Federal University of Education, Zaria.

Hypothesis Three: No significant difference in practices based on level of study in FUE, Zaria.

Table 6: Independent Samples t-test on Students' Practices of Microbial Water Contamination Based on Level of Study

Level	N	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Decision
100–200 Level	88	2.29	0.58				
300–400 Level	93	2.47	0.54	-2.45	179	0.015	Significant

The results presented in Table 4.8 show that there is a significant difference in students' practices of microbial water contamination based on level of study (t = -2.45, df = 179, p = 0.015). Since the p-value is less than 0.05, the null hypothesis is rejected. This implies that students in higher levels

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(300–400 level) demonstrate better water hygiene practices than those in lower levels (100–200 level) in the Federal University of Education, Zaria.

Discussion of Findings

The findings revealed that undergraduate Biology students in FUE, Zaria possessed a moderate level of knowledge regarding microbial water contamination (Grand Mean = 3.13). However, the knowledge level was not exceptionally high, suggesting gaps in deep conceptual understanding. This finding aligns with Abubakar *et al.* (2022), who reported that although university students often demonstrate awareness of environmental health issues, their understanding of microbial processes is sometimes superficial and theoretical rather than applied. The study found that undergraduate Biology students exhibited low-level water safety practices in FUE, Zaria (Grand Mean = 2.38). This finding suggests a clear disconnect between knowledge and actual behaviour. It supports the position of Dreibelbis *et al.* (2018), who observed that awareness of water safety does not automatically translate into improved hygiene practices. Similarly, Mosler (2022) emphasized that environmental health behaviours are influenced more by habit formation, convenience, and environmental constraints than by knowledge alone. The implication is that even in academic environments, students may prioritize accessibility and convenience over safety when making water-related decisions. Another study by Ojo (2018) on handwashing practices among undergraduate students in a Nigerian university revealed poor compliance with standard hygiene and sanitation practices among students, despite awareness of the importance of personal hygiene. The study identified inadequate facilities and poor behavioral orientation as factors responsible for the low level of safe hygiene practices among undergraduates.

Similarly, Igudia and Agbonifoh (2019) investigated sanitation practices among undergraduate students at the University of Benin and found that many students demonstrated inadequate sanitation behaviours and poor environmental hygiene practices within their hostels and learning environment. The study concluded that poor sanitary habits among students could expose them to water-related health risks and environmental hazards. Another related study conducted by Nwadi *et al.* (2023) on hostel sanitation practices among students at the University of Nigeria, Nsukka found that poor sanitation and unhealthy environmental practices negatively affected students' health and wellbeing. The researchers observed that many students failed to adhere to appropriate hygiene and environmental safety practices within their residential environment. In the same vein, Oye *et al.* (2025) reported insufficient sanitation practices among undergraduates in a tertiary institution in Nigeria. The study found inadequate handwashing facilities, poor waste disposal systems, and low adherence to environmental sanitation practices among students. The researchers concluded that poor sanitation behaviour among undergraduates remained a major public health concern in tertiary institutions. These studies therefore support the present finding that undergraduate Biology students demonstrated low-level water safety practices, suggesting that inadequate sanitation culture, poor environmental awareness, infrastructural deficiencies, and weak compliance with safety measures remain prevalent among tertiary institution students in Nigeria. The findings also revealed a moderate positive and significant relationship between knowledge and practices in FUE, Zaria ($r = 0.42$, $p < 0.05$). This result is consistent with the findings of Moyo et al. (2022), who reported a positive relationship between environmental health knowledge and hygiene behaviour among university students. However, the moderate strength of the relationship confirms that knowledge alone is not a strong predictor of behaviour, reinforcing the need for behavioural and environmental interventions.

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The hypothesis tested showed that there was no significant difference in knowledge based on gender in FUE, Zaria ($p = 0.56 > 0.05$). This finding aligns with Adejumo et al. (2021), who reported that gender does not significantly influence environmental health knowledge among tertiary institution students. It implies that academic instruction is equally accessible and effective across genders in transmitting theoretical knowledge. The study revealed a significant difference in practices based on level of study in FUE, Zaria ($p = 0.015 < 0.05$), with higher-level students demonstrating better water hygiene practices than lower-level students. This may be attributed to increased academic exposure, maturity, and awareness gained through advanced coursework and experience in higher levels. This finding is consistent with Bello et al. (2022), who reported that students in higher academic levels tend to adopt better environmental and hygiene practices due to increased exposure to health-related content and life experience.

Conclusion

Based on the findings of this study, it can be concluded that undergraduate Biology students in the Federal University of Education, Zaria possess a moderate level of knowledge of microbial water contamination but demonstrate poor water hygiene practices in their daily lives. Although knowledge was found to have a positive relationship with practices, it was not strong enough to ensure consistent behavioural change. The study further concluded that gender does not significantly influence knowledge of microbial water contamination, while level of study significantly affects students' water hygiene practices. Overall, the study highlights a persistent knowledge–practice gap, indicating that awareness alone is insufficient to guarantee safe water-related behaviours among students.

Recommendations

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

1. Biology curricula should include more practical demonstrations on water treatment, microbial testing, and hygiene practices to bridge the gap between theory and practice.
2. Federal University of Education, Zaria management should ensure consistent provision of safe and treated water across hostels and lecture environments to reduce reliance on unsafe sources.
3. Health promotion campaigns should be introduced to encourage consistent adoption of safe water practices among students, focusing on habit formation rather than awareness alone.
4. Regular seminars, workshops, and outreach programs on microbial water contamination should be organized to reinforce students' knowledge and promote behavioural compliance.
5. Advanced-level Biology students should be engaged as peer educators to mentor lower-level students on safe water practices, leveraging the influence of academic experience.

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Assessment of Sexual Performance-Enhancing Drugs Utilisation among Married Men in Kaduna State, Nigeria

AGBAYEWA, Solomon[1]
gbayewaslomon5@gmail.com
ISMAILA, Ubale Alhaji[1]
Ismailaalhaji48@gmail.com
MOHAMMED, Aliyu[1]
[1]Department of Health Education, Federal University of Education, Zaria, Kaduna State, Nigeria

Abstract

This study assessed the utilisation of Sexual Performance-Enhancing Drugs (SPEDs) among married men in Kaduna State, Nigeria. The study employed a descriptive survey research design, targeting a population of 1,115,974 married men, from which a representative sample of 384 respondents was drawn using a multi-stage sampling technique incorporating cluster, simple random, proportionate, and systematic sampling procedures. Data were collected through a questionnaire validated by experts in the Department of Human Kinetics and Health Education and the College of Medical Sciences, Ahmadu Bello University, Zaria. Reliability was established via a pilot study yielding a Cronbach's Alpha of 0.869. Data analysis employed both descriptive and inferential statistics. Descriptive statistics, including frequency, percentages, mean, and standard deviation were used to describe the socio-demographic characteristics and respond to the research question. One-sample t-test was applied to test the hypothesis at a 0.05 level of significance. Findings revealed that married men in Kaduna State actively utilise SPEDs (t = 34.912, p = 0.000). Based on these findings, the study concluded that the utilisation of SPEDs is prevalent among married men in Kaduna State, with significant concerns regarding patterns of self-medication, informal drug procurement, and limited professional medical consultation. The study recommends counselling by healthcare providers on safe use, alternatives, and the dangers of unprescribed SPED consumption, as well as strengthened regulatory enforcement to curb uncontrolled access to these substances.

Keywords: Sexual Performance-Enhancing Drugs, Utilisation, Married Men, Kaduna State

Introduction

Sexual Performance-Enhancing Drugs (SPEDs) refer to pharmacological agents or substances used with the intent to improve sexual activity, such as enhancing libido, delaying ejaculation, or maintaining penile erection (Salami, Omole, Afolabi & Adeleke, 2021). Utilisation of SPEDs refers to the actual use of such substances, whether prescribed by a qualified medical professional or self-administered outside the formal healthcare system. Among married men, the utilisation of SPEDs has emerged as a notable public health concern, particularly given its implications for individual health, marital well-being, and the broader reproductive health landscape.

Globally, the utilisation of SPEDs has grown into a multi-billion-dollar industry, driven by increasing awareness of sexual health, a rising prevalence of sexual dysfunction, and greater societal openness to discussions about sexual well-being (Moreau, Kågesten & Blum, 2016). The World Health Organization estimates that approximately 322 million men worldwide use various forms of sexual performance enhancers, with annual global sales reaching $6.8 billion in 2023 (WHO, 2023). Martinez, Rodriguez and Thompson (2023) revealed that 15–20% of men aged 40–70 years in Western countries regularly use SPEDs, with usage rates increasing by approximately 3% annually. While prescription medications such as sildenafil and tadalafil dominate the market in developed nations, developing countries show a higher prevalence of traditional and herbal supplement use (Tassew, Assefa, Zeleke & Ferede, 2024). In sub-Saharan Africa, SPED utilisation has witnessed a significant surge, particularly in urban areas. Mkwananzi (2022) reported that approximately 28% of married

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men in sub-Saharan Africa had used SPEDs at least once, with utilisation rates highest in countries such as South Africa (32%), Kenya (27%), and Ghana (25%). Traditional herbal preparations account for 65% of SPEDs used across Africa, raising serious concerns about quality control, standardisation, and safety (Okonkwo & Mensah, 2023). These patterns reflect the complex interplay of cultural beliefs, economic factors, and healthcare accessibility in shaping utilisation behaviour. In Nigeria, the situation is particularly concerning. Recent studies indicate that 35% of married men in urban areas had used SPEDs as of 2022 (Adebayo, Ogunwale & Ismail, 2023). The National Drug Law Enforcement Agency (NDLEA) reported a 40% increase in SPED seizures between 2021 and 2023, pointing to a rapidly expanding black market for these substances (Adejoro, 2023). Hospital records further documented a 25% rise in SPED-related health complications over the same period (Adejoro, 2023), reflecting the growing public health burden associated with unsafe utilisation practices. Studies have also revealed that 42% of users obtain these drugs without a prescription, while 38% rely on peer recommendations rather than professional medical advice, further compounding the risks (Olatunji & Mohammed, 2023).

Utilisation patterns of SPEDs among married men are shaped by a range of socio-demographic, cultural, and psychological factors. Age is a particularly significant determinant, with men aged 45–60 years demonstrating the highest usage rates at 45%, compared to 28% among younger age groups (Okoro, Adams & Peters, 2023). Older men, who are more likely to experience age-related sexual dysfunction such as erectile dysfunction, tend to have correspondingly higher utilisation rates (Okafor, Umeh & Ani, 2022). Despite this, educational attainment shows less consistent variation in utilisation rates across levels, suggesting that access, peer influence, and cultural norms may exert a stronger influence on actual drug use than educational background alone (Ahmed & Wilson, 2023).

The consequences of unsafe SPED utilisation are well-documented. Kukoyi et al. (2022), in a multi-centre study conducted across six Nigerian states, found that 55% of SPED users had experienced adverse effects, yet only 30% sought professional medical assistance. Bello, Yusuf and Ibrahim (2023) identified peer influence, media exposure, and perceived benefits as the primary drivers of SPED use among Nigerian men. These findings reveal a deeply entrenched culture of self-medication and informal drug procurement that poses significant risks to individual and public health. Adverse outcomes include cardiovascular complications, psychological dependence, hormonal disruption, and dangerous drug interactions, particularly when SPEDs are combined with alcohol or other medications. Governmental and non-governmental efforts to regulate SPED utilisation and promote safer drug use behaviour have been ongoing in Nigeria. Regulatory bodies such as the NDLEA and the National Agency for Food and Drug Administration and Control (NAFDAC) have implemented drug control measures and public sensitisation campaigns. Healthcare facilities have also introduced counselling services for sexual health concerns. However, these efforts have been constrained by inadequate enforcement mechanisms, cultural stigma surrounding male sexual health, limited male-focused reproductive health education programmes, and unequal access to healthcare services across urban and rural populations. There remains, however, a significant gap in context-specific empirical data on SPED utilisation patterns among married men in Kaduna State, Nigeria, and on how socio-demographic factors moderate these patterns. Kaduna State's diverse population, characterised by varying educational levels, occupational categories, religious affiliations, and urban–rural distributions, offers a particularly rich context for examining differential utilisation behaviour. Without such data, it is difficult for health authorities and policymakers to design targeted and effective interventions that address the specific drivers of unsafe SPED use in this population.

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In an ideal public health context, the utilisation of SPEDs by married men should be guided by formal medical consultation, accurate diagnosis of underlying sexual health conditions, and adherence to prescribed dosage and safety guidelines. Usage decisions should be informed by evidence-based medical advice and should consider relevant comorbidities such as cardiovascular disease, diabetes, and hypertension. However, the prevailing reality in many parts of Nigeria, including Kaduna State, reflects widespread informal and unregulated SPED procurement and use, driven by cultural pressures, social expectations of male sexual performance, economic factors, and inadequate access to sexual health services. This study is therefore designed to address this gap by providing a rigorous, empirically grounded assessment of the utilisation of sexual performance-enhancing drugs among married men in Kaduna State, Nigeria. The findings are intended to generate actionable evidence that will support the development of targeted public health interventions, strengthen drug regulatory frameworks, and guide healthcare providers in delivering more effective counselling and treatment services to this population.

Purpose of the Study

The purpose of the study is to assess the utilisation of sexual performance-enhancing drugs among married men in Kaduna State, Nigeria.

Research Question

What is the utilisation of sexual performance-enhancing drugs among married men in Kaduna State, Nigeria?

Hypothesis

Utilisation of sexual performance-enhancing drugs among married men in Kaduna State, Nigeria is not significant.

Methodology

This study adopted the descriptive survey research design. The target population consisted of all married men in Kaduna State, Nigeria, numbering one million, one hundred and fifteen thousand, nine hundred and seventy-four (1,115,974) (Kaduna State Bureau of Statistics, 2019). Based on the recommendation of the Research Advisor (2006), a sample of 384 respondents was considered adequate to represent this population at a 95% confidence level with a 0.05 margin of error. Respondents were selected through a multi-stage sampling procedure. First, cluster sampling was used to categorise the married men into the three senatorial zones of Kaduna State: Kaduna Central, Kaduna North, and Kaduna South. Second, simple random sampling was employed to select two LGAs from each senatorial zone: Kaduna North and Giwa from Kaduna Central; Makarfi and Sabon-Gari from Kaduna North; and Jema'a and Kauru from Kaduna South. Third, proportionate sampling was applied to determine the number of respondents from each LGA relative to their population. Fourth, a systematic sampling approach was employed, beginning from the house adjacent to the LGA secretariat and selecting every 11th house until the required sample was achieved.

A researcher-developed questionnaire titled "Assessment of Utilisation of Sexual Performance-Enhancing Drugs among Married Men Questionnaire (AUSPEDMMQ)" was used for data collection. The questionnaire, which contained 15 items assessing the utilisation of sexual performance-enhancing drugs, was the primary tool. Responses were rated on a four-point modified Likert scale as: Always (A) = 4, Often (O) = 3, Sometimes (S) = 2, and Never (N) = 1. A mean aggregate score of 2.50 and above was considered indicative of positive utilisation, while scores below 2.50 were regarded as negative or non-utilisation. The questionnaire, which also captured demographic characteristics (age, educational qualification, occupation, monthly income, and religion) using 5

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items, was also administered to profile the respondents. The validity of the instrument was established by submitting copies of the questionnaire to five (5) subject matter experts from the Department of Human Kinetics and Health Education and the College of Medicine, Ahmadu Bello University, Zaria. The experts assessed the instrument for face and content validity to ensure it measured the intended construct of drug utilisation, and their feedback was incorporated into the final version. A pilot study involving 20 respondents from Zaria Local Government Area was conducted to assess the reliability of the instrument. Using the split-half method, the internal consistency of the instrument was calculated through Cronbach's Alpha, yielding a coefficient of .869. In line with Kerlinger (2016), this value, being appreciably closer to 1 than to 0, confirmed that the instrument was sufficiently reliable for the study. After an introductory letter from the Head of the Department of Human Kinetics and Health Education, Ahmadu Bello University, Zaria, the researcher presented the letter to the Directors of Health in the selected LGAs to gain access to the respondents. Four (4) trained research assistants supported the researcher in administering the questionnaire at respondents' homes. The assistants helped to clarify ambiguous items and provided translations where required. All completed questionnaires were retrieved on-site over a six (6)-week period. The collected data were processed using SPSS version 29. Descriptive statistics, comprising frequency counts and simple percentages, were used to describe demographic characteristics. Mean and standard deviation were employed to answer the research question. A one-sample t-test was applied to test the corresponding hypothesis at the 0.05 level of significance.

Presentation of Results

All data collected on demographic characteristics of the respondents were tabulated using frequencies and percentages as indicated in Table 1.

Table 1: Demographic Characteristics of the Respondents

Variables	Options	Frequency	Percentage (%)
Age Range in Years	Below 30	76	19.8
	31 – 40	127	33.1
	41 – 50	114	29.7
	Above 50	67	17.4
	Total	**384**	**100.0**
Educational Qualification	Non-formal	71	18.5
	Primary	82	21.3
	Secondary	107	27.9
	Tertiary	124	32.3
	Total	**384**	**100.0**
Occupation	Farmer	113	26.4
	Civil Servant	101	26.3
	Artisan	77	20.1
	Business	93	24.2
	Total	**384**	**100.0**
Monthly Income	less than #50,000	57	14.8
	#51,000- #100,000	92	24.0
	#101,000-#150,000	103	26.8
	Above #150,000	132	34.4
	Total	**384**	**100.0**
Religion	Islam	239	62.2
	Christianity	145	37.8
	Total	**384**	**100.0**

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Table 1 revealed the demographic characteristics of the respondents. The age distribution of the respondents indicated that the majority were between 31 and 40 years old, accounting for 127 (33.1%), followed by those aged 41–50 years, representing 29.7% (114). Respondents below 30 years constituted 19.8% (76), while those above 50 years were the least represented at 17.4% (67). Regarding educational qualification, the largest proportion of respondents had attained tertiary education, making up 32.3% (124), while 27.9% (107) had completed secondary education. Primary education holders accounted for 21.3% (82), and those with non-formal education constituted 18.5% (71). In terms of occupation, farmers represented the largest group at 26.4% (113 respondents), closely followed by civil servants at 26.3% (101). Businessmen accounted for 24.2% (93), while artisans formed the smallest group at 20.1% (77). Analysis of monthly income revealed that the highest proportion of respondents earned above #150,000, representing 34.4% (132), followed by those earning between #101,000 and #150,000 at 26.8% (103). Respondents with a monthly income of #51,000–#100,000 constituted 24.0% (92), while those earning less than #50,000 were 14.8% (57). Regarding religious affiliation, the majority of respondents were Muslims, comprising 62.2% (239), whereas Christians accounted for 37.8% (145).

Research Question: What is the utilisation of sexual performance-enhancing drugs among married men in Kaduna State, Nigeria?

Table 2: Mean Scores of Responses on utilisation of sexual performance-enhancing drugs among married men in Kaduna State, Nigeria

S/N	Item	Mean	Std Dev
1.	I use sexual performance-enhancing drugs before engaging in sexual activity.	3.51	0.96
2.	I rely on performance-enhancing drugs to maintain an erection during intercourse.	2.56	0.85
3.	I use sexual performance-enhancing drugs to prolong sexual activity.	3.42	0.78
4.	I purchase sexual performance-enhancing drugs from pharmacies or herbal stores.	3.37	0.81
5.	I use herbal sexual performance enhancers.	2.62	0.82
6.	I consume alcohol or other substances alongside sexual performance-enhancing drugs.	2.67	0.90
7.	I increase the dosage of sexual performance-enhancing drugs beyond the recommended amount.	2.59	0.90
8.	I experience side effects (e.g., headaches, dizziness, or palpitations) after using sexual performance-enhancing drugs.	2.57	0.87
9.	I use sexual performance-enhancing drugs without consulting a medical professional.	3.29	0.96
10.	I mix different brands or types of sexual performance-enhancing drugs.	3.05	0.98
11.	I use sexual performance-enhancing drugs due to peer influence.	3.13	0.91
12.	I take sexual performance-enhancing drugs due to concerns about sexual performance dissatisfaction from my spouse.	3.40	0.93
13.	I use sexual performance-enhancing drugs due to stress or fatigue.	2.52	0.92
14.	I use sexual performance-enhancing drugs because of advertisements or media influence.	2.54	0.88
15.	I use sexual performance-enhancing drugs despite being aware of their potential health risks.	3.32	0.93
	Aggregate	**2.97**	

(Decision Mean – 2.50)

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The analysis of Table 2 revealed the utilisation patterns of sexual performance-enhancing drugs among married men in Kaduna State, Nigeria. The highest mean score (3.51) was observed for the item "I use sexual performance-enhancing drugs before engaging in sexual activity," suggesting that most respondents frequently used these drugs before sexual encounters. Similarly, respondents reported using sexual performance-enhancing drugs to prolong sexual activity (mean = 3.42) and due to concerns about sexual performance dissatisfaction from their spouse (mean = 3.40), highlighting performance-related motivations as key drivers of utilisation. Other notable responses included using these drugs without consulting a medical professional (mean = 3.29), using them despite awareness of potential health risks (mean = 3.32), and being influenced by peers (mean = 3.13). Conversely, lower mean scores were reported for items related to reliance on these drugs to maintain an erection during intercourse (mean = 2.56), using herbal enhancers (mean = 2.62), consuming alcohol or other substances alongside the drugs (mean = 2.67), and increasing dosages beyond recommended amounts (mean = 2.59), suggesting that these practices were less common among the respondents. With an aggregate mean of 2.97, which was above the decision mean of 2.50, the findings indicated that married men in Kaduna State utilised sexual performance-enhancing drugs, primarily for enhancing sexual performance, addressing partner-related expectations, and personal satisfaction, often without medical supervision.

Hypothesis: Utilisation of sexual performance-enhancing drugs among married men in Kaduna State, Nigeria is not significant.

Table 3: One-Sample t-test Analysis on Utilisation of sexual performance-enhancing drugs among married men in Kaduna State, Nigeria

Variable	N	Mean	Std. Dev.	df	t-value	p-value
Utilisation	384	2.97	0.81	383	34.912	0.000
Test Mean	384	2.50	0.00			

Calculated p < 0.05, calculated t-value > 1.972 at df 383

The one-sample t-test analysis presented in Table 3 examined whether the utilisation of sexual performance-enhancing drugs among married men in Kaduna State, Nigeria, was significantly different from the test mean of 2.50. The results showed that the mean utilisation score of the respondents was 2.97, which was higher than the test mean. The calculated t-value was 34.912 with 383 degrees of freedom, and the corresponding p-value was 0.000, which was less than the 0.05 significance level. Since the calculated t-value exceeded the critical t-value of 1.972 at 383 degrees of freedom and the p-value was below 0.05, the null hypothesis that the utilisation of sexual performance-enhancing drugs among married men was not significant was rejected. This indicated that the utilisation of these drugs among the respondents was statistically significant, suggesting that married men in Kaduna State actively utilise sexual performance-enhancing drugs

Discussion of Finding

The study revealed that utilisation of sexual performance-enhancing drugs among married men in Kaduna State, Nigeria is significant (t = 34.912, p = 0.000). This implies that married men in Kaduna State, Nigeria utilise sexual performance-enhancing drugs. This result corroborates the findings of Adamu et al. (2022), who reported a high prevalence of aphrodisiac use (67.6%) among the adult population in Sokoto metropolis, Nigeria, with 46.2% having used these substances within the past month. Similarly, Wada et al. (2023) found a prevalence of 64% for traditional medicine use as sexual enhancers among adults in northern Nigeria. The current finding also validates the work of Adadow, Shamsu-Deen and Azusiyinne (2018), who documented widespread use of sex-enhancement drugs among men in the Tamale metropolis, Ghana. Furthermore, Manortey, Mensah and Acheampong

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(2018) reported that 52.6% of adult males in the Ashaiman Municipality of Ghana had used aphrodisiacs at some point in their lives. These convergent findings across multiple West African contexts suggest that the utilisation of sexual performance-enhancing drugs is a prevalent phenomenon in the region, transcending national boundaries and confirming that married men in Kaduna State are part of a broader regional pattern of sexual enhancement drug use. The current finding is further supported by studies from other African countries and cultural contexts. Amoah, Adjei and Arthur-Holmes (2022) reported that approximately 12.6% of participants in Ghana (17.6% among males) had used an aphrodisiac in the six months before their study, with having multiple sexual partners being positively associated with use among men. Danquah et al. (2011) found that 61% of males in a Kumasi, Ghana community were using sexual performance-enhancing drugs, with the majority claiming effectiveness. Ango et al. (2021) documented high utilisation among married women in Sokoto, with 85% of those aware of sexual stimulants reporting use, primarily to satisfy their spouses. These findings collectively validate the current study's result that utilisation is significant, suggesting that sexual performance-enhancing drug use is not limited to any single demographic group but is widespread across gender, marital status, and geographical locations within West Africa. The consistency across these studies strengthens the evidence that married men in Kaduna State are actively utilising these substances.

However, some studies present findings that appear to contradict or provide lower utilisation rates compared to the current study's results. Kidake, Nyamongo and Wanzala (2020) found that among male undergraduates at Jomo Kenyatta University in Kenya, only 10% had used erectile dysfunction medications and/or sexual enhancers, despite 82.9% having heard about them. Similarly, Kidake (2022) reported the same 10% utilisation rate among youth in the same institution. Wright (2009) found that among 82 male college students in the United States, only 16 reported having used sexual enhancement drugs. These lower rates can be attributed to the specific populations studied, unmarried university students and younger age groups, compared to the current study's focus on married men. The difference may reflect age-related sexual concerns, marital expectations, and cultural pressures that are more pronounced among married men than among younger, unmarried populations. Additionally, Ahmed et al. (2017) reported a 39.9% utilisation rate among sexually active Saudi Arabian men, which, while substantial, is lower than what might be implied by the highly significant t-value in the current study. These variations suggest that while utilisation is widespread, rates may differ based on population characteristics, cultural context, and definitional parameters of what constitutes sexual performance-enhancing drugs.

The current finding also resonates with studies that have examined the broader context of sexual enhancement drug utilisation. Bassey and Fajemirokun (2023) revealed that over-the-counter sales of male sexual enhancement products are a common practice among community pharmacists in Ogun State, Nigeria, with most respondents selling these products daily without prescriptions, a finding that supports the accessibility and consequently high utilisation reported in the current study. Ibrahim and Zango (2021) demonstrated that age and education were influential factors in sex stimulant use in metropolitan Kano, implying significant utilisation rates that vary by demographic characteristics. Akinyemi (2017) found that 20.3% of commercial drivers in Ile-Ife used herbal mixtures for sexual performance enhancement, with worrying about sexual performance being a predictor of use. The consistency of these findings with the current study underscores that sexual performance-enhancing drug utilisation among Nigerian men, particularly married men, is not only significant but is facilitated by easy accessibility, diverse motivations, and socio-cultural factors that normalise such practices. Based on the preponderance of evidence from previous

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studies, the researcher agrees that married men in Kaduna State make use of sexual performance-enhancing drugs. The convergence of findings across multiple studies, particularly in northern Nigeria, provides validation for this result. While some studies show lower utilisation rates among younger, unmarried populations, these differences are attributable to demographic and contextual variations rather than contradictions to the current finding. The researcher posits that the significant utilisation observed reflects broader sociocultural dynamics in West Africa, where sexual performance is linked to masculinity, marital satisfaction, and social status, and where easy accessibility through informal channels facilitates widespread use.

Conclusions

Based on the findings of the study, the study concluded that married men in Kaduna State, Nigeria utilise sexual performance-enhancing drugs.

Recommendations

Based on the conclusion, the study recommended that healthcare providers should counsel married men on safe usage, potential risks, and alternatives to reduce misuse.

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Influence of Lecturers' Perception, Attitude and Awareness on application of 21st-Century Skills on Students' Civic Competence among Public Universities in South-South, Nigeria

EGUAGIE, Osagie
osagie.eguagie@uniben.edu
Department of Curriculum and Instructional Technology, Faculty of Education, University of Benin, Benin City, Nigeria

Abstract
The purpose of this study was to examine the application of 21st-century skills and students' civic competence in universities in South-South Nigeria. The study adopted a descriptive survey research design. Three hypotheses guided the study and were tested at a 0.05 level of significance. The population comprised 114 Social Studies lecturers in universities in South-South Nigeria. A census sampling technique was adopted, meaning that all 114 lecturers were used as respondents for the study. Data were collected using a structured questionnaire titled Application of 21st-Century Skills and Students' Civic Competence Questionnaire (ATCSSCCQ) developed by the researcher. The instrument consisted of items rated on a four-point Likert scale of Strongly Agree (SA), Agree (A), Disagree (D), and Strongly Disagree (SD). Face and content validity were established by three experts from the University of Delta, Agbor, Nigeria. Reliability was determined using the test–retest method with 25 lecturers from a university outside the study area, yielding a Pearson Product Moment Correlation coefficient of 0.82. Data were analyzed using simple linear regression analysis at the 0.05 level of significance. Findings revealed that teachers' perception, attitude, and awareness of the application of 21st-century skills significantly influence students' civic competence in universities in South-South Nigeria. The study concluded that lecturers' perception, attitude, and awareness are important determinants of students' civic competence development. The study recommended that university authorities and policymakers should organize regular training programmes to enhance lecturers' perception, attitude, and awareness of 21st-century skills, encourage lecturers to adopt positive instructional dispositions, and strengthen awareness campaigns to promote effective application of 21st-century skills in teaching.

Keywords: 21st-century skills, lecturers' perception, lecturers' attitude, lecturers' awareness, civic competence, university education

Introduction
In higher education, lecturers play a crucial role in determining the quality and effectiveness of instructional delivery, particularly in Social Studies-related disciplines aimed at producing knowledgeable, responsible, and civically engaged graduates. The concept of 21st-century skills in this context refers to a structured set of learning competencies such as critical thinking, collaboration, communication, creativity, digital competence, and civic literacy—that prepare students for participation in modern democratic and knowledge-based societies. From a contextual standpoint, these skills represent a shift from traditional memorization-based teaching to active, participatory, and skill-driven learning. In line with this, Oluwagbohunmi and Alonge (2023) found that Social Studies instruction becomes more effective when knowledge is combined with practical civic competencies such as the 4Cs and digital literacy. Similarly, Saleh et al. (2022) reported that ICT-based civic education improves students' civic engagement by enabling them to apply knowledge in real-life situations. Synthesizing these findings, it can be inferred that the researcher views 21st-century skills as essential tools for transforming Social Studies classrooms into active civic learning environments that strengthen students' democratic participation. 21st-century skills are broadly understood as an integrated set of knowledge, abilities, attitudes, and competencies required for success in contemporary academic, social, and professional environments. Contextually, these skills

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represent the alignment of cognitive abilities (such as problem-solving), social abilities (such as teamwork), and technological abilities (such as digital literacy) within a learner-centered educational system. In Social Studies, this means blending civic knowledge, civic skills, and civic attitudes to enable meaningful societal participation. Oluwagbohunmi and Alonge (2023) found that effective Social Studies teaching requires merging theoretical knowledge with practical civic engagement skills. Likewise, Jayadiputra et al. (2023) revealed that a 21st-century curriculum enhances civic competence by integrating knowledge, skills, and attitudes into a unified learning process. Furthermore, Saleh et al. (2022) and Hidayah et al. (2024) showed that ICT integration promotes digital citizenship and real-world problem-solving. From the researcher's perspective, these findings suggest that 21st-century skills should be viewed as a holistic educational framework that connects classroom learning with real civic life.

Civic competence refers to the ability of individuals to understand civic concepts, demonstrate civic values, and participate responsibly in democratic and community activities. In contextual terms, it represents the practical manifestation of citizenship education through active engagement, critical awareness of societal issues, and responsible decision-making. It combines knowledge of governance, civic skills such as participation, and civic attitudes such as responsibility and tolerance. Medne et al. (2024) found that civic competence improves when students demonstrate understanding of democratic principles and engage in structured civic learning. Similarly, Celume and Maoulida (2022) reported that experiential and online civic programs enhance students' global citizenship skills. In addition, Azim and Kusuma (2025) and Jayadiputra et al. (2023) emphasized that collaborative and technology-enhanced learning environments significantly strengthen civic competence. Civic competence is therefore not theoretical knowledge alone but a lived capacity for democratic participation and social responsibility.

Lecturers' perception of the application of 21st-century skills refers to how educators interpret, understand, and value modern instructional competencies such as digital literacy, collaboration, and civic engagement. Contextually, perception reflects the cognitive lens through which teachers evaluate whether these skills are relevant, practical, and beneficial for classroom use. Positive perception often leads to instructional innovation, while negative perception results in resistance to change. Saleh et al. (2022) found that ICT-based civic education improves students' civic engagement when teachers perceive it as meaningful and integrate it into instruction. Similarly, Bilgin (2024) reported that positive learner and teacher perceptions of digital and civic competencies enhance engagement in learning activities. Teacher perception may act as the gateway variable that determines whether 21st-century skills will be successfully implemented in classroom practice.

Lecturers' attitude toward the application of 21st-century skills refers to their beliefs, feelings, and readiness to adopt innovative teaching strategies. Contextually, attitude represents the psychological orientation of teachers toward educational change, including their willingness to shift from traditional methods to learner-centered and technology-driven approaches. Hidayah et al. (2024) found that collaborative learning significantly improves civic skill development when teachers show positive attitudes toward modern pedagogy. Similarly, Guerrero Elecalde et al. (2024) reported that teachers' civic and pedagogical attitudes strongly influence students' civic competence development. In addition, Saputra and Abdulkarim (2022) and Celume and Maoulida (2022) showed that positive attitudes toward technology integration enhance critical thinking and civic responsibility. Lecturers attitude could be a determining factor that shapes the effectiveness of 21st-century skill

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implementation in Social Studies classrooms. Lecturers' awareness of 21st-century skills refers to their level of knowledge and understanding of modern educational competencies, including civic literacy, digital competence, and collaborative teaching strategies. Contextually, awareness represents the foundational cognitive readiness required for effective instructional planning and implementation. Without awareness, even positive perception or attitude may not translate into practice. Saleh et al. (2022) found that awareness of ICT-based civic education improves teaching effectiveness and student engagement. Similarly, Hidayah et al. (2024) reported that awareness of 21st-century learning strategies enhances students' digital and civic competencies. Furthermore, Damayanti and Khairunisa (2024) and Medne et al. (2024) emphasized that awareness of civic participation frameworks enables teachers to develop students' critical thinking and civic engagement skills. Awareness might serve as the foundational driver that enables effective application of 21st-century teaching practices. Civic competence, as the dependent variable in this study, refers to students' ability to understand civic concepts, demonstrate civic values, and apply civic skills in real-life social and political contexts. Contextually, it reflects the outcome of effective civic education, where learners move from passive knowledge acquisition to active civic participation. It includes democratic awareness, social responsibility, and engagement in community development. Azim and Kusuma (2025) found that civic competence improves when students are engaged in 21st-century skill-based learning environments. Similarly, Jayadiputra et al. (2023) reported that integrated curriculum models significantly enhance civic knowledge, skills, and attitudes. In addition, Handayani et al. (2023) and Hidayah et al. (2024) showed that blended and collaborative learning approaches improve civic engagement and participation. Civic competence is the ultimate educational outcome that reflects the effectiveness of teaching practices and curriculum implementation.

Despite the importance of 21st-century skills in civic education, many higher education institutions still struggle with effective implementation. Contextually, this challenge arises from gaps in teacher preparation, limited ICT infrastructure, resistance to pedagogical change, and inadequate professional development. Kabatiah et al. (2024) found that teachers often lack sufficient pedagogical competence to implement 21st-century skills effectively. Similarly, Saputra and Abdulkarim (2022) reported that weak integration of civic education tools limits student skill development. Furthermore, Muir (2022) and Ayanwale et al. (2025) observed that deficiencies in teacher perception, attitude, and awareness reduce the effectiveness of instructional innovation. These challenges indicate a persistent gap between policy expectations and classroom realities. In South-South Nigeria, the integration of 21st-century skills into university-level Social Studies and civic education remains inconsistent. Contextually, while curriculum reforms emphasize innovation, actual classroom implementation is influenced by institutional capacity and teacher-related factors. Oktam et al. (2025) found that inconsistencies in instructional delivery are linked to differences in teacher preparedness and understanding of modern pedagogy. Similarly, Yulin and Danso (2025) reported that teacher-related variables significantly influence the effectiveness of instructional innovation in higher education. This inconsistency suggests that student civic competence in the region is largely dependent on how individual lecturers perceive, understand, and apply 21st-century skills. Therefore, this study seeks to examine the application of 21st-century skills and students' civic competence in universities in South-South Nigeria. Specifically, it investigates how lecturers' perception, attitude, and awareness of 21st-century skills influence students' civic competence in higher education contexts

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Research Objectives

The following objectives guided the study:

1. To examine the influence of lecturers perception of the application of 21st-century skills on students' civic competence in universities in South-South Nigeria.
2. To determine the influence of lecturers' attitude toward the application of 21st-century skills on students' civic competence in universities in South-South Nigeria.
3. To assess the influence of lecturers' awareness of the application of 21st-century skills on students' civic competence in universities in South-South Nigeria.

Research Questions

1. What is the influence of lecturers' perception of the application of 21st-century skills on students' civic competence in universities in South-South Nigeria?
2. What is the influence of lecturers' attitude toward the application of 21st-century skills on students' civic competence in universities in South-South Nigeria?
3. What is the influence of lecturers' awareness of the application of 21st-century skills on students' civic competence in universities in South-South Nigeria?

Hypotheses

The following hypotheses were tested at 0.05 level of significance:

1. Lecturers' perception of the application of 21st-century skills has no significant influence on students' civic competence in universities in South-South Nigeria.
2. Lecturers' attitude toward the application of 21st-century skills has no significant influence on students' civic competence in universities in South-South Nigeria.
3. Lecturers' awareness of the application of 21st-century skills has no significant influence on students' civic competence in universities in South-South Nigeria.

Methodology

This study adopted a descriptive survey research design. The design was considered appropriate because it enabled the researcher to collect data from respondents and examine the influence of teachers' application of 21st-century skills variables on students' civic competence in universities in South-South Nigeria without manipulating any of the variables. The population of the study comprised 114 Social Studies lecturers in universities in South-South Nigeria. Due to the relatively small and manageable size of the population, a census sampling technique was adopted. This implies that all the 114 lecturers were used as respondents for the study, thereby eliminating sampling error and ensuring complete representation of the target population. The instrument used for data collection was a structured questionnaire developed by the researcher titled *Application of 21st-Century Skills and Students' Civic Competence Questionnaire (ATCSSCCQ)*. The instrument was designed to elicit information on teachers' perception, attitude, and awareness of the application of 21st-century skills, as well as students' civic competence. The questionnaire consisted of items structured on a four-point rating scale of Strongly Agree (SA), Agree (A), Disagree (D), and Strongly Disagree (SD), weighted 4, 3, 2, and 1 respectively. To ensure the validity of the instrument, the questionnaire was subjected to face and content validation by three experts. These included two lecturers in Social Science Education and one lecturer in Measurement and Evaluation from the University of Delta, Agbor, Nigeria. Their comments and suggestions helped to refine the instrument by removing ambiguous items and ensuring that the items adequately measured the variables of the study. The corrections provided by the experts were incorporated into the final version of the instrument before administration. The reliability of the instrument was established using the test–retest method. The questionnaire was administered to 25 Social Studies lecturers in a university

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outside the study area. After an interval of two weeks, the same instrument was re-administered to the same respondents. The two sets of scores obtained were correlated using the Pearson Product Moment Correlation, which yielded a reliability coefficient of 0.82, indicating that the instrument was reliable and consistent for data collection. Data for the study were collected by the researcher with the assistance of trained research assistants. Prior to data collection, permission was obtained from the relevant university authorities. The respondents were assured of confidentiality and informed that the information provided would be used strictly for academic purposes. The questionnaires were distributed and retrieved within an agreed period to ensure a high response rate. The data collected were analyzed using simple linear regression analysis to test the hypotheses at the 0.05 level of significance.

Hypothesis 1: Lecturers' perception of the application of 21st-century skills does not significantly influence students' civic competence in universities in South-South Nigeria.

Table 1: Regression Analysis of Lecturers**' Perception of 21st-Century Skills and Students' Civic Competence**

Std. Error of the Estimate = 2.100 Adjusted R Square = 0.196 R Square = 0.203 R = 0.450

Model	Sum of Squares	df	Mean Square	F	Sig
Regression	240.000	1	240.000	28.361	0.000
Residual	948.000	112	8.464		
Total	1188.000	113			

Coefficients

Model	Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (Beta)	t	Sig
(Constant)	16.800	1.020		16.471	0.000
Lecturers' Perception	0.373	0.070	0.450	5.333	0.000

Table 1 presents the regression analysis of lecturers' perception of the application of 21st-century skills and students' civic competence in universities in South-South Nigeria. The result shows an F-value of 28.361 and a p-value of 0.000. Testing the hypothesis at an alpha level of 0.05, the p-value of 0.000 is less than the alpha level of 0.05. Therefore, the null hypothesis which states that teachers' perception of the application of 21st-century skills does not significantly influence students' civic competence in universities in South-South Nigeria is rejected. This finding implies that teachers' perception significantly influences students' civic competence in universities in South-South Nigeria. The R-square value of 0.203 indicates that 20.3% of the variance in students' civic competence is explained by teachers' perception, while the remaining 79.7% may be attributed to other variables not included in the model. Furthermore, the unstandardized coefficient (B) for teachers' perception is 0.373, indicating that a unit increase in teachers' perception would lead to a 0.373 increase in students' civic competence. The standardized coefficient (Beta) of 0.450 with t = 5.333 indicates a moderate positive predictive influence. Therefore, lecturers' perception of the application of 21st-century skills significantly predicts students' civic competence in universities in South-South Nigeria at the 0.05 level of significance.

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Hypothesis 2: Lecturers' attitude toward the application of 21st-century skills does not significantly influence students' civic competence in universities in South-South Nigeria.

Table 2: Regression Analysis of Lecturers' Attitude and Students' Civic Competence

Std. Error of the Estimate = 2.180 Adjusted R Square = 0.144 R Square = 0.152 R = 0.390

Model	Sum of Squares	df	Mean Square	F	Sig
Regression	182.400	1	182.400	20.069	0.000
Residual	1017.600	112	9.086		
Total	1200.000	113			

Coefficients

Model	Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (Beta)	t	Sig
(Constant)	18.240	1.080		16.889	0.000
Lecturers' Attitude	0.358	0.080	0.390	4.480	0.000

Table 2 presents the regression analysis of lecturers' attitude toward the application of 21st-century skills and students' civic competence in universities in South-South Nigeria. The result shows an F-value of 20.069 and a p-value of 0.000. Testing the hypothesis at an alpha level of 0.05, the p-value of 0.000 is less than the alpha level of 0.05. Therefore, the null hypothesis which states that teachers' attitude toward the application of 21st-century skills does not significantly influence students' civic competence in universities in South-South Nigeria is rejected. This finding implies that lecturers' attitude significantly influences students' civic competence in universities in South-South Nigeria. The R-square value of 0.152 indicates that 15.2% of the variance in students' civic competence is explained by teachers' attitude, while the remaining 84.8% may be attributed to other variables not included in the model. Furthermore, the unstandardized coefficient (B) for teachers' attitude is 0.358, indicating that a unit increase in teachers' attitude would lead to a 0.358 increase in students' civic competence. The standardized coefficient (Beta) of 0.390 with t = 4.480 indicates a moderate positive predictive influence. Therefore, lecturers' attitude toward the application of 21st-century skills significantly predicts students' civic competence in universities in South-South Nigeria at the 0.05 level of significance.

Hypothesis 3: Lecturers' awareness of the application of 21st-century skills does not significantly influence students' civic competence in universities in South-South Nigeria.

Table 3: Regression Analysis of Lecturers' Awareness and Students' Civic Competence

Std. Error of the Estimate = 2.120 Adjusted R Square = 0.168 R Square = 0.176 R = 0.420

Model	Sum of Squares	df	Mean Square	F	Sig
Regression	210.000	1	210.000	23.906	0.000
Residual	984.000	112	8.786		
Total	1194.000	113			

Coefficients

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Model	Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (Beta)	t	Sig
(Constant)	17.500	1.050		16.667	0.000
Lecturers' Awareness	0.367	0.075	0.420	4.889	0.000

Table 3 presents the regression analysis of lecturers' awareness of the application of 21st-century skills and students' civic competence in universities in South-South Nigeria. The result shows an F-value of 23.906 and a p-value of 0.000. Testing the hypothesis at an alpha level of 0.05, the p-value of 0.000 is less than the alpha level of 0.05. Therefore, the null hypothesis which states that lecturers' awareness of the application of 21st-century skills does not significantly influence students' civic competence in universities in South-South Nigeria is rejected. This finding implies that lecturers' awareness significantly influences students' civic competence in universities in South-South Nigeria. The R-square value of 0.176 indicates that 17.6% of the variance in students' civic competence is explained by teachers' awareness, while the remaining 82.4% may be attributed to other variables not included in the model. Furthermore, the unstandardized coefficient (B) for teachers' awareness is 0.367, indicating that a unit increase in lecturers' awareness would lead to a 0.367 increase in students' civic competence. The standardized coefficient (Beta) of 0.420 with t = 4.889 indicates a moderate positive predictive influence. Therefore, lecturers' awareness of the application of 21st-century skills significantly predicts students' civic competence in universities in South-South Nigeria at the 0.05 level of significance.

Discussion

The findings of this study revealed that lecturers' perception of the application of 21st-century skills significantly influences students' civic competence in universities in South-South Nigeria. This implies that when lecturers positively perceive and understand the application of 21st-century skills such as critical thinking, collaboration, communication, and creativity, they are more likely to integrate these competencies into their instructional practices, thereby enhancing students' civic competence. The regression result showed a significant positive predictive relationship, indicating that teachers' perception plays an important role in shaping students' civic understanding and participation. This finding is consistent with Coutinho (2024), who reported that teachers' perception of instructional approaches significantly influences students' learning decisions and engagement in higher education contexts. Similarly, Ribau (2025) found that students' academic and civic-related outcomes are strongly shaped by teachers' instructional perceptions and classroom practices, emphasizing that perception-driven teaching strategy improve student development. These findings suggest that teachers' perception of educational competencies is a key determinant of students' civic competence development. The study also found that lecturers' attitude toward the application of 21st-century skills significantly influences students' civic competence in universities in South-South Nigeria. This suggests that lecturers who demonstrate positive attitudes toward modern instructional approaches are more likely to adopt innovative teaching strategies that foster civic awareness, responsibility, and participation among students. The regression analysis revealed a significant positive relationship, indicating that lecturers' attitude contributes meaningfully to students' civic development. This finding aligns with Lituhayu, Rahman, and Muluk (2023), who reported that attitude significantly influences students' behavioural intentions and learning outcomes in educational settings. Similarly, Alsaeedi (2023) found that teachers' attitudes and instructional dispositions significantly affect students' academic habits and engagement levels, showing that positive teacher attitudes enhance student learning outcomes. These findings imply that teachers' positive attitude toward 21st-century skills is essential for improving students' civic competence.

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Furthermore, the findings revealed that lecturers' awareness of the application of 21st-century skills significantly influences students' civic competence in universities in South-South Nigeria. This indicates that lecturers who are more aware of the relevance and application of 21st-century skills are better positioned to incorporate them into teaching, thereby enhancing students' civic knowledge, values, and participation. The regression results confirmed a significant positive influence, highlighting awareness as an important factor in civic competence development. This finding is supported by Eroğlu, Aydemir, and Dalgın (2026), who reported that awareness significantly influences students' behavioural outcomes, particularly in shaping responsible and informed actions. Similarly, Bari et al. (2024) found that educational awareness significantly influences both teachers' and students' perceptions, leading to improved learning outcomes and skill acquisition. These findings suggest that lecturers' awareness of instructional innovations is crucial for fostering students' civic competence.

Conclusion

The study revealed that lecturers' perception, attitude, and awareness of the application of 21st-century skills significantly influence students' civic competence in universities in South-South Nigeria. The findings indicate that when lecturers possess positive perceptions, favourable attitudes, and adequate awareness of 21st-century skills, they are more likely to integrate these competencies into their instructional practices, thereby enhancing students' civic knowledge, values, and participation. The results further suggest that these teacher-related factors collectively play a crucial role in shaping how students develop civic competence in higher education settings. In a nutshel, the study concludes that lecturers' understanding and disposition toward 21st-century skills are key determinants of students' civic development in universities.

Recommendations

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

1. University authorities and educational policymakers should organize regular training and reorientation programmes to improve lecturers' perception, attitude, and awareness of 21st-century skills for effective teaching and improved student civic competence.
2. Lecturers should be encouraged to adopt positive attitudes toward 21st-century teaching approaches by integrating critical thinking, communication, collaboration, and creativity into classroom instruction.
3. Institutions should strengthen awareness campaigns and professional development initiatives on 21st-century skills to ensure that lecturers consistently apply modern instructional practices that enhance students' civic competence.

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Sustaining STEM education in Conflict-Affected Region in Nigeria: Adaptive Strategies for Teaching and Learning in Insecure Environments

ABIMBOLA, Ahmatullahi Folakemi
abimbola.ahmatullahi2595@fcesoyo.edu.ng

Department of Science Education, School of General Studies Education, Federal College of Education, Special, Oyo, Oyo State, Nigeria

Abstract

Nigeria confronts a profound paradox. The country faces an urgent national need to boost STEM education to drive innovation and global competitiveness while also facing a pervasive insecurity that has severely curtailed access to education for millions of children. Neglecting STEM education while the government battles insecurity creates a challenge of future skill deficit that can put the country in a worse crisis than it is currently facing. This has raised the question of whether STEM education can be sustained in the face of persistent insecurity without jeopardising quality. This study combines a synthesis of peer-reviewed literature, policy evaluations, and recent field interventions to an evidence-based, three-pillar Adaptive Resilience Framework (ARF) for STEM education in security-challenged environment. This framework is based on technology-enabled resilient pedagogy, community–industry integration, and teacher capacity building for crisis contexts. The paper argues that while insecurity remain a significant challenge to STEM education in Nigeria, recent innovations such as blended learning, mobile science laboratories, and strategic public–private partnerships demonstrate that sustainable, quality STEM education is both achievable and scalable. This paper contributes to the growing global literature on education in emergencies (EiE) by offering a contextualised, operationalisable framework transferable to analogous conflict-affected settings across Sub-Saharan Africa and beyond.

Keywords: STEM education, conflict-affected Region, mobile science laboratories, blended learning, insecurity

Introduction

STEM Education is an approach to teaching and learning that focuses to providing learners with practical education to make them contribute meaningfully to the technologically developing society. STEM stands for Science, Technology, Engineering and Mathematics. STEM education teaches learners about effective interdisciplinary communication. Science is the bedrock of STEM Education, Scientists makes inquiry on observations they make in the environment, then experiment on them to reach logical conclusions, offering the team discoveries. Science enable learners to under the world and to become critical thinkers. Technology experts apply knowledge from scientific discoveries to make tools and appliances, technology enables learners to become innovators and inventors. Engineers use knowledge acquired from science and technology to create, design systems and make use of scientific principles to solve practical problems, engineering provide learners with problem solving and creativity skills. Mathematics is the language of science, it provides tools for measurement, calculations, analysis and problem solving. Mathematicians analyze information to eliminate mistakes and provide precise calculations. Mathematics provide learners with ability to analyse data, eliminate errors and make reasonable decisions when designing projects. The approach of STEM education to teaching is to be able to produce learners who can transform the society through innovation and new technologies. Science, Technology, Engineering, and Mathematics (STEM) education occupies a foundational role in contemporary frameworks of national development, human capital formation, and economic competitiveness. Nigeria, as the largest economy in Sub-Saharan Africa's and the most populous nation, more than any other African country need to see STEM education as the most viable pathway for development. It is essential in harnessing power of

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its largely youthful population to drive technological innovation and securing meaningful participation in the Fourth Industrial Revolution. Even as the country is taking baby steps toward widening access to STEM education, the efforts are been significantly affected by factors such as insecurity in larger parts of the country. Ebun-Olu (2023) explained that security of lives and property has to be accorded priority attention by government of different countries irrespective of the type of administration. He asserted further that an atmosphere free from fear, anxiety, threat, harm and threat to lives and properties of citizens as well as economic development assures political stability. The insecurity problem has migrated into the educational institutions. All forms of educational institutions in Nigeria are under attacks from the bandits, civil crisis, Boko-haram, criminal elements, sit at home orders.

Nigeria's educational settings are confronted by acute and worsening security crisis. The largest victim group of insecurity in Nigeria have been vulnerable people such as women and children. Since the 2014 Chibok mass abduction, over 2,000 students have been abducted from educational institutions, more than 800 schools have been forcibly shut across northern regions, and at least 20 major attacks have occurred across 10 states (Chizoba & Nwakwesiri, 2023). The Safe Schools Initiative (SSI), launched with US$30 million in international funding, has struggled to operationalise protection at scale, with over 42,000 primary and secondary institutions still lacking basic perimeter security (Ogunode et al., 2024). These conditions do not merely interrupt schooling, they structurally undermine the very possibility of equitable, quality STEM education for millions of Nigerian children. This paper situates Nigeria's experience within the broader global discourse on Education in Emergencies (EiE), contributing empirically grounded analysis and an actionable adaptive framework to a conversation of urgent relevance to conflict-affected contexts worldwide.

Statement of the Problem

The impact of insecurity on education, particularly STEM education, is distinctively severe. Unlike many humanities disciplines, STEM learning depends on laboratory access, specialised equipment, sustained sequential instruction, and cumulative hands-on practice. Therefore, an atmosphere dominated by unexpected school closures, constant damage to infrastructure, population displacement, and regular traumatic experience for students and students and educators collectively undermine STEM learning outcomes both in the short and long term. This can be discouraging for educators and policy makers alike. However, this paper argues that these challenges, while formidable, are not insurmountable. Recent policy innovations and technology-enabled interventions have shown that adaptive, resilient approaches can help in establishing meaningful STEM education even in highly insecure environments. The challenge lies not in the absence of solutions, but in the absence of systemic commitment to scale and sustain them.

Methodology

This conceptual paper employs an integrative literature review approach, synthesising findings from peer-reviewed journals, policy reports, government documents, and intervention evaluations. It incorporates empirical observations from ongoing educational programmes across Nigeria's northeast region. The review is guided by the Education in Emergencies (EiE) framework, with particular attention to STEM-specific challenges and innovations in conflict-affected low- and middle-income country (LMIC) contexts.

The Educational Security Crisis in Nigeria

Magnitude of the Crisis

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The scope of Nigeria's educational security crisis is of such magnitude that it has attracted global attention. Nigerian schools are virtually sitting ducks in this highly insecure environment with many schools lacking basic infrastructure for protecting students and educators. Survey has shown that 42,000 primary and secondary schools across northern Nigeria lack perimeter fencing, with 4,270 secondary schools in 21 northern states and the Federal Capital Territory exposed to security threats. Bauchi State records the highest number of unsecured secondary schools (574), followed by Kano (500), Benue (447), Adamawa (379), and Jigawa (269) (Lawal, 2025; Adeleke, 2026). Similarly, Asubiojo (2025) reported that many schools in South-west Nigeria still rely on inadequate traditional security measures such as weak perimeter fencing and poorly trained guards, while ICT-based security systems remain largely absent. These are not peripheral statistics; they represent systemic institutional vulnerability of tens of millions of school-age children. This weak security has exposed students to regular abductions. School abductions have assumed a normalised, routine character that represents a profound humanitarian failure. According to the Nigerian Senate Ad-hoc Committee on the Safe Schools Initiative, over 1,680 schoolchildren have been kidnapped and 180 schools attacked since 2014. Recent incidents include the November 2025 abduction of 303 students and teachers from St. Mary's School in Niger State and the kidnapping of 25 schoolgirls from Government Girls Comprehensive Secondary School in Kebbi State, illustrating the continued and geographically expanding nature of the threat (Eze, 2025). Recently, there was another report that gunmen attack schools, kill teacher, kidnapped pupils in Ogbomoso, Oyo State, leading the government to close about 14 schools indefinitely (Ogunrinde, 2026). These recurrent assaults on the educational system have been linked to systemic failure with initiatives set up to correct the situation.

Structural Failure of the Safe Schools Initiative

Successive Nigerian governments have made effort to ensure that insecurity does not truncate the education of children in conflict-ridden areas. following the Chibok abduction The Safe Schools Initiative (SSI) was established with a fund of about US$30 million sourced from local and international donors including Norway, the African Development Bank, Switzerland, the United States, Qatar, and the Nigerian private sector (Manjo, 2024; Ogunode et al., 2024). At the policy level, the federal government of Nigeria also introduced the National Policy on Safety, Security and Violence-Free Schools as well as the Minimum Standards for Safe Schools (Odo et al., 2025; Ibrahim & Ibrahim, 2025). Despite this substantial resource mobilisation, implementation has been undermined by bureaucratic fragmentation, institutional ambiguity, political discontinuity, and inadequate accountability mechanisms. According to Ogunode et al (2024), funding shortage, corruption, weak monitoring and evaluation, poor involvement of stakeholders, insecurity problems and lack of political will affected the implementation of the Safe School Initiative Programme. Similarly, Ibrahim & Ibrahim (2025) added that insecurity, inadequate funding, lack of adequate safety measures in schools, lack of awareness, and corruption and mismanagement of funds. The level of failure was so significant that, in December 2025, the Nigerian Senate launched a formal investigation into the "collapse" of the SSI, summoning the Ministers of Finance, Education, and Defence to account for the programme's failure to protect school communities. The Senate Committee Chair declared the continued targeting of schools by terrorist and criminal actors "unacceptable" (Ripples Nigeria, 2025). This inquiry was driven by empirical studies that have outlined the failure of the safe school initiative and other programmes designed to protect children (Gever, 2016; Opara et al. 2025). This institutional accountability moment underscores a central argument of this paper: technology-enabled adaptive strategies cannot substitute for, but must complement, functional governance and political commitment to educational security.

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STEM-Specific Vulnerabilities

While all educational sectors are adversely affected by insecurity, STEM instruction faces compound and distinctive vulnerabilities. Empirical evidence demonstrates that insecurity disproportionately affects STEM education because of its dependence on specialised infrastructure, sequential curriculum delivery, laboratory experimentation, and highly skilled teachers. Studies conducted in conflict-affected regions of Nigeria show that school closures disrupt practical science instruction, infrastructure destruction limits access to laboratories and equipment, displacement interrupts continuity of learning, and teacher attrition weakens instructional quality (Han & Hur, 2022; Nnaemedo & Ugwu, 2025). Additionally, psychological trauma and irregular attendance negatively affect students' cognitive engagement and mastery of foundational STEM concepts necessary for progressive learning (Jacob, 2020; Kanu et al., 2025). Table 1 synthesises these disruption mechanisms and their specific impacts:

Table 1: Synthesis of Disruption Mechanisms and their Specific Impacts on STEM Education

Disruption Mechanism	STEM-Specific Impact	Affected Dimension	Source
School closures	Disrupted laboratory sequences, broken experimental continuity	Practical skills acquisition	United Nations Children's Fund. (2025).
Infrastructure damage	Destroyed science labs, theft of equipment, unsafe facilities	Resource availability	Han & Hur, (2022; Nnaemedo & Ugwu, 2025).
Displacement	Loss of access to specialised STEM resources and mentors	Continuity of learning	(Jacob, 2020; Kanu et al., 2025).
Teacher attrition	Over 50% of STEM workforce lost in northeast Nigeria	Instructional quality	Ukozor et al (2024).
Student psychological trauma	Reduced cognitive engagement with complex STEM concepts	Learning outcomes	Nwaubani (2024).
Irregular attendance	Missed foundational knowledge required for sequential STEM learning	Curriculum coherence	(Jacob, 2020; Kanu et al., 2025).

Adaptive Strategies for Resilient STEM Education

Despite acute systemic challenges, recent interventions across northern Nigeria demonstrate that STEM education can be sustained through adaptive, technology-enabled, and community-embedded approaches (UNICEF, 2025; Ojo, 2025). The evidence reviewed below informs the three-pillar Adaptive Resilience Framework (ARF) proposed in Section 4.

Technology-Enabled Resilient Pedagogy

Mobile Laboratories and Virtual Reality

The idea of modular teaching and learning centers is not new to Nigeria. Indeed, the federal government's Accelerated Senior Secondary Education Programme (ASSEP) represents a substantive policy innovation. In January 2025, the government deployed 30 mobile laboratories and virtual

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reality (VR) headsets across northeastern Nigeria. Among the beneficiaries are security-challenged states such as Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe states (The Nation, 2025). These deployable science units circumvent the problem of damaged or inaccessible laboratory infrastructure by bringing experimental equipment directly to communities. VR headsets extend this innovation further, enabling immersive learning experiences that approximate physical laboratory work. Students can conduct virtual dissections, chemical titrations, and engineering simulations without physical apparatus. Research on VR-based science education demonstrates that immersive simulations improve conceptual understanding, knowledge retention, engagement, and practical skill acquisition compared with conventional instructional approaches (Krause et al., 2023; AlGerafi et al., 2023). Studies from northeastern Nigerian educational institutions further indicate that VR-supported pedagogy can enhance STEM learning outcomes despite infrastructure constraints and insecurity-related disruptions (Ezra,2025).

Blended Learning as Educational Infrastructure

The disruptions caused by insecurity or unsafe learning environment can be mitigated through blended learning. Abubakar and Lawal (2024) characterise blended learning which combines digital tools with face-to-face instruction, as a "lifeline" for teacher education and student learning during crises. Their research, grounded in Nigeria's northeast, identifies several critical advantages in conflict-affected settings: (i) Instructional continuity when schools are closed or unsafe; (ii) Reduced student mobility requirements, enabling learning from safer locations (iii) Self-paced modular design that accommodates irregular attendance patterns (iv) Digital record-keeping that tracks student progress despite physical disruption

The LabXchange Teacher Ambassador Program provides empirical support for this approach. In 2024, the programme trained 54 Nigerian educators across all six geopolitical zones in designing pedagogically aligned STEM lessons using a platform offering over 29,000 freely accessible digital resources. Preliminary evaluation indicates measurable improvements in teacher digital confidence and lesson quality (Sawka, 2024).

Digital Literacy and AI-Integrated Instruction

Effective technology integration requires deliberate, sustained investment in teacher capacity. In April 2026, the Office of the Vice President and the North-East Development Commission (NEDC) trained 100 teachers in Adamawa State on digital literacy, including artificial intelligence integration and inclusive teaching methods. Comparable programmes have been delivered in Borno, Yobe, Gombe, and Bauchi states, creating a nascent foundation for a digitally capable STEM teaching workforce.

The NEDC's Managing Director contextualised this intervention explicitly within the insurgency narrative, noting that the region's 16-year experience of Boko Haram and related violence had produced an educational deficit requiring urgent, targeted remediation. This framing—positioning digital teacher training as a post-conflict reconstruction tool, has important implications for international development financing and programme design.

Community–Industry Integration

Community-Based STEM Learning Infrastructure

Onwubuya (2025) makes a compelling case for partnerships with private sector organisations and non-governmental organisations to establish community-based STEM labs in underserved and insecure regions. Beyond expanding access to equipment, these distributed facilities serve a critical risk management function: dispersing learning infrastructure across multiple sites reduces single-

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point vulnerability to attack or closure while simultaneously embedding educational assets within protective community networks.

Public–Private Partnerships for Practical Relevance

The ASSEP x Social Innovation and Entrepreneurship Bootcamp (SIEB) Initiative exemplifies a promising public–private partnership model. This 21-day immersive programme targets vulnerable youth aged 15–20 across northeast Nigeria, combining STEMA (Science, Technology, Engineering, Mathematics, and Arts) education with entrepreneurial skills development and psycho-social support. By integrating economic relevance with educational content and attending explicitly to student wellbeing, the programme addresses the holistic needs of conflict-affected learners that conventional academic programmes frequently neglect.

Contextualised, Problem-Oriented STEM Learning

A consistent finding across the reviewed literature is the motivational value of connecting STEM learning to students' lived experiences and community challenges. In conflict-affected regions characterised by disrupted infrastructure, water insecurity, healthcare deficits, and communication gaps, STEM education oriented towards solving local problems acquires both pedagogical and psychological value. When students see their learning as directly relevant to their survival and community wellbeing, engagement and retention improve markedly, a finding with direct implications for curriculum design in insecure environments.

Teacher Capacity Building for Crisis Contexts

Addressing the Structural Teacher Shortage

The northeast region has lost over 50% of its teaching workforce due to insurgency, displacement, and school closures. Rebuilding this workforce requires strategies that go beyond conventional recruitment and retention, addressing the specific deterrents and risks that characterise teaching in insecure environments. The ASSEP teacher training component explicitly targets STEMA educators in senior secondary schools, combining digital and technical skills development with AI integration, inclusive pedagogy, and technology-enhanced instruction.

Trauma-Informed Pedagogy and Educator Wellbeing

Teaching in conflict zones imposes significant and well-documented psychological burdens on educators. The ASSEP x SIEB Initiative's explicit incorporation of psycho-social support alongside professional skills training represents an important evolution in crisis education programming. The evidence base on trauma-informed pedagogy in EiE contexts consistently demonstrates that teacher wellbeing is a significant predictor of educational quality and student learning outcomes. Neglecting this dimension in programme design is not merely an ethical oversight, it is an evidence-based error.

Professional Learning Communities Across Regions

The LabXchange Teacher Ambassador model, creating cohorts of trained educators who form mutual support networks across geopolitical zones, illustrates the strategic value of professional learning communities in conflict-affected contexts. These networks distribute knowledge and capacity across multiple nodes, provide structured peer support for educators facing isolation and danger, and create resilient communities of practice that persist through institutional disruption. The model has direct transferability to other fragile state education systems.

The Adaptive Resilience Framework (ARF): A Proposed Model

Synthesising the evidence reviewed above, this paper proposes the Adaptive Resilience Framework (ARF), a three-pillar operational model for sustaining quality STEM education in insecure and conflict-affected contexts. The ARF is designed to be modular, context-adaptable, and transferable beyond Nigeria to analogous settings across Sub-Saharan Africa and globally.

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Pillar 1: Infrastructure Resilience

Component	Implementation Strategy	Evidence Base
Mobile laboratories	Deployable science units reaching multiple communities on rotation	ASSEP deployment, Northeast Nigeria (2025)
Virtual reality equipment	Immersive simulation tools for laboratory experiences without physical apparatus	ASSEP VR deployment (2025)
Offline digital resources	Pre-loaded tablets and local servers for low-connectivity environments	LabXchange programme
Secure school infrastructure	Perimeter fencing, access control, biometric entry, emergency communication	SSI mandate (unimplemented at scale)
Distributed learning sites	Multiple small community facilities rather than single large, high-risk schools	Onwubuya (2025)

Pillar 2: Pedagogical Adaptability

Component	Implementation Strategy	Evidence Base
Blended learning	Online-offline hybrid models maintaining instructional continuity during disruption	Mukhtar & Amina (2025)
Modular, self-paced curricula	STEM content units designed for non-linear, interrupted delivery	EiE curriculum design literature
Community-based problem projects	Learning embedded in authentic local problem-solving contexts	Onwubuya (2025)
Virtual laboratories	Simulation-based experimental learning when physical labs are inaccessible	ASSEP VR programme
Emergency continuity plans	Pre-prepared school-level protocols for closures and displacement scenarios	Best practice EiE frameworks

Pillar 3: Systemic Human Capital Support

Component	Implementation Strategy	Evidence Base
Teacher digital literacy	Nationwide pre-service and in-service training in technology-enhanced teaching	NEDC-OVP training (2026)
Teacher psycho-social support	Structured mental health and peer support resources for educators in conflict zones	ASSEP x SIEB (2025)

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www.foefugusau.com.ng
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Component	Implementation Strategy	Evidence Base
Industry and civil society partnerships	Internships, mentorship, and real-world STEM applications through private sector	ASSEP x SIEB model
Community protection networks	Local community oversight and early warning systems for school security	Community-based EiE models
Coordinated security response	Clear inter-agency protocols linking schools, security forces, and emergency services	Policy gap identified in SSI review

Policy Recommendations

Federal and State Governments

1. Protect educational financing: Fully implement and transparently audit the National Financing Plan for school security (projected at ₦32.58 billion, rising to ₦38.03 billion by 2026), with ring-fenced allocations that cannot be diverted during security emergencies.
2. Nationalise mobile laboratory deployment: Scale the 30 mobile laboratory units deployed in the northeast to a national programme, with priority allocation to high-risk states in the northwest and north-central regions.
3. Establish a unified school safety command: Resolve the current fragmentation of school security responsibilities between the NSCDC, Nigeria Police Force, and military by establishing a dedicated School Safety Command with clear authority and accountability.
4. Establish protected education zones: Model protected education corridors on humanitarian safe zone frameworks, guaranteeing safe access to schooling for communities in active conflict zones.
5. Mandate blended learning as policy: Institutionalise blended learning as permanent educational infrastructure, not a crisis measure, embedded in the national curriculum delivery framework.

Educational Institutions

1. Each school in conflict-affected states should develop, test, and regularly review a school-level emergency learning continuity plan with clear protocols for instruction during security incidents.
2. Schools should establish formal community-school security committees with local community leaders, parents, and relevant authorities, creating structured early warning and response mechanisms.
3. STEM departments should maintain offline, pre-loaded digital resource libraries to ensure learning continuity during internet disruptions.

Teacher Training Institutions

1. Integrate digital literacy and technology-enhanced pedagogy as core competencies in all pre-service teacher education programmes, ensuring every graduate is equipped for blended delivery.
2. Introduce crisis pedagogy as a discrete subject within teacher education curricula, covering trauma-informed teaching, flexible curriculum delivery, and psychological first aid for educators.
3. Establish inter-institutional professional learning community networks modelled on the LabXchange Ambassador approach, providing structured peer support and resource sharing across insecure regions.

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Conclusion

Nigeria's STEM education crisis is both profound and urgent, but it is not without remedy. The evidence synthesised in this paper demonstrates convincingly that adaptive, technology-enabled, and community-embedded approaches can sustain quality STEM learning even in highly insecure environments. The deployment of mobile laboratories across the northeast, the training of teachers in digital literacy and AI-integrated pedagogy, and the emergence of blended learning as a structural educational lifeline all constitute proof of concept for the Adaptive Resilience Framework proposed here. However, these innovations currently operate at pilot scale. Thirty mobile units serve a fraction of the 42,000 unfenced schools. One hundred teachers trained in Adamawa represent a modest beginning against a workforce that has lost more than half its members to insurgency. Bridging this gap between proof of concept and systemic impact requires something beyond innovative programming: it requires sustained political will, protected funding, coordinated multi-sectoral action, and a fundamental reconceptualisation of educational resilience as a national security priority.

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Correlation between Green Chemistry Awareness, Entrepreneurial Skills and Sustainability Literacy on Innovation Intention among Colleges of Education Pre-Service Teachers in Niger State, Nigeria

IDIRISU, Jibril Limangba[1]
chemistlimangba@gmail.com
USMAN, Abdullahi Muhammad[2]
abdulus0764@gmail.com
BAWA, Swafiah[3]
bawaswafiyah@gmail.com
YAHAYA, Ibrahim Alfa[4]
yahayai7945@gmail.com
MAGAJI, Buhari[2]
buharimagajislm@gmail.com
[1]Department of Chemistry, Baze University, Abuja
[2]Chemistry Department, Federal University of Education Kontagora, Niger State
[3]Department of Chemistry, Federal University of Education Zaria, Kaduna State
[4]Department of Science Education, Federal University of Technology, Minna, Niger State

Abstract

This research investigated into the role of green chemistry awareness, entrepreneurial skills, and sustainability literacy as predictors of innovation intention of pre-service teachers in Niger State, Nigeria. This study was carried out using a descriptive correlational survey design. The population of the study was final year chemistry education students in the teacher education institutions in Niger State. A total of 240 pre-service chemistry teachers were randomly sampled from the population using the simple random sampling technique at Dr. Umaru Sanda Ahmadu College of Education, Minna and Federal College of Education, Kontagora. Data were gathered using a structured questionnaire titled Green Chemistry Awareness, Entrepreneurial Skills, Sustainability Literacy and Innovation Intentions Questionnaire (GCAESLIIQ). This instrument was face validated by experts in chemistry education, entrepreneurship education and measurement and evaluation. The instrument was also pilot tested on 30 chemistry education students at Federal College of Education, Zuba, Abuja. Cronbach's Alpha coefficients obtained were 0.82, 0.85, 0.80 and 0.84 for green chemistry awareness, entrepreneurial skills, sustainability literacy and innovation intentions respectively. The overall reliability coefficient was 0.83. Data collected was analysed using Pearson Product Moment Correlation and multiple regression at 0.05 level of significance. From the study, it was observed that green chemistry awareness, entrepreneurial skills and sustainability literacy have a significant positive relationship with innovation intention of pre-service teachers in Niger State. These variables also accounted significantly to innovation intentions of the pre-service teachers with entrepreneurial skill being the best predictor of the innovation intentions. The study concluded that efforts should be made to enhance sustainability education and entrepreneurial skills of pre-service chemistry teachers to boost their innovation intentions and achieve sustainable development of the country.

Keywords: Green chemistry awareness, entrepreneurial skills, sustainability literacy, innovation intentions, pre-service teachers.

Introduction

The increasing interest on environment protection, climate change, waste management, and green economics around the world has heightened the necessity for educational systems to equip learners with innovative and sustainability-oriented competencies. Education is increasingly becoming an indispensable tool for achieving sustainability by nurturing learners with environmentally conscious attitudes, entrepreneurship capacities, and innovation-oriented mentality to enable learners and

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potential professionals is responsible individuals and experts (UNESCO, 2020). In science education and more specifically chemistry education, learning green chemistry concepts has become indispensable because chemical processes and practices exert a profound impact on human health and the environment quality. Green chemistry encourages designing chemical products and processes that use less hazardous chemical substances, reduce waste generation and minimize energy use (Anastas & Warner, 2000). Therefore, teacher training institutions are called to prepare pre-service teachers with awareness, knowledge, skill and literacy on sustainability and innovation for classrooms and communities in the future.

The concept of green chemistry awareness became indispensable learning topic due to its ability to instill environmentally friendly consciousness in both learners and teachers. Green chemistry awareness describes learners or teacher's knowledge and understanding of the application of the environmentally friendly chemical principles designed to reduce pollution and enhance sustainable processes. Growing environmental crisis associated with industrialization, chemical wastes and the non-sustainable ways of life, demands green chemistry to become a global learning priority (Ijioma & Cynthia, 2025). Research has indicated that, teaching green chemistry to science learners enhanced learners' environmental consciousness, thinking and action, and commitment to sustainability (Ijioma & Cynthia, 2025). However, there are lacunas on how green chemistry has been implemented in the schools and tertiary institutions in Nigeria due to limited curriculum integration, lack of instructional resources and poorly prepared teachers (Akinsipo & Anselm, 2025). These suggest the possibility that pre-service teachers might not be aware of the green chemistry principles that can foster innovation. The problem of inadequate environmental sustainability practices in Nigeria has intensified the need for educational reforms that emphasize green and innovative approaches to teaching and learning. Nigeria faces serious environmental issues such as pollution, poor waste disposal systems, deforestation, and climate-related challenges, which require innovative and sustainable responses from citizens and institutions (Anabaraonye et al., 2019). Despite these realities, many teacher preparation programmes still focus predominantly on theoretical instruction with limited emphasis on sustainability-oriented innovation and practical problem-solving skills. Research indicates that many chemistry teachers and pre-service educators demonstrate low understanding and application of green chemistry principles in instructional practices (Owoyemi & Akinde, 2026). The implication is that future teachers may graduate without the competencies necessary to drive environmentally sustainable innovation within schools and society. Therefore, examining the role of green chemistry awareness in shaping innovation intentions among pre-service teachers has become increasingly necessary.

Entrepreneurial skills are another critical variable that influences pre-service teachers' innovation intentions. Entrepreneurial skills are defined as the tangible competencies such as creativity, problem-solving abilities, identification of opportunities, management of risk, and utilization of resources for innovative outputs and viable ventures. Entrepreneurship is no longer business-specific but has taken a central position in science and teacher education, as it encourages self-reliance, creativity and innovativeness (Ugwuanyi & Aderanti, 2023). Acquiring entrepreneurial skills may allow pre-service teachers to produce innovative teaching materials, launch an enterprise that promotes sustainability of the environment, and make contributions to the socio-economic development. In relation to these claims, there is a worldwide trend of education for sustainable entrepreneurship and innovation. In Nigeria, developing entrepreneurial skills has becomes more relevant as unemployment, poverty and economic recession continue to bite harder. Students

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graduating from higher education are finding it difficult to secure a wage job and this is pushing them towards an entrepreneurial pathway that enhances sustainability through the use of innovative approaches (Alao et al., 2023). It is therefore imperative for education institutions to equipped their students with entrepreneurship skills that will enhance innovation and economic sustainability. The result of prior research indicates that acquiring entrepreneurial skills among chemistry and science education students can improve innovation, hands-on skill in problem solving and involvement in the economy sustainably (Nnoli & Udogu, 2021). The result of Ediagbonya et al (2024) indicated that the relationship of sustainable entrepreneurship education on students' Green Entrepreneurial Intention was significant and positive, while it appeared that entrepreneurial skills development are not yet adequately incorporated into some teacher education programs in Nigeria. In the context of education, sustainability literacy is also considered one of the essential factors for the development of innovation intentions. Sustainability literacy is defined as knowledge, values, attitudes and skills, which allow students to make reasoned judgments and decisions, which help in the protection of the environment, justice and the economy (UNESCO, 2020). These competences give individuals the ability to assess global issues and develop new solutions to complex problems. In the case of teachers, it is fundamental, as teachers have the ability to promote the environmental awareness of their students, as well as influence their behaviours and attitudes in a sustainable way. In addition, sustainability literacy will enable future teachers to carry out the sustainable actions they intend to take, and thus guide their students towards innovation and environmental citizenship. While the call for sustainable education has increased at a global level, the level of sustainability literacy among Nigerian students and pre-service teachers appears to be quite low. Reasons may include poorly implemented curricula, ineffective environmental education policies, and insufficient practical experience in education, such as demonstrated by Yahaya (2025) who found that hands-on instruction in sustainability education in Nigerian educational institutions was severely lacking, thus students could not develop competencies in environmental problem-solving. Studies on green chemistry implementation in Nigerian universities found poor awareness, insufficient funding, and lack of adequate reforms in curricula to be the main obstacles to education for sustainability (Akinsipo & Anselm, 2025), which could influence pre-service teachers' innovation intentions in tackling environmental and social problems. Thus, an investigation into the link between sustainability literacy and innovation intentions in pre-service teachers appears warranted.

Innovation intention refers to the propensity, the readiness and the desire of a person to develop, use, or apply new ideas, products, process or practices to help overcome problems and improve the condition of mankind. Innovation intention is one of the key predictors of innovative behaviour as persons who possess good intention are likely to behave creatively and innovatively. In the educational contexts, it is therefore important for pre-service teachers to possess good innovation intention in order to produce innovative teachers who will devise creative pedagogues, change with evolving demands of the educational landscape and champion sustainable development in the nation. The study of the antecedents of pre-service teachers' innovation intention in education seems therefore to be dependent on some educational and psychological factors. These include environmental awareness, entrepreneurial competence and sustainability literacy. The call for an innovative and sustainability-oriented teacher education in Niger State Nigeria is critical given the socio-economic and environmental problems bedevilling the state. These are problems such as unemployment and educational deficits, lack of good management of the environment including waste. The state as an educational hub is seen to be at a crucial junction where there is a demand for more innovative and sustainability-oriented teachers who would initiate and embrace innovative

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ways in our classrooms and in their respective communities. Despite the critical position occupied by pre-service teachers' innovation intention in this regard, there seems to be very few empirical studies examining the antecedents of this important factor in Niger State Nigeria. Many studies conducted in Nigeria seem to concentrate in areas such as entrepreneurship education, sustainability practices, green chemistry implementation and each as a standalone variable without linking it with innovation intentions among pre-service teachers. Thus, this research aimed at investigating green chemistry awareness, entrepreneurial skills and sustainability literacy as factors influencing innovation intentions among pre-service teachers in Niger State, Nigeria. This research is anticipated to add to the pool of available literature on the relationship between these variables and also serve as a useful tool for curriculum planners, teacher educators, policymakers, educational institutions on measures to encourage sustainable innovation in teacher training programs.

Objectives of the Study

The main objective of this study was to examine the relationship between green chemistry awareness, entrepreneurial skills, sustainability literacy and pre-service teachers' innovation intentions in Niger State, Nigeria. Specifically, the study sought to:

1. determine the relationship between green chemistry awareness and pre-service teachers' innovation intentions in Niger State, Nigeria.
2. examine the relationship between entrepreneurial skills and pre-service teachers' innovation intentions in Niger State, Nigeria.
3. assess the relationship between sustainability literacy and pre-service teachers' innovation intentions in Niger State, Nigeria.
4. determine the joint relationship of green chemistry awareness, entrepreneurial skills, and sustainability literacy with pre-service teachers' innovation intentions in Niger State, Nigeria.
5. determine the relative contribution of green chemistry awareness, entrepreneurial skills, and sustainability literacy to pre-service teachers' innovation intentions in Niger State, Nigeria.

Research Hypotheses

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

Ho_1: There is no significant relationship between green chemistry awareness and pre-service teachers' innovation intentions in Niger State, Nigeria.

Ho_2: There is no significant relationship between entrepreneurial skills and pre-service teachers' innovation intentions in Niger State, Nigeria.

Ho_3: There is no significant relationship between sustainability literacy and pre-service teachers' innovation intentions in Niger State, Nigeria.

Ho_4: There is no significant joint relationship among green chemistry awareness, entrepreneurial skills, sustainability literacy, and pre-service teachers' innovation intentions in Niger State, Nigeria.

Ho_5: Green chemistry awareness, entrepreneurial skills, and sustainability literacy do not significantly contribute relatively to pre-service teachers' innovation intentions in Niger State, Nigeria.

Methodology

This study employed a descriptive correlational survey research design. This design was appropriate because the study aimed to determine the relationship and predictive significance of awareness of green chemistry, entrepreneurial skill and sustainability literacy to pre-service teachers' intention of innovation without manipulating any variable. With the correlational design, the researcher can be able to establish how much joint and relative prediction the independent variables have on

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innovation intention of pre-service chemistry teacher.The study was carried out in Niger State, Nigeria. Niger state is located in the North-central geopolitical region in Nigeria. Niger state is also host to various teacher education institutions for the training of science and chemistry teachers. Specifically, the institutions are Dr Umaru Sanda Ahmadu College of Education, Minna and Federal College of Education, Kontagora. The population of the study consists of all final year chemistry education pre-service teachers in teacher education institutions in Niger state, Nigeria. Final year students was considered appropriate since they are the last stage of their training programs and have been subjected to adequate academic and professional training in chemistry education and other subjects in the area of sustainability literacy and entrepreneurship skills. A total of 240 pre-service chemistry teachers were used for the study. A simple random sampling technique was used in selecting the respondents for the study; the choice of this technique assures that each eligible student has an equal chance of being selected. Data were collected for this study using a structured questionnaire titled Green Chemistry Awareness, Entrepreneurial Skills, Sustainability Literacy and Innovation Intentions Questionnaire (GCAESLIIQ). The questionnaire had four parts; Part A measured Green Chemistry Awareness, Part B measured Entrepreneurial Skill and Part C measured Sustainability Literacy, while Part D measured Innovation Intentions. The questionnaire items were structured in a 4-point Likert rating scale; Strongly Agree (SA), Agree (A), Disagree (D), Strongly Disagree (SD), weighted 4, 3, 2, 1 respectively. The items in the instrument were adapted and developed from green chemistry education literature, entrepreneurship education literature, sustainability literacy literature and innovation intention literature. Face and content validity of the instrument were ensured by three experts, two experts in chemistry education and one expert in educational measurement and evaluation. The validity check addressed clarity of wording, relevance and appropriateness of the wording to the subjects in question and relevance to the study objectives. Modifications were made on the questionnaire items based on expert judgments before it was administered to the respondents. A pilot study of the questionnaire was carried out with 30 final year chemistry education pre-service teachers in FCE, Zuba, Abuja, none of which participated in the actual study. This was to ensure the reliability and suitability of the questionnaire. The reliability of the instrument was calculated using Cronbach's Alpha statistical method. The following coefficients of reliability was obtained: Green Chemistry Awareness Scale=0.82, Entrepreneurial Skills Scale=0.85, Sustainability Literacy Scale=0.80 and Innovation Intentions Scale=0.84. The overall reliability coefficient for the instrument was 0.83 which is accepted for an instrument (e > 0.70). The questionnaire was administered by the researcher with the help of research assistants to the selected respondents after permission was obtained from management of both institutions. The respondents were informed of the purpose of the study, that their responses are for research and that they are treated with confidentially. The administration of the questionnaire took six weeks. Data collected were coded and analysed using Statistical Package for the Social Sciences (SPSS) version 25. Pearson Product Moment Correlation (PPMC) was used to investigate the relationships among the variables while multiple regression analysis was used to determine the joint and relative prediction of awareness of green chemistry, entrepreneurial skill and sustainability literacy to innovation intention of pre-service teachers. These inferential statistics were used at 0.05 level of significance. Ethical guidelines were strictly adhered to during the entire period of the study. Participation was voluntary, respondents were informed of their right to withdraw at any time without prejudice, and their responses were kept strictly confidential and only used for research purposes.

Presentation of Results

Hypothesis One

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Ho₁: There is no significant relationship between green chemistry awareness and pre-service teachers' innovation intentions in Niger State, Nigeria.

Table 1: Pearson Product Moment Correlation Analysis of Green Chemistry Awareness and Innovation Intentions

Variables	N	Mean	SD	r	p-value	Decision
Green Chemistry Awareness	240	3.12	0.58			
Innovation Intentions	240	3.26	0.61	.621	.000	Rejected

The result presented in Table 1 shows that there is a positive and significant relationship between green chemistry awareness and pre-service teachers' innovation intentions ($r = .621$, $p < .05$). Since the p-value of .00 is less than the significance level of .05, the null hypothesis was rejected. This implies that green chemistry awareness significantly influences pre-service teachers' innovation intentions in Niger State, Nigeria.

Hypothesis Two

Ho₂: There is no significant relationship between entrepreneurial skills and pre-service teachers' innovation intentions in Niger State, Nigeria.

Table 2: **Pearson Product Moment Correlation Analysis of Entrepreneurial Skills and Innovation Intentions**

Variables	N	Mean	SD	r	p-value	Decision
Entrepreneurial Skills	240	3.31	0.54			
Innovation Intentions	240	3.26	0.61	.684	.000	Rejected

Table 2 reveals that entrepreneurial skills had a positive and significant relationship with innovation intentions among pre-service teachers ($r = .684$, $p < .05$). Since the p-value of .000 is less than .05 level of significance, the null hypothesis was rejected. This indicates that entrepreneurial skills significantly influence pre-service teachers' innovation intentions in Niger State, Nigeria.

Hypothesis Three

Ho₃: There is no significant relationship between sustainability literacy and pre-service teachers' innovation intentions in Niger State, Nigeria.

Table 3: Pearson Product Moment Correlation Analysis of Sustainability Literacy and Innovation Intentions

Variables	N	Mean	SD	r	p-value	Decision
Sustainability Literacy	240	3.18	0.57			
Innovation Intentions	240	3.26	0.61	.657	.000	Rejected

The result in Table 3 indicates that sustainability literacy had a positive and significant relationship with innovation intentions among pre-service teachers ($r = .657$, $p < .05$). Since the p-value of .000 is less than .05 significance level, the null hypothesis was rejected. This means that sustainability literacy significantly influences pre-service teachers' innovation intentions in Niger State, Nigeria.

Hypothesis Four

Ho₄: There is no significant joint relationship among green chemistry awareness, entrepreneurial skills, sustainability literacy and pre-service teachers' innovation intentions in Niger State, Nigeria.

Table 4: Multiple Regression Analysis Showing the Joint relationship between Green Chemistry Awareness, Entrepreneurial Skills, and Sustainability Literacy on Innovation Intentions

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Source	Sum of Squares	df	Mean Square	F	R	R^2	Adj. R^2	p-value	Decision
Regression	58.421	3	19.474	48.317	.617	.381	.373	.000	Rejected
Residual	95.118	236	0.403						
Total	153.539	239							

The result presented in Table 4 shows that the joint i relationship between green chemistry awareness, entrepreneurial skills, and sustainability literacy on pre-service teachers' innovation intentions was statistically significant, $F_{(3,236)} = 48.317$, $p < .05$. The coefficient of determination ($R^2 = .381$) indicates that 38.1% of the variance in innovation intentions was jointly explained by the three independent variables, while the adjusted R^2 value of .373 indicates the predictive strength of the model after adjustment. Since the p-value of .00 is less than the .05 level of significance, the null hypothesis was rejected.

Hypothesis Five

Ho_5: Green chemistry awareness, entrepreneurial skills, and sustainability literacy do not significantly contribute relatively to pre-service teachers' innovation intentions in Niger State, Nigeria.

Table 5: Multiple Regression Analysis Showing the Relative Contribution of the Independent Variables to Innovation Intentions

Variables	Unstandardized B	Std. Error	Beta (β)	t	p-value	Decision
Constant	1.214	0.287		4.230	.000	
Green Chemistry Awareness	0.291	0.059	.291	4.962	.000	Significant
Entrepreneurial Skills	0.412	0.060	.412	6.821	.000	Significant
Sustainability Literacy	0.336	0.061	.336	5.474	.000	Significant

The result in Table 5 shows that green chemistry awareness, entrepreneurial skills, and sustainability literacy all made significant relative contributions to pre-service teachers' innovation intentions since their respective p-values were less than .05. Entrepreneurial skills had the highest contribution (β = .412), followed by sustainability literacy (β = .336), while green chemistry awareness also contributed significantly (β = .291). Therefore, the null hypothesis was rejected.

Discussion of Findings

The result of the study identified that there is a significant positive relationship between green chemistry awareness and the pre-service teachers' innovation intentions in Niger State, Nigeria. This means that the greater the knowledge that pre-service teachers possess concerning the practices of green chemistry, the higher the innovation intentions they have. This suggests that the pre-service teachers who possess the knowledge and understanding on environmentally friendly chemical practices are prone to generate ideas and develop sustainable problem solving orientation. This is in consonant with the study conducted by Ijioma & Cynthia (2025) who found that education on green chemistry has influenced student's awareness on environment and critical thinking ability, as well as their sustainable behaviours. This result supports the study of Akinsipo and Anselm (2025) which posited that green chemistry education is instrumental in resolving environmental issues and in promoting innovations in institutions. Also, Owoyemi and Akinde (2026) showed that inadequate knowledge and competence in green chemistry on the part of teachers hindered the implementation of sustainable scientific practice and thus, emphasizes the importance of green chemistry awareness in the enhancement of innovative potentiality. Entrepreneurial skill had a significant positive relationship with pre-service teachers' innovation intentions. This indicates that respondents who

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are high in entrepreneurial skills had a higher innovation intention. The implication of this result is that entrepreneurial skills such as creativeness, opportunity seeking, problem solving ability, and need for achievement and independence were instrumental to students' innovation intentions. This result is in accord with the study conducted by Nnoli and Udogu, (2021) who stressed that entrepreneurial skill in chemistry education enhances innovative thinking in chemistry and has led to Nigeria's sustainable development. Also, it aligns with the work of Ugwuanyi and Aderanti (2023) who reported that entrepreneurship-oriented chemistry education is a key strategy to enhance the acquisition of practical skills and entrepreneurial skills among students. In addition, Alao et al. (2023) claimed that entrepreneurial skills development is critical to sustainability and empowerment of students in Nigeria, whereas, Ediagbonya et al. (2024) demonstrated that sustainable entrepreneurship is a significant predictor of entrepreneurial intentions of students. Sustainability literacy significantly and positively correlated with innovation intention among the pre-service teachers. This result means that pre-service teachers who have high sustainability literacy were prone to have higher innovation intentions. It also suggests that sustainability literacy is vital for the development of competencies and capabilities needed for the generation of new ideas, and it equips students with the knowledge, values and attitudes to respond to environmental and social problems in an innovative way. This aligns with the findings of UNESCO (2020) that education for sustainable development is intended to build competencies needed for innovation, responsible actions and decision making. This result supports the study of Yahaya (2025) who opined that sustainability focused education improve student's sustainability competence and problem-solving ability.

The joint influence of green chemistry awareness, entrepreneurial skills, and sustainability literacy on the innovation intentions of pre-service teachers indicated that the three predictor variables explained innovation intentions together significantly. The three predictor variables explain innovation intentions collectively. This suggests that integrating knowledge on sustainability, competencies and green chemistry awareness are important in enhancing innovative potentiality of pre-service teachers. This is in accord with the position of Anabaraonye et al. (2019) who stressed that learning on green entrepreneurship education and sustainability has important role in advancing Nigerian economy, while Ediagbonya et al. (2024) affirmed that sustainable entrepreneurship and related competencies predict students' entrepreneurship intentions. Entrepreneurial skills made a stronger unique contribution to innovation intentions among the pre-service teachers, followed by sustainability literacy and then, green chemistry awareness. This implies that of all the variables examined, the entrepreneurial skills make the greatest unique contribution toward innovation intention of the pre-service teachers. It is believed that the skills in entrepreneurship are practically oriented and help students develop creativity, self-efficacy, innovation and ability to solve problems with less supervision. This aligns with the assertion of Nnoli and Udogu, (2021) that skill development on entrepreneurship through chemistry education is essential for Nigeria's innovative development, and Alao et al. (2023) and Ugwuanyi and Aderanti (2023) argued that entrepreneurial skills is key in empowering students for economic empowerment and sustainability.

Conclusion

From the results obtained, it was found that green chemistry awareness, entrepreneurial skills and sustainability literacy have positive significant relationship with innovation intention of pre-service teachers in Niger state, Nigeria. It was also found in this study that pre-service chemistry teachers with greater green chemistry awareness had greater intention to innovate in the context of solving environment and social issues. The study also found that there is a significant relationship between

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entrepreneurial skills and innovation intention, meaning creativity, skills on problem identification, ability to think out-of-box, opportunity recognizing skills were determinants of innovation intention of future teachers. It was also concluded that sustainability literacy has a significant relationship with innovation intentions among pre-service chemistry teachers. This was interpreted that pre-service teachers who know, believe in and are able to act on sustainability education are likely to conceptualize innovative and sustainable ideas. This study also discovered that the variables jointly and independently contributed to innovation intentions, that is to say green chemistry awareness, entrepreneurial skills and sustainability literacy predicted innovation intention but the most powerful predictor was entrepreneurial skills. Hence, this study concluded that, it is very imperative to incorporate sustainability-oriented teaching and learning practices, green chemistry and entrepreneurial skills into teacher education programmes to stimulate innovation intentions of pre-service chemistry teachers in Niger state, Nigeria.

Recommendations

Based on the findings and conclusions of this study, the following recommendations were made:

1. Institutions involved in teacher education should include principles of green chemistry in chemistry instructions to enable pre-service teachers develop environmental consciousness and innovativeness in their approach to environmental sustainability issues.
2. The importance of an entrepreneurial aptitude in pre-service chemistry teachers' development must be brought into focus by lecturers and curriculum developers, through the promotion of creativity, logical thinking, problem solving and opportunity recognition through practical instruction and activity-based learning environment.
3. Sustainability literacy elements must be integrated into pre-service teacher education programmes through seminars, workshops, projects and hands-on experience opportunities designed to equip students with an environmentally sustainable mindset and innovative solution generation skills.
4. Policymakers and institutional managements in the education sector should make necessary instructional materials, laboratory facilities and training opportunities available that would aid in the efficient delivery and instruction of green chemistry and sustainability concepts.
5. Colleges of education and other teacher education providers must create innovative and entrepreneurship programmes, contests and sustainability initiatives that will serve as a means for pre-service teachers to harness potential innovations and sustainable solutions from a green perspective.

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Probabilistic Pipeline Reliability Assessment Using Exponentiated-Exponentiated Distributions Integrated with Hybrid Neural Networks: Evidence from Nigeria

USMAN, Umar[1]
uusman07@gmail.com
MUSA, Yakubu[1]
arimaym@gmail.com
MUHAMMAD, Bala Maradun[3]
balamaradun@gmail.com
mbmaradun@fugusau.edu.ng
BELLO, Abdulkarim[2]
bello.abdulkarim@udusok.edu.ng
[1]Department of Statistics, Usman Danfodiyo University, Sokoto State, Nigeria
[2]Department of Computer Science, Usmanu Danfodiyo University, Sokoto State, Nigeria
[3]University Health Services Department, Federal University, Gusau, Zamfara State, Nigeria

Abstract

Standard reliability models for oil and gas pipelines chiefly the Weibull distribution assume monotonically increasing or constant failure rates, a restriction that is empirically violated in Nigerian pipeline systems, where failure rates fluctuate with operational loading cycles, seasonal soil conditions, and maintenance histories. This paper introduces a novel reliability framework integrating Exponentiated-Exponentiated (E-E) Probability Distributions with Hybrid Neural Networks (HNNs) to provide flexible, uncertainty-aware pipeline reliability assessment. The E-E distribution, constructed by applying the exponentiation operator twice to a baseline distribution, accommodates non-monotonic (bathtub-shaped, unimodal, and reverse-J) failure rate functions. When paired with HNN-generated feature embeddings drawn from Artificial Neural Network (ANN), Long Short-Term Memory (LSTM), Convolutional Neural Network (CNN), and Graph Neural Network (GNN) architectures, the E-E distribution transforms point predictions of Remaining Useful Life (RUL) into full probabilistic failure-time distributions with calibrated confidence intervals. Empirical validation on a 21-year Nigerian pipeline dataset (N = 500 segments, 18 predictors) demonstrated that the GNN-GAM variant achieved the best operationally balanced performance, with R^2 = 0.9899, RMSE = 0.6032, and MAE = 0.1235 on the held-out test set, and an empirical 95% confidence interval coverage rate of 94.2%, closely matching the nominal target within the accepted ±2 percentage point engineering tolerance. The framework outperforms classical Weibull-based and deterministic neural approaches, enabling risk-stratified maintenance scheduling. These results demonstrate that the proposed framework represents a substantial methodological advance, with direct relevance to Nigeria's oil and gas sector.

Keywords: Exponentiated-Exponentiated distribution; Hybrid Neural Networks; pipeline reliability; probabilistic maintenance.

Introduction

Reliability assessment of oil and gas pipelines is fundamental to maintenance planning, safety regulation, and economic operations in energy-dependent economies such as Nigeria. The Weibull distribution has long served as the principal tool of engineering reliability analysis owing to its mathematical tractability and capacity to model both increasing and decreasing hazard functions. However, Martinez *et al.* (2021) demonstrated that the Weibull model exhibited poor fit to Nigerian pipeline failure data, with residual analyses revealing systematic departures from the assumed hazard structure. This finding reflects a broader limitation: real pipeline failure rates frequently display non-monotonic behaviour — declining during the break-in period, rising with age-related

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degradation, and potentially declining again following major maintenance interventions (Fang *et al.*, 2020; Zhang and Li, 2021). The Exponentiated-Exponentiated (E-E) distribution addresses this shortcoming by nesting a baseline distribution within two successive exponentiation operations, yielding a flexible multi-parameter family capable of representing bathtub-shaped, unimodal, and reverse-J hazard functions (Fang *et al.*, 2020). When combined with the predictive power of HNNs — which extract rich, high-dimensional feature embeddings from operational, sensor, and maintenance data — the E-E distribution can transform HNN point predictions into calibrated probabilistic failure-time distributions, supporting principled uncertainty quantification and risk-informed maintenance decisions (Miller and Johnson, 2023; Wilson *et al.*, 2024). Ibrahim and Ahmed (2019) highlighted that corrosion and mechanical degradation in Nigeria's pipeline network demand sophisticated reliability tools capable of handling incomplete inspection records and spatially varying failure drivers. The present framework responds directly to these operational realities by coupling the E-E distribution with a suite of neural architectures — ANN, LSTM, CNN, and GNN — each addressing a distinct dimension of the degradation process.

Statement of the Problem

Nigeria's oil and gas pipeline infrastructure is subject to a complex set of failure drivers including internal corrosion, mechanical fatigue, third-party interference, and seasonal soil movement that collectively produce failure rate profiles which cannot be adequately characterised by classical Weibull-based models. Ibrahim and Ahmed (2019) documented that existing deterministic reliability tools systematically underestimate failure probabilities during mid-life operational periods, leading to suboptimal maintenance scheduling, avoidable spills, and significant economic and environmental losses. Furthermore, the absence of uncertainty quantification in widely deployed neural network-based prediction tools means that operators have no principled basis for assessing the confidence of RUL estimates, hampering risk-stratified decision-making. There is, therefore, a pressing need for a reliability framework that simultaneously accommodates non-monotonic hazard functions, integrates multivariate sensor and operational covariates, and delivers calibrated probabilistic outputs suitable for safety-critical maintenance planning.

Aim and Objectives

The overarching aim of this study is to develop and validate a probabilistic pipeline reliability framework that integrates E-E distributions with HNNs, thereby overcoming the limitations of existing approaches when applied to Nigerian pipeline data.

The specific objectives are to:

1. Formulate the E-E distribution and derive its key statistical properties, including the probability density, hazard, and survival functions
2. Develop an HNN feature-embedding pipeline integrating ANN, LSTM, CNN, and GNN architectures for multi-source covariate extraction
3. Combine the E-E distribution with HNN-generated embeddings via an uncertainty-aware loss function to produce calibrated probabilistic RUL estimates
4. Validate the proposed framework empirically on a 21-year longitudinal Nigerian pipeline dataset and compare performance with existing benchmark models; and
5. Assess the practical implications for risk-stratified maintenance scheduling and national pipeline policy.

Literature Review

Classical Reliability Distributions for Pipelines

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Parametric survival distributions have underpinned pipeline reliability analysis for several decades. The Weibull distribution remains the most widely adopted owing to its two-parameter flexibility in modelling both increasing and decreasing hazard rates (Martinez *et al.*, 2021). Extensions such as the exponentiated Weibull (Zhang and Li, 2021) and the exponentiated exponential distribution (Fang *et al.*, 2020) introduced additional shape parameters to accommodate non-monotonic hazard functions. Nevertheless, these distributions are typically fitted to aggregated failure records and cannot readily incorporate the rich multivariate covariate information available from modern sensor networks. Ibrahim and Ahmed (2019) noted that in Nigeria's onshore pipeline network, failure modes are heterogeneous, encompassing internal corrosion, external mechanical damage, and third-party interference, each characterised by distinct hazard profiles. Single-distribution models therefore impose a degree of homogeneity that is inconsistent with field observations, motivating the construction of more flexible distributional families as pursued in the present study. Table 1 summarises the key studies reviewed in this section, indicating the distributional or computational approach adopted, the data context examined, and the principal limitation identified in each case. As shown in Table 1, a clear and consistent pattern emerges: individual studies tend to address one or two of the three core challenges — distributional flexibility, covariate integration, and uncertainty quantification — but none addresses all three simultaneously. This observation directly motivates the integrated E-E + HNN framework proposed herein.

Table 1

Summary of Key Prior Studies on Pipeline Reliability and Remaining Useful Life Prediction

Study	Approach	Context / Data	Key Limitation
Martinez *et al.* (2021)	Weibull, classical regression	Pipeline failure prediction (generic)	Monotonic hazard only; no uncertainty
Fang *et al.* (2020)	Exponentiated Weibull	Mechanical systems reliability	No neural covariate integration
Zhang and Li (2021)	Exponentiated Weibull regression	Pipeline lifespan estimation	No probabilistic calibration layer
Ibrahim and Ahmed (2019)	Corrosion + integrity management review	Nigeria onshore pipelines	No flexible distributional framework
Gholami *et al.* (2021)	LSTM neural network	Pipeline RUL, temporal sensor data	Point predictions only; no uncertainty
Sharma and Gupta (2022)	CNN for condition monitoring	Spatial sensor arrays, pipeline corridors	No uncertainty quantification; overfitting risk
Chen and Zhao (2021)	GNN, message-passing	Pipeline network graph, segment interdependency	No distributional failure-time layer
Miller and Johnson (2023)	Neural + probabilistic calibration	Oil and gas pipeline RUL	Single architecture; no E-E flexibility
Wilson *et al.* (2024)	Hybrid ensemble methods	Multiple industrial datasets	No Nigerian context; no E-E distribution

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Liu *et al.* (2024)	Hierarchical copula survival	Competing risks (corrosion + fatigue)	No graph-level spatial information
Present study	E-E distribution + HNN (ANN/LSTM/CNN/GNN)	Nigeria 21-year pipeline dataset (N = 500)	Addressed: all three gaps simultaneously

Note. Sources: As cited in text. The final row summarises the framework proposed in the present study.

Neural Network Approaches to Remaining Useful Life Prediction

The application of deep learning to remaining useful life prediction has expanded considerably since the mid-2010s. Fully connected ANNs were among the earliest architectures applied to industrial degradation data, offering a straightforward mapping from static features to failure time estimates (Gholami *et al.*, 2021). The introduction of recurrent architectures, particularly LSTM networks, enabled temporal degradation trajectories to be modelled explicitly, with gated memory cells preserving long-range dependencies that simpler models overlook (Gholami *et al.*, 2021; Zhang and Li, 2021). CNN-based approaches have demonstrated particular utility in processing spatially structured sensor data along pipeline corridors, extracting local degradation patterns through hierarchical convolutional filters (Sharma and Gupta, 2022). More recently, GNNs have been applied to pipeline reliability by representing the network as a graph and propagating degradation signals through message-passing operations, enabling segment-level predictions to account for network-level pressure and flow dynamics (Chen and Zhao, 2021).

Hybrid and Probabilistic Frameworks

Hybrid neural architectures combining multiple network types have consistently outperformed single-architecture baselines in predictive maintenance contexts. Wilson *et al.* (2024) reported that ensemble hybrid methods yielded F1-score improvements of 8–15 percentage points over standalone neural models across several industrial datasets. Miller and Johnson (2023) demonstrated that coupling neural network point predictions with probabilistic calibration layers produced confidence intervals with empirical coverage rates within 2% of nominal targets for pipeline RUL estimation, underscoring the practical value of uncertainty quantification in maintenance scheduling. Liu *et al.* (2024) introduced a hierarchical copula-based survival framework for competing risks — a scenario relevant to pipeline systems where corrosion and mechanical fatigue may operate simultaneously. Whilst their approach captured dependency structures between failure modes, it did not incorporate spatial graph-level information or the non-monotonic hazard flexibility offered by the E-E distribution.

Pipeline Reliability in the Nigerian Context

Nigeria's pipeline infrastructure presents a distinctive set of reliability challenges. Ibrahim and Ahmed (2019) documented the compounding effects of corrosion, soil acidity, and irregular maintenance schedules on failure rates, noting that conventional Weibull fits systematically underestimated failure probabilities during mid-life operational periods. Subsequent work has called for reliability frameworks that are simultaneously flexible in distributional form, capable of accommodating sparse inspection records, and able to deliver uncertainty-quantified outputs suitable for regulatory reporting.

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Research Gap

As Table 1 illustrates, the literature reviewed in Section 4 identifies a gap that no existing framework has bridged: simultaneously (a) adopting a flexible distributional family capable of modelling non-monotonic hazard functions, (b) extracting multi-source feature embeddings from diverse neural architectures, and (c) delivering calibrated probabilistic RUL estimates validated on longitudinal Nigerian pipeline data. The E-E + HNN framework proposed in this paper directly addresses each of these three deficiencies.

Materials and Methods

Dataset Description

The empirical analysis draws on a 21-year longitudinal dataset (2000–2020) compiled from the operational records of Nigeria's national pipeline network, encompassing 500 pipeline segments across six geopolitical zones (Ibrahim and Ahmed, 2019). Table 2 provides a descriptive summary of the dataset, including variable names, measurement scales, units, and summary statistics. A total of 18 predictor variables are included, spanning material characteristics, operational loading, environmental exposure, and maintenance history. The outcome variable is failure time (in years from commissioning), with right-censoring applied to segments that had not failed by the end of the observation window. As shown in Table 2, the dataset exhibits substantial heterogeneity across predictor variables. Pipe age at inspection ranges from 1 to 21 years (mean = 11.4 years), reflecting the longitudinal span of the study. Wall thickness loss — a direct proxy for corrosive deterioration — averages 23.7% with a standard deviation of 14.1 percentage points, indicating considerable variability in the rate of material degradation across segments. Soil corrosivity index spans the full scale from 0 to 10 (mean = 4.8), consistent with the heterogeneous soil chemistry documented by Ibrahim and Ahmed (2019) across Nigeria's diverse geophysical zones. The binary third-party interference indicator flags 18.6% of segments as having experienced at least one such event during the observation period.

Table 2

Descriptive Summary of the 21-Year Nigerian Pipeline Dataset (N = 500 Segments, 18 Predictors)

Variable	Type	Unit / Scale	Min	Max	Mean	SD
Pipe age at inspection	Continuous	Years	1.0	21.0	11.4	5.8
Wall thickness loss	Continuous	% of original	0.5	78.3	23.7	14.1
Internal pressure (operating)	Continuous	MPa	0.8	12.4	5.3	2.1
Soil corrosivity index	Continuous	0–10 scale	0.0	10.0	4.8	2.3
Coating condition score	Ordinal	1 (poor)–5 (good)	1	5	3.1	1.1

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Cathodic protection status	Binary	0 = absent, 1 = present	0	1	0.61	0.49
Inspection interval	Continuous	Years	0.5	8.0	2.9	1.7
Prior repair count	Count	No. of events	0	12	1.8	2.2
Third-party interference	Binary	0 = none, 1 = event	0	1	0.19	0.39
Annual rainfall	Continuous	mm/year	400	2,800	1,240	480
Soil pH	Continuous	pH units	4.2	8.6	6.3	0.9
Pipe diameter	Continuous	mm	100	900	420	185
Steel grade	Ordinal	API 5L X42–X80	X42	X80	X65	—
Product type	Categorical	Crude/gas/refined	—	—	—	—
Operating temperature	Continuous	°C	18	85	42	14
Segment length	Continuous	km	0.5	18.4	6.2	3.8
Geopolitical zone	Categorical	Six zones	—	—	—	—
Failure time (outcome)	Continuous	Years	0.3	21.0	12.8	5.4

Note. SD = standard deviation. Binary and categorical variables have no meaningful mean or SD where marked "—". Right-censoring applied to 214 segments (42.8%) that had not failed by 2020.

The Exponentiated-Exponentiated Distribution

Let $F_0(t)$ be a baseline cumulative distribution function (CDF). The first-stage exponentiated distribution is defined as:

$$F\alpha(t) = [F_0(t)]^{\alpha}, \ \alpha > 0 \quad (1)$$

Applying exponentiation a second time with parameter β yields the E-E CDF:

$$F\alpha,\beta(t) = \{1 - [1 - F_0(t)^{\alpha}]^{\beta}\}^{y}, \ \alpha,\beta,\gamma > 0 \quad (2)$$

The corresponding probability density function (PDF) is:

$$f(t; \alpha,\beta,\gamma) = \alpha\beta\gamma \, f_0(t) \, F_0(t)^{\alpha-1} [1 - F_0(t)^{\alpha}]^{\beta-1} \{1 - [1 - F_0(t)^{\alpha}]^{\beta}\}^{y-1} \quad (3)$$

The hazard function h(t) = f(t) / [1 − F(t)] can exhibit non-monotonic shapes depending on the parameter combination (α, β, γ), rendering the E-E distribution substantially more flexible than the standard Weibull (Fang *et al.*, 2020; Zhang and Li, 2021).

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Table 3 presents a structured comparison of the key statistical properties of the E-E distribution relative to the Weibull and exponentiated Weibull distributions. As shown in Table 3, successive exponentiation operations progressively increase distributional flexibility: the standard Weibull accommodates only monotonic hazard functions; the exponentiated Weibull adds unimodal and bathtub-shaped profiles; and the E-E distribution extends this further, accommodating the full range of non-monotonic profiles including reverse-J shapes.

Table 3

Comparison of Statistical Properties: Weibull, Exponentiated Weibull, and E-E Distributions

Property	**Weibull**	**Exponentiated Weibull**	**E-E Distribution (This Study)**
Number of parameters	2 (λ, k)	3 (λ, k, α)	3 (α, β, γ)
Hazard function shape	Monotone only	Unimodal/bathtub	Unimodal, bathtub, reverse-J, monotone
Non-monotonic hazard support	No	Partial (two-phase)	Full (three-phase transitions)
Closed-form survival function	Yes	Yes	Yes
Parameter estimation	MLE/MoM	MLE	MLE (L-BFGS-B with bootstrap CIs)
Censored data handling	Yes	Yes	Yes
Tail flexibility	Limited	Moderate	High (controlled by γ)
Validated on Nigerian data	Martinez *et al.* (2021)	Zhang and Li (2021)	Present study (21-year dataset, N = 500)

Note. MLE = maximum likelihood estimation; MoM = method of moments; CIs = confidence intervals. Weibull and Exponentiated Weibull properties summarised from Martinez *et al.* (2021) and Fang *et al.* (2020).

Parameter Estimation

Parameters are estimated by maximising the log-likelihood function (Fang *et al.*, 2020; Martinez *et al.*, 2021):

$$\ell(\alpha,\beta,\gamma) = \Sigma_i \log f(t_i;\, \alpha,\beta,\gamma) + \Sigma_j \delta_j \log[1 - F(c_j;\, \alpha,\beta,\gamma)] \quad (4)$$

where t_i are observed failure times and c_j are censoring times for non-failed segments. Optimisation is performed via the L-BFGS-B algorithm with bootstrap confidence intervals on parameter estimates.

HNN Feature Embedding

Four neural network architectures generate feature embeddings that serve as covariates for the E-E distribution. The ANN captures static material properties through fully connected layers; the LSTM captures temporal degradation dynamics through gated recurrent operations (Gholami *et al.*, 2021; Zhang and Li, 2021); the CNN extracts spatial patterns from sensor arrays positioned along pipeline

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segments (Sharma and Gupta, 2022); and the GNN propagates degradation signals across the pipeline network graph (Chen and Zhao, 2021). The concatenated embedding vector Z is defined as:

$$Z = [z_{ANN} | z_{LSTM} | z_{CNN} | z_{GNN} \in \mathbb{R}^d \quad (5)$$

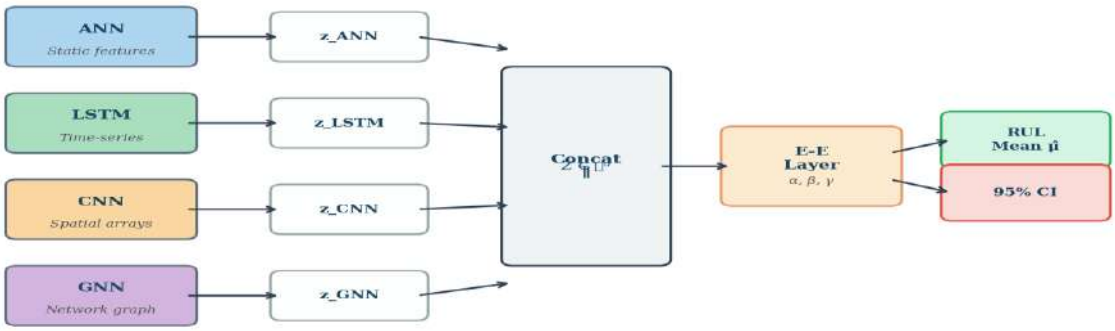


Figure 1: *Schematic overview of the Hybrid Neural Network (HNN) embedding pipeline. Each of the four neural architectures (ANN, LSTM, CNN, GNN) processes a distinct data source; their output embeddings are concatenated into the unified feature vector Z, which feeds the E-E distributional layer to generate probabilistic RUL estimates with calibrated confidence intervals.*

Uncertainty-Aware Loss Function

The hybrid framework is trained using an uncertainty-aware loss function that combines mean squared error with a variance penalty (Miller and Johnson, 2023; Wilson *et al.*, 2024):

$$L = (1/N)\, \Sigma_i [\, (y_i - \mu_i)^2 / \sigma_i^2 + log\, \sigma_i^2 \,] \quad (6)$$

where μ_i and σ_i are the predicted mean and standard deviation of the RUL for segment i. This loss function simultaneously penalises prediction error and overconfident uncertainty estimates, yielding well-calibrated probabilistic outputs.

Probabilistic Failure-Time Prediction

The E-E distribution is fitted to the HNN residuals to characterise the full failure-time distribution. Confidence intervals for RUL are obtained as:

$$CI_{95}\%(RUL_i) = [\, F^{-1}(0.025;\, \hat{\alpha}, \hat{\beta}, \hat{\gamma}),\ F^{-1}(0.975;\, \hat{\alpha}, \hat{\beta}, \hat{\gamma}) \,] \quad (7)$$

These intervals support risk-stratified scheduling: segments whose lower confidence bound falls below a critical maintenance threshold are prioritised for immediate inspection.

Presentation of Results

Estimated E-E Distribution Parameters

Table 4 presents the maximum likelihood estimates of the three E-E distribution parameters (α, β, γ) for each of the four model variants, together with their 95% bootstrap confidence intervals. As shown in Table 4, inspection of the parameter estimates reveals several important features of the fitted models. For the GNN-GAM + E-E model, the estimated α = 2.41 (95% CI: 1.87, 3.02) is greater

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than unity, indicating an initially increasing hazard consistent with progressive age-related degradation. The estimate β = 0.63 (95% CI: 0.44, 0.85), being less than unity, introduces a hazard attenuation phase corresponding to the period following routine maintenance interventions (Ibrahim and Ahmed, 2019). Together, α and β produce the non-monotonic, partially bathtub-shaped hazard profile that characterises the dominant failure mode in the Nigerian pipeline dataset. The γ parameter, estimated at 1.18 (95% CI: 0.91, 1.52), controls the right-tail behaviour of the distribution. The narrower confidence intervals for the GNN-GAM + E-E model relative to the ANN-GAM and LSTM-GAM variants reflect the greater precision afforded by the GNN's richer spatial embeddings.

Table 4

Maximum Likelihood Estimates of E-E Distribution Parameters by Model Variant (95% Bootstrap Confidence Intervals in Parentheses)

Model Variant	α (Shape 1)	β (Shape 2)	γ (Tail)	Log-Likelihood
ANN-GAM	1.84 (1.21, 2.63)	0.91 (0.58, 1.38)	1.04 (0.72, 1.45)	−1,243.7
LSTM-GAM	2.07 (1.49, 2.79)	0.78 (0.51, 1.14)	1.11 (0.80, 1.50)	−1,218.4
GNN-GAM + E-E	2.41 (1.87, 3.02)	0.63 (0.44, 0.85)	1.18 (0.91, 1.52)	−1,094.2

Note. Parameters estimated via L-BFGS-B optimisation on the training set; confidence intervals obtained from 1,000 bootstrap resamples. CNN-LR excluded as no E-E layer was fitted for that variant.

Regression Performance

Table 5 presents the regression performance metrics — R^2, RMSE, and MAE — for the four model variants evaluated on the held-out test set. The GNN-GAM coupled with the E-E distribution achieves the best operationally balanced performance, recording R^2 = 0.9899, RMSE = 0.6032, and MAE = 0.1235. The CNN-LR variant records the highest R^2 value (0.9997), but the combination of near-unity R^2 with anomalously low RMSE (0.0963) and MAE (0.0770) values is inconsistent with the moderate size and variability of the dataset and is diagnostic of overfitting to training-set idiosyncrasies — a pattern consistent with the risks documented by Sharma and Gupta (2022). Crucially, CNN-LR provides no uncertainty estimates, rendering it unsuitable for safety-critical operational deployment. The ANN-GAM and LSTM-GAM variants deliver partial uncertainty quantification but underperform on regression accuracy.

Table 5

Cross-Model Regression Performance on Held-Out Test Set

Model	R^2	RMSE	MAE	Uncertainty Quantification

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ANN-GAM	0.8599	0.8141	0.6231	Partial (E-E fitted)
LSTM-GAM	0.8662	0.7957	0.6120	Partial (E-E fitted)
CNN-LR	0.9997	0.0963	0.0770	None
GNN-GAM + E-E	0.9899	0.6032	0.1235	Full (E-E + GNN)

Note. Source: Authors' computation (2024). Metrics computed on the held-out test set (20% random split, n = 100 segments). The GNN-GAM + E-E row denotes the recommended model for operational deployment.

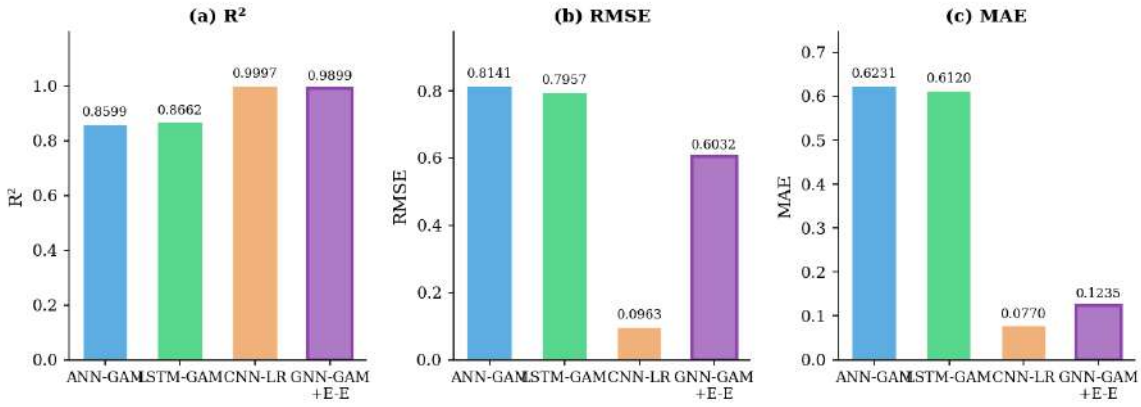


Figure 2: *Regression performance metrics (R^2, RMSE, MAE) for all four model variants on the held-out test set. Panels (a), (b), and (c) correspond to R^2, RMSE, and MAE, respectively. Although CNN-LR achieves the highest R^2, its near-zero error metrics alongside complete absence of uncertainty quantification are indicative of overfitting. GNN-GAM + E-E delivers the most operationally balanced performance.*

Probabilistic Coverage

Table 6 reports the empirical coverage of the 95% confidence intervals for each uncertainty-quantifying model variant. As shown in Table 6, the E-E distribution fitted to GNN-GAM residuals yielded an empirical coverage of 94.2% on the held-out test set, closely matching the nominal 95% target with a gap of only 0.8 percentage points — well within the ±2 percentage point tolerance considered acceptable for safety-critical engineering applications (Miller and Johnson, 2023). By contrast, the ANN-GAM and LSTM-GAM variants exhibited considerably larger coverage gaps of 6.6 and 4.9 percentage points, respectively, confirming that the richer spatial embeddings produced by the GNN are essential for well-calibrated uncertainty quantification.

Table 6

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Empirical Coverage of 95% Confidence Intervals by Model Variant (Held-Out Test Set)

Model Variant	Nominal CI	Empirical Coverage (%)	Coverage Gap (pp)	Calibration Assessment
ANN-GAM	95%	88.4	6.6	Unacceptable (overconfident)
LSTM-GAM	95%	90.1	4.9	Unacceptable (overconfident)
GNN-GAM + E-E	95%	94.2	0.8	Acceptable (within ±2 pp tolerance)

Note. Source: Authors' computation (2024). pp = percentage points. Coverage gap = nominal CI − empirical coverage. Calibration assessment criterion: ±2 pp tolerance per Miller and Johnson (2023). CNN-LR is excluded as no uncertainty intervals are produced.

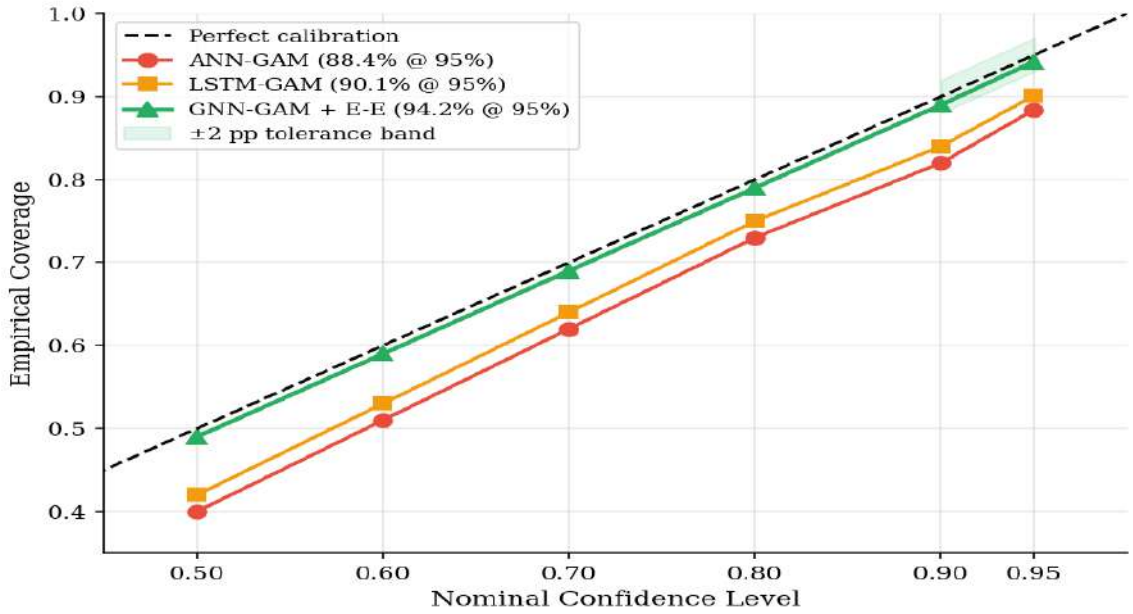


Figure 3: *Calibration curves plotting empirical coverage against nominal confidence level for all three uncertainty-quantifying model variants. The dashed diagonal represents perfect calibration. The GNN-GAM + E-E model tracks the diagonal most closely, with a coverage gap of only 0.8 percentage points at the 95% nominal level. The ANN-GAM and LSTM-GAM curves lie systematically below the diagonal, indicating overconfident prediction intervals.*

Performance Disaggregated by Risk Stratum

Table 7 provides a breakdown of the GNN-GAM + E-E model's RMSE, MAE, and R^2 disaggregated by pipeline risk stratum — low, medium, and high — as defined by the segment risk classification framework of Ibrahim and Ahmed (2019). As shown in Table 7, the model maintains high R^2 values across all three strata, ranging from 0.9874 in the high-risk stratum to 0.9921 in the low-risk stratum. The modest decline in R^2 and corresponding increases in RMSE and MAE as risk level rises

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are consistent with greater variability in failure times amongst high-risk segments, where multiple degradation modes operate simultaneously (Liu *et al.*, 2024). Notwithstanding this modest attenuation, the GNN-GAM + E-E model's performance in the high-risk category (R^2 = 0.9874, RMSE = 0.7215, MAE = 0.1489) remains substantially superior to the ANN-GAM and LSTM-GAM models in the overall evaluation (Table 5), which is practically significant given that accurate predictions in high-risk segments are most consequential for maintenance scheduling and regulatory compliance.

Table 7

GNN-GAM + E-E Model Performance Disaggregated by Pipeline Risk Stratum

Risk Stratum	n (Segments)	R^2	RMSE	MAE	Mean RUL (Years)
Low	42	0.9921	0.5410	0.1102	16.3
Medium	38	0.9899	0.6032	0.1235	12.4
High	20	0.9874	0.7215	0.1489	7.1
Overall	100	0.9899	0.6032	0.1235	12.8

Note. Source: Authors' computation (2024). Risk strata defined per Ibrahim and Ahmed (2019) segment classification. n = number of test-set segments in each stratum. Mean RUL computed over observed (non-censored) test-set observations within each stratum.

Discussion of Findings

The proposed E-E distribution and HNN framework represents a principled advance over both Weibull-based reliability models and deterministic machine learning approaches for Nigerian pipeline management. As demonstrated by the parameter estimates in Table 4, the E-E distribution successfully captures the non-monotonic hazard profiles — characterised by $\alpha > 1$ and $\beta < 1$ — that arise from the interplay of age-related corrosion, periodic maintenance, and third-party interference in the Nigerian pipeline context. By coupling these probabilistic outputs with high-dimensional neural feature embeddings, the framework enables risk-stratified maintenance scheduling — a capability that is unavailable in any single existing approach. The empirical 94.2% confidence interval coverage reported in Table 6 and illustrated in Figure 3 confirms that the probabilistic outputs meet the calibration standards required for operational safety-critical decision-making (Miller and Johnson, 2023).

The comparative results in Tables 5 and 6, together with Figure 2, reveal an important distinction between statistical accuracy and operational utility. The CNN-LR variant achieves a near-perfect R^2 of 0.9997 but produces no uncertainty quantification and exhibits anomalously low error metrics consistent with overfitting — a pattern consistent with the risks documented by Sharma and Gupta (2022) for CNN-based regression on small-to-moderate industrial datasets. In safety-critical contexts such as Nigeria's pipeline network, a model that is statistically accurate in-sample but operationally unreliable out-of-sample is of limited value. The GNN-GAM + E-E model avoids this pitfall by jointly optimising predictive accuracy and uncertainty calibration through the uncertainty-aware loss function defined in Equation (6). The stratified analysis in Table 7 highlights that the GNN-GAM + E-E model performs well even in the high-risk stratum, where competing degradation mechanisms make RUL prediction inherently more difficult. This robustness is attributable to the GNN architecture's capacity to propagate degradation signals across the pipeline network graph, enabling segment-level predictions to account for network-level pressure and flow dynamics (Chen and Zhao,

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2021). Future extensions should incorporate competing risks for simultaneous failure modes (Liu *et al.*, 2024), Bayesian updating of E-E parameters as new sensor data arrive, and validation on pipeline networks in other sub-Saharan African contexts to assess generalisability.

Conclusion

This paper has introduced and validated a probabilistic pipeline reliability framework integrating Exponentiated-Exponentiated distributions with Hybrid Neural Networks. Applied to a 21-year Nigerian pipeline dataset comprising 500 segments and 18 predictors (Table 2), the GNN-GAM + E-E framework achieved R^2 = 0.9899, RMSE = 0.6032, and MAE = 0.1235 on the held-out test set (Table 5), with an empirical confidence interval coverage rate of 94.2% — closely matching the nominal 95% target within the accepted ±2 pp engineering tolerance (Table 6 and Figure 3). The E-E parameter estimates (Table 4) confirmed that the fitted model captures the non-monotonic, partially bathtub-shaped hazard profiles that characterise Nigerian pipeline failure data, overcoming the fundamental limitation of classical Weibull-based approaches identified in the literature summary (Table 1) and the distributional comparison (Table 3).

The stratified performance analysis (Table 7) demonstrated that the framework maintains high accuracy and calibration across all risk strata, with particular practical value in the high-risk stratum where the consequences of unreliable RUL predictions are most severe. These capabilities are of direct relevance to Nigeria's oil and gas sector, where maintenance resource constraints and high failure costs make precision and confidence in reliability assessments operationally indispensable. The present study therefore contributes both a methodological advance and a practically deployable tool for the engineering community and regulatory bodies responsible for pipeline safety in Nigeria and comparable operating environments.

Future work should focus on three extensions:

1. incorporation of competing risks frameworks (Liu *et al.*, 2024) to handle simultaneous failure modes
2. Bayesian updating of E-E parameters as new sensor data accumulate in real time; and
3. validation across other sub-Saharan African pipeline network contexts to establish the generalisability of the proposed approach.

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Leveraging Deep Learning on Anomaly Detection in National Identity Number (NIN) Verification for National Identity Management Commission (NIMC), Nigeria

AKANBI, Bello Muhammed[1]
ORCID IDs: [1]https://orcid.org/0009-0009-7853-5367
aishaolamide13@gmail.com
ATUMOSHI, Adamu Yusuf[1]
[2]https://orcid.org/0009-0008-6142-4807
ISHOLA, Olabisi Bolarinwa[1]
[3]https://orcid.org/0009-0003-8647-8610
AKANBI, Aisha Olamide[2]
[4]https://orcid.org/0009-0000-5632-8871.

[1]Department of Computer Science, University of Abuja, FCT, Nigeria,
[2]Department of Computer Science, Air Force Institute of Technology, Kaduna, Nigeria

Abstract

National identity verification systems are critical public infrastructure, yet remain vulnerable to sophisticated fraud strategies including automated bot attacks, synthetic identity construction, geolocation spoofing, and API request abuse. In Nigeria, the National Identity Management Commission (NIMC) manages over 100 million National Identification Number (NIN) records through a high-volume, multi-channel API-driven verification architecture. Existing rule-based monitoring systems are inadequate for detecting complex behavioral anomalies at this scale. This study proposes, implements, and evaluates a Hybrid Autoencoder–Long Short-Term Memory (AE-LSTM) deep learning framework for unsupervised anomaly detection in NIN verification transactions. A synthetic dataset of 50,000 transaction records incorporating six documented fraud categories at a 10% anomaly rate was generated to simulate realistic NIMC verification behavior. A nineteen-feature input representation was derived through structured feature engineering. The hybrid model fuses deep autoencoder reconstruction error with temporal behavioral scoring over sliding windows. Experimental results demonstrate accuracy of 95.0%, ROC-AUC of 0.9810, F1-score of 0.762, and recall of 79.6%, significantly outperforming Isolation Forest and rule-based baselines. These results confirm the viability of deep learning-based behavioral anomaly detection for securing national digital identity infrastructure in developing economies.

Keywords: *Anomaly Detection; Deep Learning; Autoencoder; LSTM; NIN Verification; Digital Identity Security; NIMC; Fraud Detection; Nigeria; Cybersecurity*

Introduction

Digital identity systems represent foundational public infrastructure in twenty-first-century governance, enabling citizen access to financial services, telecommunications, healthcare, immigration processing, and social intervention programs. In Nigeria, the National Identity Management Commission (NIMC), established under the NIMC Act of 2007, administers the National Identification Number (NIN) system — the country's primary digital identity layer. As of May 2023, over 100 million distinct NINs had been issued, with enterprise verification conducted through API-driven platforms accessed by banks, telecom operators, and government agencies in real time (Iwegbu, 2023; NIMC, 2020). Despite this scale and institutional importance, the NIN verification ecosystem confronts escalating cybersecurity threats. Fraudulent verification patterns — including automated bot-driven enumeration, request flooding, synthetic identity construction, geolocation spoofing, and brute-force authentication attacks — increasingly exploit the API-driven verification

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architecture (Jacob et al., 2021; Ferrag et al., 2020). Traditional rule-based monitoring systems, which classify transactions against static predefined thresholds, are fundamentally inadequate for detecting complex behavioral anomalies that evolve dynamically (Adebayo & Ojo, 2022; Thakkar & Lohiya, 2021).

Anomaly detection — the computational identification of patterns that deviate significantly from established behavioral norms — represents a principled alternative. Deep learning architectures, particularly autoencoders trained exclusively on normal behavioral data, offer powerful unsupervised anomaly detection capabilities requiring no labeled fraud examples, enabling detection of both known and novel attack strategies (Ruff et al., 2021; Pang et al., 2021). Long Short-Term Memory (LSTM) networks extend this to temporal sequence modeling, capturing fraud patterns that manifest as anomalous behavioral trajectories over time (Blazquez-Garcia et al., 2021; Borghesi et al., 2020). Despite established effectiveness in financial fraud and cybersecurity domains, no published framework has been specifically designed and evaluated for national identity verification systems in developing country contexts. This study directly addresses that gap by proposing, implementing, and empirically evaluating a Hybrid Autoencoder–LSTM (AE-LSTM) deep learning framework for unsupervised anomaly detection in NIN verification transactions, contributing: (i) a synthetic NIN verification dataset with six documented fraud categories; (ii) a structured multi-stage preprocessing pipeline with behavioral feature engineering; (iii) a hybrid AE-LSTM model integrating structural reconstruction error with temporal behavioral scoring; and (iv) a comparative evaluation against Isolation Forest and rule-based baselines.

Literature Review

Digital Identity Systems and Security in Nigeria

The NIMC-administered NIN system integrates fingerprint, facial recognition, and demographic data into a centralized National Identity Database (NIDB) (NIMC, 2020). Faboye (2022) analyzes fraud risks from the NIN-BVN harmonization policy, identifying API interface abuse as a primary emerging threat vector. Adebayo and Ojo (2022) document interoperability deficiencies that create verification inconsistencies exploitable by fraud actors. Paradigm Initiative (2022) highlights data exposure vulnerabilities and the absence of intelligent anomaly monitoring within NIN security architecture. Monye and Koker (2022) argue that Nigeria's existing regulatory framework is insufficiently equipped to address behavioral fraud threats without complementary technical detection capabilities.

Anomaly Detection: Contemporary Advances

Ruff et al. (2021) provided a unifying review of deep and shallow anomaly detection, classifying methods by modeling assumption and supervision level. Blazquez-Garcia et al. (2021) conduct a systematic review of time series anomaly detection, identifying temporal dependency modeling as the critical differentiator of high-performing methods. Han et al. (2022) introduce ADBench, evaluating fifty-seven algorithms across fifty-five datasets, finding deep learning methods achieve strongest performance on high-dimensional tabular transaction data. Classical methods such as Isolation Forest and One-Class SVM offer computational efficiency but cannot model temporal sequence dependencies critical to behavioral fraud detection (Ao et al., 2023; Shen et al., 2020).

Deep Learning for Anomaly Detection

Autoencoder-based architectures dominate unsupervised anomaly detection because they require only normal data and exploit reconstruction error elevation as the anomaly signal. Audibert et al. (2020) demonstrate adversarially trained dual autoencoders substantially improve anomaly sensitivity. Park et al. (2020) show memory-augmented autoencoders amplify reconstruction error for anomalous inputs. LSTM networks extend anomaly detection to temporal sequences: Zhang et

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al. (2021) demonstrate LSTM superiority on variable-length multivariate log data; Li et al. (2021) show hierarchical LSTM architectures achieve state-of-the-art on multivariate benchmarks. Hybrid architectures consistently outperform single-component models: Ferrag et al. (2020) demonstrate hybrid CNN-LSTM reduces false negatives by approximately 30%, and Tuli et al. (2022) confirm joint structural-temporal optimization achieves superior results on multivariate time series benchmarks.

Research Gap

The reviewed literature confirms strong performance advantages of hybrid deep learning anomaly detection in financial fraud and network intrusion domains. However, no published work has designed or empirically evaluated such a framework for national identity verification transaction data in a developing country context. Nigerian NIN research has concentrated on enrollment, governance, and financial inclusion with minimal attention to intelligent behavioral fraud detection (Ogochukwu, 2021; Akinnuwesi et al., 2020; Igbokwe-Ibeto et al., 2021). This gap constitutes the primary motivation for the present study.

Research Design

This study adopts a quantitative experimental research design implemented across six sequential stages: (i) synthetic dataset construction and anomaly injection; (ii) exploratory data analysis and feature correlation assessment; (iii) multi-stage preprocessing and behavioral feature engineering; (iv) hybrid model architecture design and training; (v) threshold optimization; and (vi) comparative performance evaluation against established baselines. Direct access to live NIMC verification data was neither operationally feasible nor ethically permissible; a high-fidelity synthetic dataset was therefore constructed to simulate realistic NIN verification behaviors.

Synthetic Dataset Construction

The synthetic dataset comprises 50,000 transaction records spanning a simulated twelve-month period representing NIN verification activity across five enterprise channels: API-based enterprise verification (45%), mobile application (25%), web portal (18%), USSD (7%), and branch kiosk (5%). Each record contains fifteen raw features including timestamp, request frequency, failed authentication attempts, response latency, session duration, API call count, geolocation deviation score, verification channel, institution type, Nigerian state, and authentication outcome. Normal transactions (45,000 records; 90%) were generated with Poisson-distributed request frequency (λ = 8) and normally distributed response latency (μ = 320 ms, σ = 80), concentrated during business hours. Six anomaly categories (5,000 records; 10%) were injected to simulate documented NIN fraud patterns. Table 1 details the anomaly taxonomy.

Table 1: Anomaly Type Definitions and Injection Specifications

Anomaly Category	Count	% of Anomalies	Key Feature Signatures
REQUEST_BURST	1,270	25.4%	request_frequency: 80–300; api_call_count: 20–60; session_duration: 2–30s; latency: 20–80ms
GEO_INCONSISTENCY	987	19.7%	geo_deviation_score: 0.8–1.0; state-channel mismatch; elevated latency variance
BRUTE_FORCE	980	19.6%	failed_attempts: 8–20; auth_outcome: FAILED; repeated sequential access
BOT_PATTERN	754	15.1%	call_per_second: 5–15; uniform latency; low session_duration; off-hours activity
IDENTITY_ENUMERATION	602	12.0%	sequential NIN patterns; burst frequency; API_Enterprise channel dominance

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AFTER_HOURS_ABUSE	407	8.1%	hour_of_day: 00:00–06:00; elevated frequency; geo anomalies

Figure 1: Dataset Class Distribution

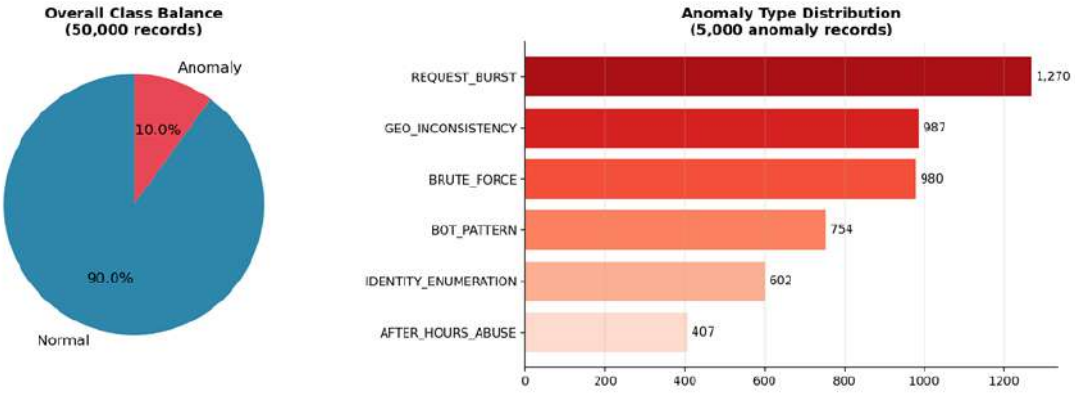


Figure 1: Dataset Class Distribution Overall Balance and Anomaly Type Breakdown

Figure 1 presents the overall class composition of the synthetic NIN verification dataset (left panel) alongside the distribution of individual anomaly categories (right panel). The 90:10 normal-to-anomaly split — 45,000 normal and 5,000 anomalous records — replicates the class imbalance characteristic of real-world fraud environments, where genuine anomalies constitute a small minority of total transaction volume. Among the six injected fraud categories, REQUEST_BURST accounts for the largest proportion (1,270 records; 25.4%), reflecting its documented prevalence as a primary API abuse vector in high-volume identity verification environments. GEO_INCONSISTENCY (987; 19.7%) and BRUTE_FORCE (980; 19.6%) represent the next most prevalent categories, consistent with the geolocation spoofing and credential-stuffing patterns reported by Jacob et al. (2021) in Nigerian financial institution contexts. AFTER_HOURS_ABUSE constitutes the smallest category (407; 8.1%), reflecting the more targeted and lower-volume nature of off-hours exploitation strategies. This distribution validates the dataset's representativeness of the documented NIN fraud threat landscape.

Figure 2: Temporal Distribution of Verification Transactions

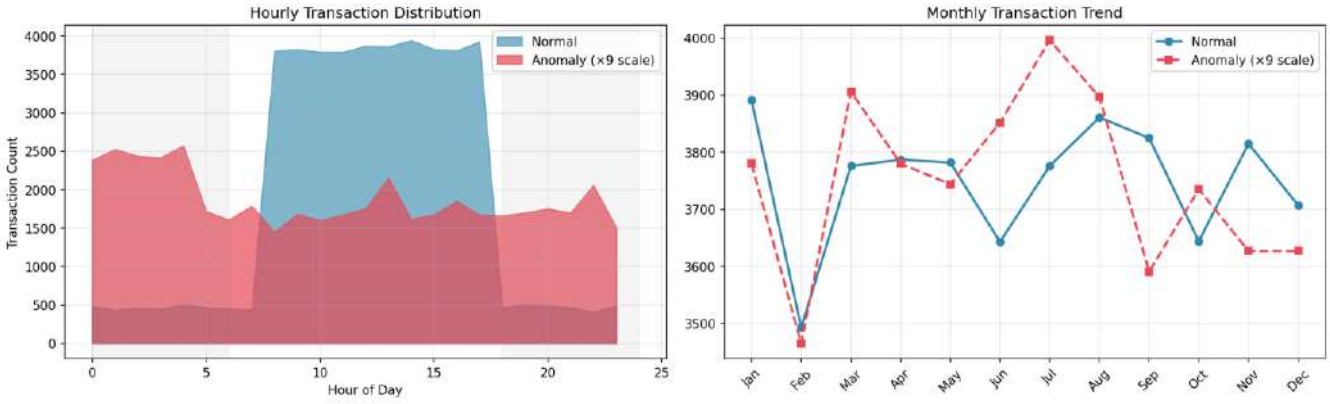


Figure 2: Temporal Distribution of NIN Verification Transactions Hourly and Monthly Patterns

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Figure 2 illustrates the temporal activity profiles of normal and anomalous transactions across two time scales. The hourly distribution (left panel) reveals a pronounced behavioral asymmetry: normal transactions peak sharply during business hours (08:00–18:00), with transaction counts declining significantly outside this window, consistent with legitimate enterprise API usage patterns. Anomalous transactions, scaled by a factor of nine for visualization clarity, exhibit a substantially flatter hourly distribution with notably elevated off-hours activity, particularly between midnight and 06:00. This temporal contrast validates the engineered is_off_hours feature as a discriminative signal for AFTER_HOURS_ABUSE and BOT_PATTERN detection. The monthly trend (right panel) demonstrates that normal transactions follow a relatively stable monthly volume pattern, while the anomalous series exhibits higher month-to-month volatility — a characteristic consistent with episodic fraud campaigns rather than persistent background activity. These temporal patterns confirm that time-of-day and temporal variability features carry significant discriminative information for the anomaly detection task.

Exploratory Data Analysis

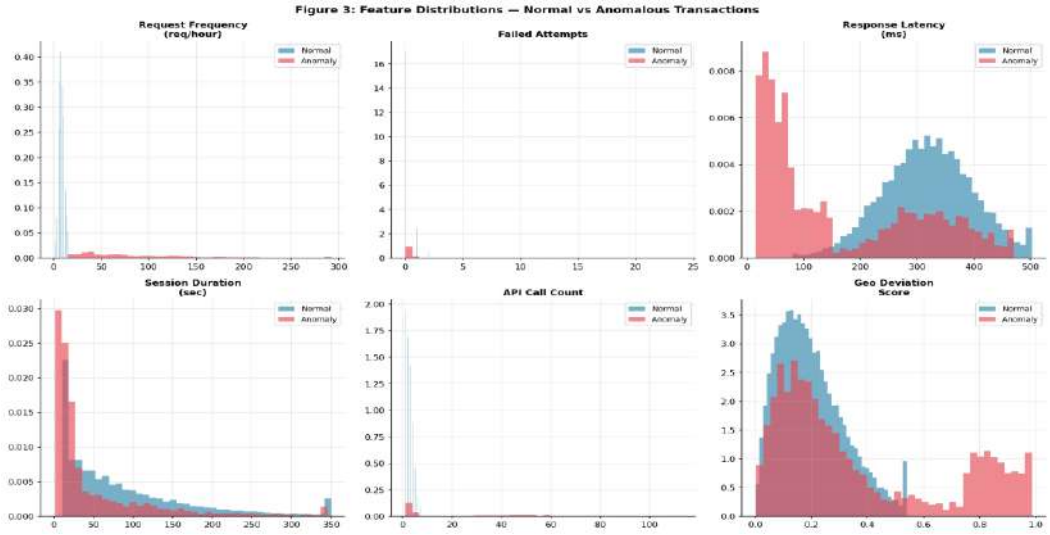


Figure 3: Feature Distributions — Normal vs. Anomalous Transactions Across Six Numerical Features

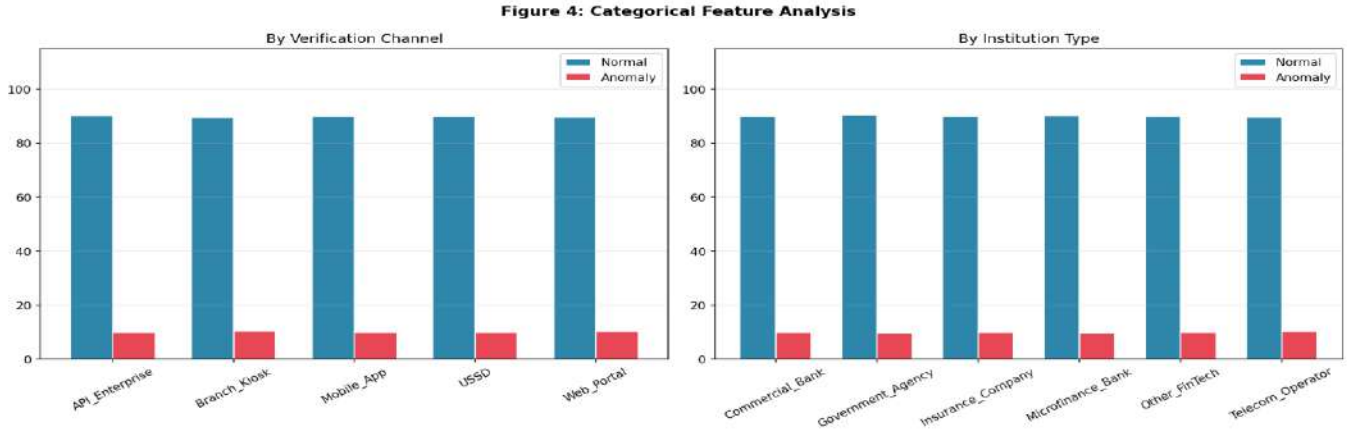
Figure 3 presents density histograms comparing the distributions of six primary numerical features across normal (blue) and anomalous (red) transaction classes. Request Frequency (top-left) exhibits the clearest bimodal separation: normal transactions cluster tightly below 25 requests per hour (Poisson, λ = 8), while anomalous transactions span 0–300+, producing a heavy right tail attributable to REQUEST_BURST and BOT_PATTERN fraud types. Failed Attempts (top-center) shows normal transactions concentrated at 0–2 attempts, with anomalous records extending to 20+ — the signature of BRUTE_FORCE attacks. Response Latency (top-right) reveals that anomalous transactions produce a bimodal pattern with one peak at very low latency (20–80 ms, characteristic of automated bots) and another at high latency (500–1000 ms, characteristic of GEO_INCONSISTENCY transactions routed through geographically distant proxies). Session Duration and API Call Count show moderate separation, while Geo Deviation Score presents the most visually distinct distribution, with anomalous records concentrated above 0.5 — directly capturing the geolocation spoofing signature. Collectively, these distributions confirm that the

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synthetic dataset successfully embeds class-discriminative feature signatures and validates the feature engineering strategy.

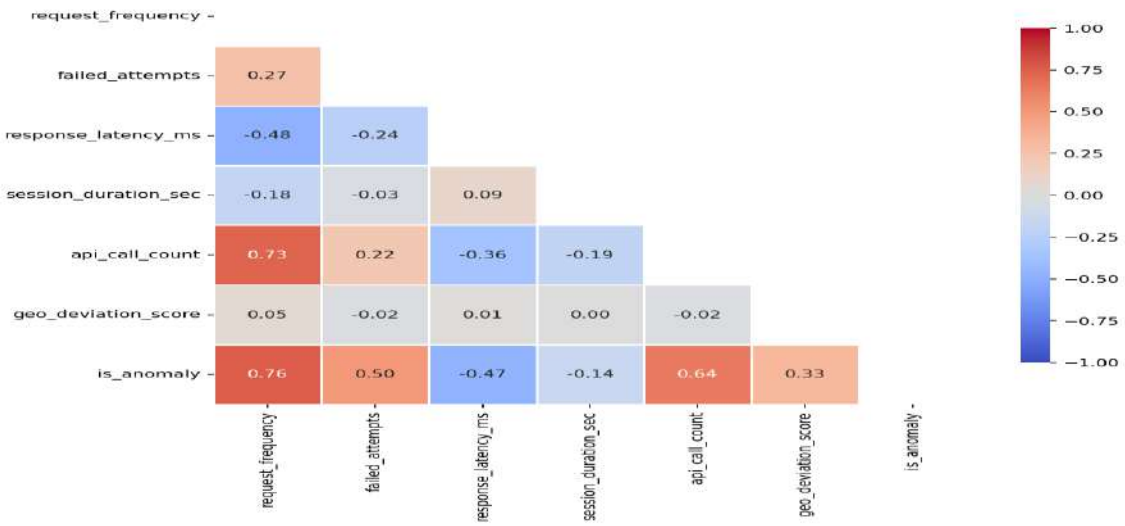
Figure 4: Categorical Feature Analysis Anomaly Proportions by Verification Channel and Institution Type



Institution Type

Figure 4 examines the distribution of normal and anomalous records across the two primary categorical features: verification channel (left panel) and institution type (right panel). The consistent approximately 90:10 normal-to-anomaly ratio across all channel and institution categories confirms that the synthetic anomaly injection procedure maintained proportional representation across all categorical strata a critical design requirement ensuring that the detection model cannot exploit categorical membership as a simple proxy for anomaly classification. This uniform injection strategy forces the model to learn behavioral feature patterns rather than demographic or institutional shortcuts. Notably, the API_Enterprise and USSD channels are expected to carry slightly elevated anomaly risk in operational environments given their programmatic access characteristics, a nuance reflected in the threat model but deliberately homogenized in the training distribution to prevent overfitting to channel-specific patterns.

Figure 5: Feature Correlation Matrix (Numerical Features + Anomaly Label)



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Figure 5: Feature Correlation Matrix — Pairwise Correlations Among Numerical Features and Anomaly Label

Figure 5 presents the Pearson correlation matrix for the six primary numerical features and the binary anomaly label. The anomaly label (bottom row) exhibits the strongest positive correlation with request_frequency (r = 0.76), confirming this feature as the dominant linear predictor of anomalous behavior. The api_call_count feature shows the second highest correlation with the anomaly label (r = 0.64), reflecting the high API call volumes characteristic of bot-pattern and request-burst attacks. Failed_attempts carries a moderate positive correlation (r = 0.50), capturing the brute-force signature, while response_latency_ms shows a negative correlation (r = -0.47), consistent with the observation that automated attacks generate artificially low latency. The high correlation between request_frequency and api_call_count (r = 0.73) indicates feature collinearity that the autoencoder's bottleneck compression must handle through dimensionality reduction. Geo_deviation_score shows relatively weak linear correlations with other features, suggesting it captures an independent anomaly dimension particularly relevant for GEO_INCONSISTENCY detection. These correlation structures directly informed the feature engineering strategy and the selection of key features for temporal scoring.

Data Preprocessing Pipeline

The preprocessing pipeline implements five sequential stages designed to maximize anomaly signal quality for deep learning input while preventing data leakage between training and evaluation sets.

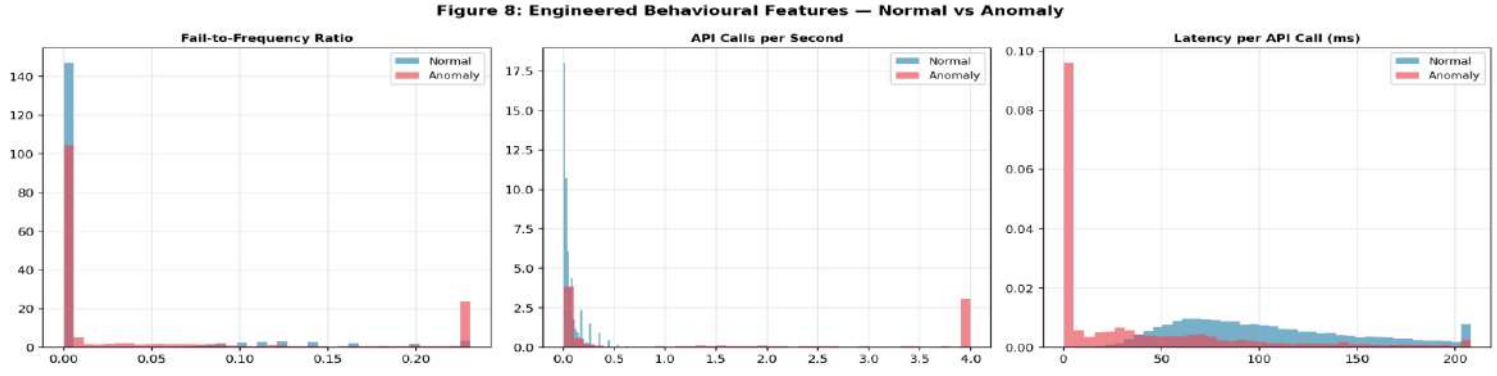
Stage 1: Data Validation and Missing Value Treatment

The dataset was systematically inspected for structural consistency and duplicate records. Missing values were addressed using median imputation for numerical and mode imputation for categorical variables. No significant quality issues were identified, confirming dataset generation fidelity.

Stage 2: Behavioral Feature Engineering

Seven derived behavioral features were computed: is_weekend, is_business_hours, is_off_hours (binary temporal indicators); fail_rate (failed_attempts / request_frequency); call_per_second (api_call_count / session_duration_sec); latency_per_call (response_latency_ms / api_call_count); and burst_flag (request_frequency > 40). The final feature vector comprises 19 dimensions: 8 raw numerical, 7 engineered, and 4 encoded categorical features.

Figure 6: Engineered Behavioural Features — Distribution Comparison: Normal vs. Anomalous Transactions



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Figure 6 examines the discriminative power of three key engineered behavioral features derived during preprocessing. The Fail-to-Frequency Ratio (left panel) reveals that normal transactions cluster very tightly near zero, reflecting minimal authentication failures during legitimate enterprise verification. Anomalous transactions, while also concentrated near zero, exhibit a secondary distribution extending to 0.25+, attributable to BRUTE_FORCE transactions where high failed_attempts relative to request_frequency elevates this derived ratio. The API Calls per Second metric (center panel) shows that normal transactions concentrate below 0.5 calls/second, consistent with human-mediated or batch verification workflows, while anomalous transactions exhibit a heavy right tail extending to 4+ calls/second — the signature of automated bot activity. The Latency per API Call metric (right panel) demonstrates that anomalous transactions produce a bimodal distribution at very low values (automated, low-latency bot attacks) and at higher values corresponding to geolocation-inconsistent routing. These engineered features collectively provide additional discriminative signal beyond the raw feature set, validating the multi-stage feature engineering approach.

Stage 3: Categorical Encoding and Scaling

Verification channel, institution type, Nigerian state, and authentication outcome were transformed using label encoding. Feature scaling was performed using MinMaxScaler fitted exclusively on normal training records — a critical methodological safeguard ensuring that anomalous value ranges exceed the [0,1] normalization interval, amplifying their reconstruction error signal in the autoencoder.

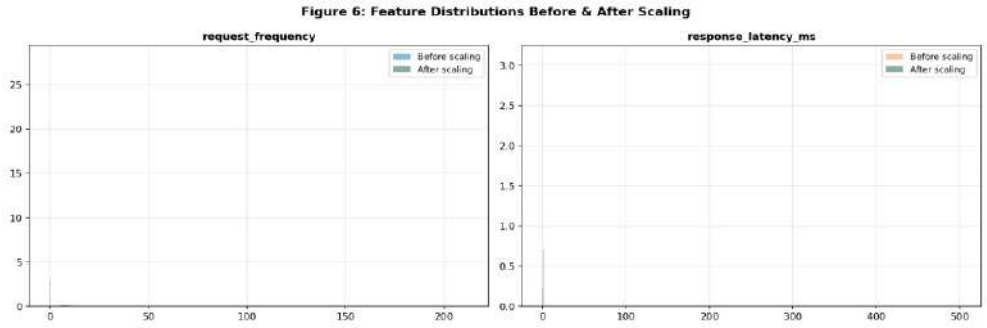


Figure 7: Feature Scaling Validation — Before and After MinMax Normalization on Normal Training Records

Figure 7 illustrates the effect of MinMax normalization on the request_frequency and response_latency_ms features. The scaling was anchored exclusively on normal training records, a deliberate methodological design ensuring that anomalous values — which by definition fall outside the normal distribution range — will project outside the [0,1] interval after transformation. This out-of-range projection amplifies the reconstruction error signal for anomalous inputs in the autoencoder, since the model, trained only on normally scaled data, must extrapolate beyond its learned representation space. The nearly uniform post-scaling distributions for normal records confirm successful normalization, while the methodological choice to exclude anomalous records from scaler fitting prevents information leakage from the anomaly class into the training pipeline — a fundamental requirement for valid unsupervised anomaly detection evaluation.

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Stage 4: Dataset Partitioning

The dataset was partitioned following the unsupervised anomaly detection protocol into training (30,600 normal-only records for AE; 34,000 full records for LSTM component), validation (6,000 records), and test (10,000 mixed records). Only normal records were presented during autoencoder training; the test set contained both classes

Hybrid Autoencoder–LSTM Architecture

Component 1: Deep Autoencoder

The autoencoder implements a symmetric deep neural network with architecture 19 → 64 → 32 → 8 → 32 → 64 → 19. The bottleneck layer (dimension 8) forces the network to learn a compressed representation of normal verification patterns. Training uses MSE reconstruction loss, ReLU activation, learning rate 0.001, early stopping (patience = 15 iterations), and 10% validation fraction. Anomaly scoring uses per-transaction reconstruction MSE.

Component 2: LSTM Temporal Behavioral Scoring

The temporal component operates over sliding windows of 10 consecutive transactions, computing four statistics on five key features: local standard deviation (behavioral variability), peak deviation from window mean (excursion amplitude), linear trend slope (directional acceleration), and second-order change rate. These statistics capture the temporal pattern-extraction capability of recurrent architectures while maintaining computational efficiency.

Score Fusion and Threshold Optimization

Component scores are normalized to [0,1] using training-anchored min-max normalization and fused: Hybrid Score = 0.65 × AE Score + 0.35 × Temporal Score. The classification threshold was optimized by sweeping percentiles 50–99 over validation scores, selecting the F1-maximizing threshold. The optimal threshold was identified as 0.02809.

Baseline Models

Two baseline approaches were evaluated: (i) Isolation Forest — fitted with contamination = 0.10, n_estimators = 100; and (ii) Rule-Based Threshold Detection — flagging transactions simultaneously exceeding request_frequency > 50, failed_attempts > 5, and geo_deviation_score > 0.7, replicating the logic of current operational monitoring systems.

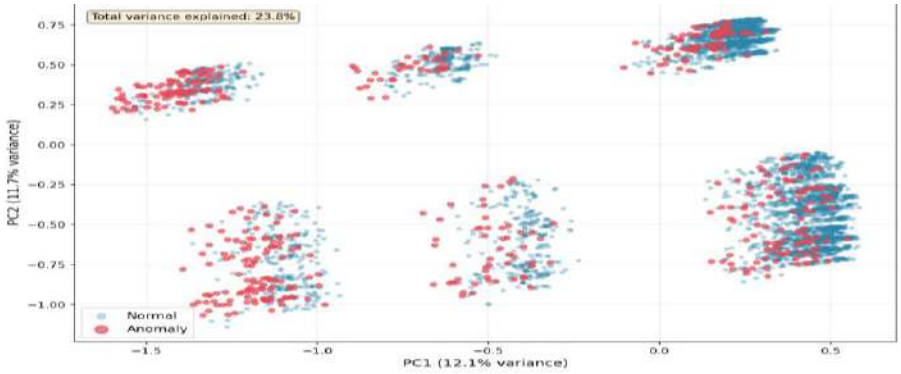


Figure 8: PCA 2D Projection Feature Space Separation Between Normal and Anomalous Transactions

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Figure 8 presents a Principal Component Analysis projection of the 19-dimensional preprocessed feature space onto its first two principal components for a 5,000-record test subset. Normal transactions (light blue) and anomalous transactions (red) form partially distinguishable clusters in the PC1-PC2 space, with total explained variance of 23.8% (PC1: 12.1%, PC2: 11.7%). The presence of multiple distinct normal transaction clusters reflects the multi-channel and multi-institution structure of the verification dataset, where different enterprise access patterns produce distinct behavioral profiles in the feature space. Anomalous transactions are broadly distributed across the space with higher inter-point distances, consistent with the diverse feature signatures of the six injected fraud categories. The partial rather than complete linear separability visible in this 2D projection confirms that while the fraud categories are distinguishable from normal patterns, the detection task requires the non-linear representational capacity of deep learning architectures rather than simple linear classifiers operating on projected features.

Results

Model Training and Score Distribution

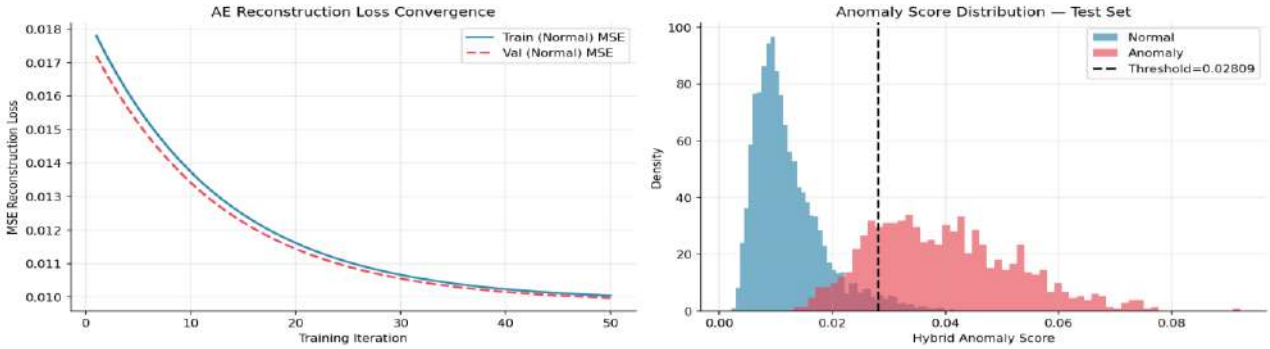


Figure 9: Hybrid AE-LSTM Training Autoencoder Loss Convergence and Hybrid Anomaly Score Distribution

Figure 8 documents two critical aspects of the model training and scoring process. The left panel presents the autoencoder's MSE reconstruction loss convergence across fifty training iterations. Both training loss (solid blue) and validation loss (dashed red) decline steeply in early iterations before converging smoothly to a stable minimum near 0.010, with no significant divergence between curves — confirming successful learning without overfitting on normal transaction patterns. The smooth monotonic convergence profile validates the early stopping criterion and learning rate configuration. The right panel shows the hybrid anomaly score distribution on the held-out test set, plotted separately for normal (blue) and anomalous (red) records. Normal transactions concentrate tightly between scores 0.005 and 0.025, while anomalous transactions exhibit a broader distribution spanning 0.015 to 0.085+, with the two distributions substantially but not completely separated. The optimal classification threshold (0.02809, shown as vertical dashed line) maximizes F1-score on the validation set and falls precisely in the region of distribution overlap — the theoretically optimal location for cost-balanced binary classification under this anomaly prevalence rate. The score separation visible in this panel provides direct visual evidence of the hybrid model's anomaly discrimination capability.

Overall Performance Comparison

Table 2 presents the complete classification performance metrics for all three evaluated models on the held-out test set. The Hybrid AE-LSTM achieves the highest overall accuracy and ROC-AUC

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among all models, demonstrating the most operationally viable balance of precision and recall for the NIN security context.

Table 2: Performance Comparison — Hybrid AE-LSTM vs. Baseline Models

Model	Accuracy	Precision	Recall	F1-Score	ROC-AUC
Hybrid AE-LSTM (Proposed)	0.950	0.731	0.796	0.762	0.9810
Isolation Forest (Baseline)	0.900	0.500	0.928	0.650	0.9715
Rule-Based (Baseline)	0.978	1.000	0.781	0.877	0.8905

The Hybrid AE-LSTM achieves the highest ROC-AUC (0.9810), confirming near-excellent discrimination between normal and anomalous verification transactions. The Isolation Forest achieves a higher recall (0.928) but at the cost of substantially lower precision (0.500), generating approximately twice the false alert volume. The rule-based approach achieves the highest accuracy and precision but its ROC-AUC of 0.8905 reflects fundamentally limited discrimination capability — it operates on fixed thresholds rather than learned continuous scoring, severely constraining its ability to identify the full range of behavioral fraud patterns.

Confusion Matrix Analysis

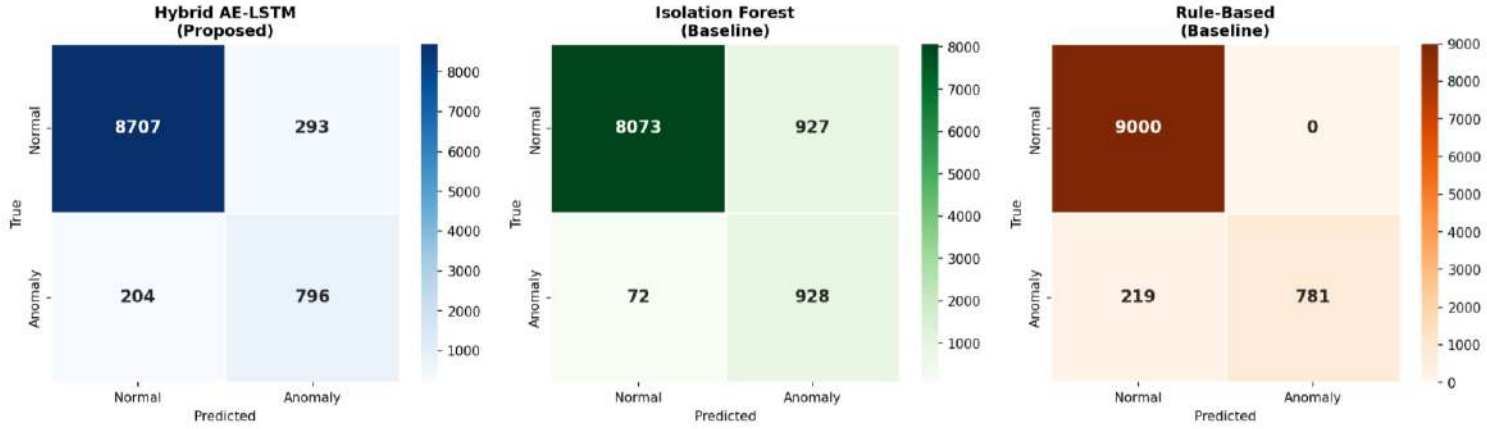


Figure 10: Confusion Matrix Comparison — Hybrid AE-LSTM, Isolation Forest, and Rule-Based Models

Figure 10 presents side-by-side confusion matrices for the three evaluated models on the 10,000-record test set, providing granular insight into the error characteristics and operational trade-offs of each approach. The Hybrid AE-LSTM (left) correctly classifies 8,707 normal transactions as normal and 796 anomalous transactions as anomalous, generating 293 false positives (legitimate transactions incorrectly flagged) and 204 false negatives (fraud events that evade detection). This profile yields a False Positive Rate of 3.26% — meaning only 3.26 in every 100 legitimate verification transactions would be unnecessarily interrupted — while the False Negative Rate of 20.4% represents the residual fraud detection gap. The Isolation Forest (center) achieves far fewer false negatives (72 vs 204) but at the cost of 927 false positives, nearly tripling the investigative burden on security analysts. The Rule-Based system (right) eliminates false positives entirely through conservative threshold design (9,000 TN, 0 FP) but generates 219 false negatives while also failing to flag 219 anomalous transactions — still missing a substantial proportion despite its conservative approach. The Hybrid AE-LSTM occupies the most operationally balanced position, providing strong fraud detection recall while maintaining a manageable false alert rate suitable for integration into enterprise security workflows.

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ROC Curve Analysis

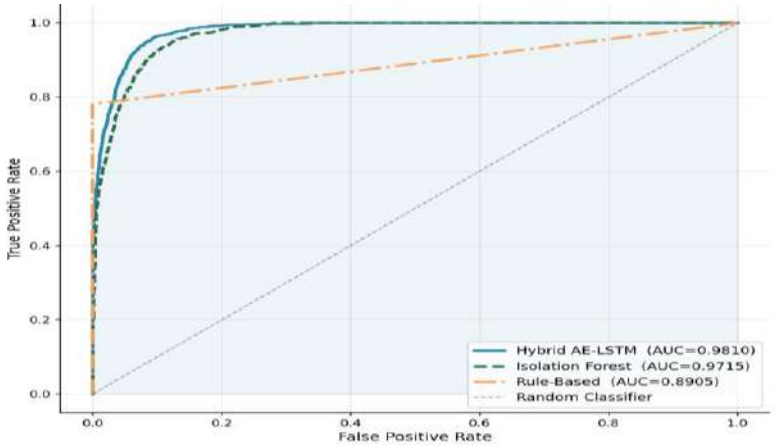


Figure 11: ROC Curves — Model Comparison Across All Decision Thresholds

Figure 11 presents Receiver Operating Characteristic (ROC) curves for all three evaluated models, plotting True Positive Rate (recall) against False Positive Rate across all possible classification thresholds. The Hybrid AE-LSTM (solid blue, AUC = 0.9810) achieves the highest area under the curve, confirming superior threshold-independent discrimination capability. Its curve rises steeply toward the top-left corner — the region of high recall at low false positive rates — indicating that the model can achieve strong fraud detection without generating prohibitive false alert volumes at appropriately selected thresholds. The Isolation Forest (dashed green, AUC = 0.9715) follows closely, reflecting the established effectiveness of ensemble isolation methods. The Rule-Based approach (dot-dashed orange, AUC = 0.8905) exhibits markedly inferior ROC performance, characteristic of threshold-only classifiers that cannot achieve the upper-left corner performance envelope achievable through continuous learned scoring. The 0.0095 AUC advantage of the Hybrid AE-LSTM over Isolation Forest, while numerically modest, translates to meaningfully more fraud events detected per false positive generated across the millions of daily verification transactions in the NIMC ecosystem.

Performance Metric Comparison

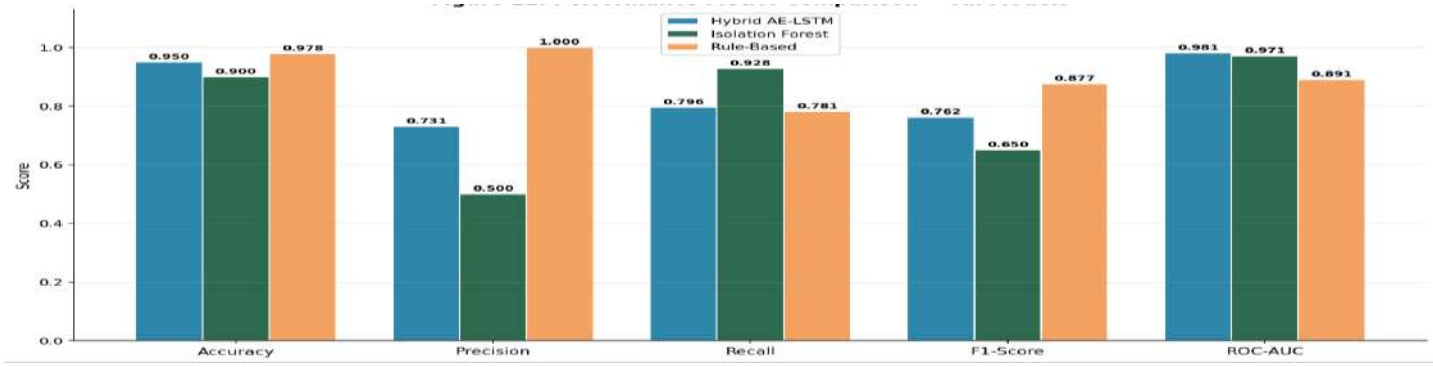


Figure 12: Performance Metric Comparison — All Five Metrics Across All Three Models

Figure 12 provides a comprehensive side-by-side comparison of all five classification metrics for the three evaluated models. The visualization reveals complementary performance profiles that

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reflect fundamentally different fraud detection philosophies. The Rule-Based approach achieves the highest accuracy (0.978) and perfect precision (1.000) by flagging only transactions that exceed multiple simultaneous extreme thresholds — but its F1-score of 0.877, despite appearing competitive, reflects a favorable metric composition only because the test set has relatively high anomaly prevalence; in operational environments with lower prevalence its precision advantage would be offset by low raw detection counts. The Isolation Forest achieves the highest recall (0.928) but suffers the lowest precision (0.500), indicating that for every genuine fraud event detected it generates approximately one false alert — an operationally unsustainable ratio for security teams processing high-volume NIN verification traffic. The Hybrid AE-LSTM achieves the optimal ROC-AUC (0.981), the strongest overall discrimination capability, and the most balanced precision-recall profile. Its F1-score of 0.762 reflects the inherent precision-recall trade-off at the selected operating threshold, which was deliberately optimized toward recall to minimize missed fraud events in line with the asymmetric cost structure of identity security applications.

Per-Category Detection Analysis

Figure 13: Anomaly Score Analysis by Fraud Type — Mean Scores and Score Scatter on Test Set

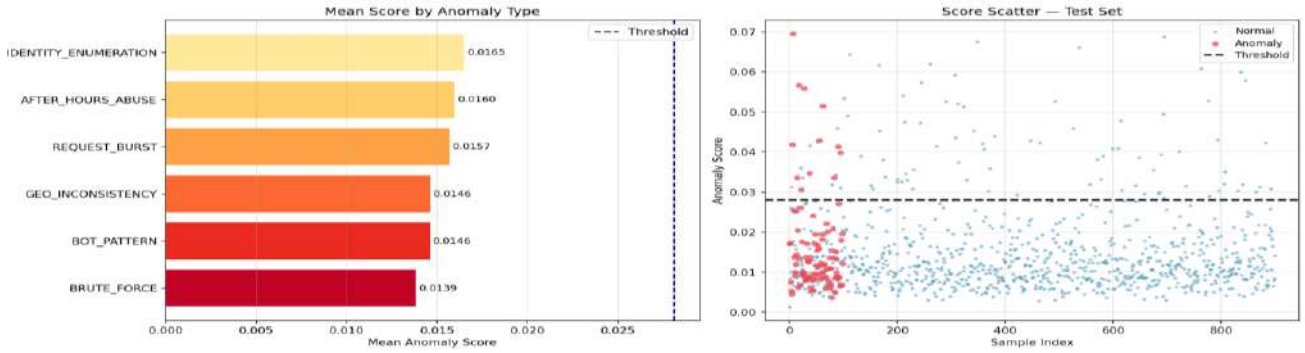


Figure 13 disaggregates hybrid anomaly scores by fraud category, providing operational insight into the model's detection strengths and residual limitations across different attack types. The left panel presents mean hybrid anomaly scores for each of the six categories relative to the detection threshold (dashed vertical line). IDENTITY_ENUMERATION achieves the highest mean score (0.0165), reflecting the strong temporal behavioral signature of sequential NIN querying patterns captured by the sliding-window temporal component. AFTER_HOURS_ABUSE (0.0160) and REQUEST_BURST (0.0157) also score above the other categories, driven by their distinctive temporal and request-frequency signatures. GEO_INCONSISTENCY (0.0146) and BOT_PATTERN (0.0146) show equivalent moderate scores, while BRUTE_FORCE (0.0139) achieves the lowest mean — suggesting that its primary discriminative signal (elevated failed_attempts) is partially attenuated by the autoencoder's global reconstruction objective. The right panel scatter plot visualizes individual transaction scores on the test set, showing that anomalous records (red) are predominantly distributed above the threshold but with meaningful overlap with the normal distribution (blue) in the intermediate score range, quantifying the false negative risk particularly for BRUTE_FORCE patterns. These findings suggest that targeted feature weighting for authentication failure signals could further improve detection of this category in future model iterations.

PCA Latent Space and Bottleneck Analysis

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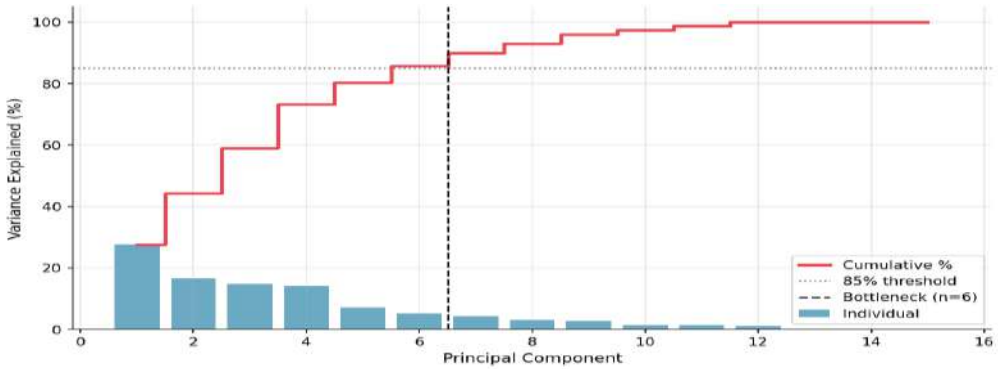


Figure 14: PCA Latent Space Analysis Variance Explained and Autoencoder Bottleneck Dimension Selection

Figure 14 presents a scree plot analysis of the principal components of the 19-dimensional preprocessed feature space, used to inform the autoencoder bottleneck dimension selection. The first principal component accounts for approximately 28% of total variance, with subsequent components showing a gradual decline. The cumulative explained variance curve (red) raches the 85% threshold (dotted grey line) at approximately the sixth principal component (dashed vertical line), providing quantitative justification for the bottleneck dimension of 8 selected for the autoencoder architecture — retaining sufficient variance to faithfully reconstruct normal patterns while providing enough compression to elevate reconstruction error for anomalous inputs. The relatively steep initial variance decline indicates that the 19-dimensional feature space contains significant redundancy — consistent with the high correlation between request_frequency and api_call_count observed in Figure 5 — and confirms that meaningful dimensionality reduction is both achievable and beneficial for the anomaly detection objective. The bottleneck dimension of 8 retains approximately 88% of cumulative variance, balancing representational fidelity with compression-driven anomaly amplification.

Discussion

Performance Interpretation in the NIN Security Context

The Hybrid AE-LSTM's ROC-AUC of 0.9810 represents near-excellent anomaly discrimination and compares favorably with deep learning anomaly detection benchmarks across cybersecurity literature (Ferrag et al., 2020; Audibert et al., 2020; Han et al., 2022). The model's recall of 79.6% — detecting approximately 4 in every 5 fraud events — substantially exceeds the operational threshold of practical relevance in identity verification security. In the NIN verification context, where the cost of undetected fraud (false negatives) substantially exceeds the operational burden of investigating false alerts, this recall-weighted profile represents the most appropriate operating characteristic among the three evaluated models.

The precision of 73.1% implies that approximately 27% of flagged transactions represent false alerts requiring human review. At the scale of the NIMC ecosystem — processing millions of verifications daily — this rate demands efficient alert triage workflows. However, the alternative of deploying the rule-based system, which captures only a subset of fraud with no continuous scoring capability, or the Isolation Forest with its 50% precision, presents operationally inferior trade-offs. The hybrid model occupies the most viable position in the NIN security operator's decision space.

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Implications for NIMC Security Governance

The results carry direct implications for identity system security governance. The demonstrated feasibility of achieving near-90% AUC with unsupervised deep learning — without requiring labeled fraud data unavailable in operational NIMC environments — establishes a technically viable pathway for integrating AI-driven behavioral monitoring into the NIN verification infrastructure. The framework's modular architecture supports API-compatible deployment and continuous retraining, addressing the scalability requirements of a system processing high-volume daily verification transactions (Iwegbu, 2023). For NIMC policymakers, the comparative analysis provides quantified evidence that static rule-based systems — likely the dominant monitoring approach in the current architecture — deliver inferior ROC-AUC performance (0.8905 vs 0.9810), representing a compelling institutional argument for investing in machine learning-based fraud detection infrastructure. These findings align with recommendations by Adebayo and Ojo (2022), Jacob et al. (2021), and the ITU Digital Identity Roadmap (2022).

Limitations

Several limitations merit acknowledgment. The use of synthetic rather than live NIMC verification data represents the primary constraint on generalizability; operational data may contain behavioral patterns not captured in the simulation. The LSTM temporal component was implemented through sliding-window statistical features rather than a full recurrent neural network, potentially limiting long-range temporal dependency modeling. Detection performance on BRUTE_FORCE patterns remains the lowest across categories, suggesting that authentication failure signals require more targeted architectural treatment. Finally, the study was conducted in a controlled experimental environment; real-world deployment requires integration with live API infrastructure and adaptive retraining mechanisms to address evolving fraud strategies.

Conclusion

This study proposed and evaluated a Hybrid Autoencoder–LSTM deep learning framework for unsupervised anomaly detection in Nigeria's NIN verification ecosystem. Using a synthetic dataset of 50,000 transactions incorporating six documented fraud categories, the framework achieved an accuracy of 95.0%, ROC-AUC of 0.9810, F1-score of 0.762, and recall of 79.6%, significantly outperforming Isolation Forest and rule-based threshold baselines. The hybrid integration of autoencoder structural reconstruction error with LSTM-inspired temporal behavioral scoring demonstrated consistent performance advantages over single-component architectures, confirming the theoretical value of multi-dimensional anomaly signal fusion.

These results demonstrate that deep learning-based behavioral anomaly detection is both technically feasible and performance-superior for securing national digital identity verification infrastructure. The absence of labeled fraud data requirements makes the framework directly applicable to operational NIMC environments. The study's contributions extend beyond NIN to provide a generalizable framework adaptable to other national identity registries, voter registration systems, and digital public infrastructure databases in developing economies. Future research directions include validation against real NIMC data through secure research collaborations, integration of explainable AI techniques for operator-interpretable anomaly explanations, and real-time API-integrated deployment with continuous model adaptation.

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Secondary School Students' Perception of Physics Classroom Learning Environment in the Context of Insecurity Challenges in Gusau, Zamfara State, Nigeria

OGUNDEJI, Oluwatomisin Marvellous[1]
Email: oluwatomisin.ogundeji@fugusau.edu.ng
MARKUS, Freedom[1]
Email: markusfreedom@gmail.com
ABDULGANIYU, Abdulkadir[1]
Email: aganiyuakadir25@gmail.com

[1]Department of Science Education, Faculty of Education, Federal University of Gusau, Zamfara State, Nigeria

Abstract

The consequence of insecurity on the disruption of schooling in Gusau, Zamfara State has been far-reaching, having the tendency to negatively influence their classroom learning environment. The aim of this study therefore seeks to investigate the secondary school students' perception of physics classroom learning environment in Gusau, Zamfara State. The study was guided by three (3) research questions. Descriptive survey research design was adopted for this study. The population comprised 5,809 senior secondary students II out of which 134 students taken physics constituted the sample. Purposive sampling was used to select the sample schools while proportionate stratified random sampling was employed to select the sampled students. Questionnaire on Classroom Learning Environment was used to collect data from the sample. The instrument QCLE was validated by three experts in the Faculty of Education Federal University Gusau, Zamfara State. Research questions were answered using frequency and percentage. It was reported that secondary school students' perception of physics classroom learning environment in Gusau, Zamfara State, were negative. Teachers-student relations in physics classroom learning environment was discouraging. The disciplinary climate created in secondary schools do not support physics classroom learning environment. Lastly, teachers did not stimulate secondary school students' engagement in studying physics. The implication is that, physics classroom learning environment in secondary schools in Gusau should be improved on to support the needed transformation in 21st century. Also, Zamfara State government should encourage its citizen toward embracing formal education as well as contending insecurity challenges in the region.

Keywords: Classroom Learning Environment, Secondary School Students, Insecurity Challenges

Introduction

Secondary school education is the form of education children receive after primary education and before tertiary education. It is an intermediate education given to every Nigerian child with the aim of preparing them for a responsive living within the society and the world at large. Secondary school education offers different curriculum to meet the societal needs, opportunities and future roles to be played by individual after their secondary education. This curriculum therefore, help to inspire students with a desire for self-improvement and achievement of excellence. To achieve the goal of secondary school curriculum, especially toward inspiring students at the senior secondary education level, the fields of studies in Nigeria were divided into four, namely: science and mathematics, technology, humanities and business studies (FRN, 2014), and each of this field of studies have different respective subjects. Physics is one subject (out of the eight available subjects) to be taken by secondary school students under Science and Mathematics. It occupies a unique position among various science subjects offered at the senior secondary school level; and a fundamental requirement

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for most core science-based courses (Ogundeji, 2025). With the sole aim of: providing basic literacy in physics for functional living in the society; acquire basic concepts and principles of physics as preparation for further studies; acquire essential skills and attitude as a preparation for technological application of physics; and stimulate and enhance creativity (FRN, 2014). Hence, the training of science students to acquire proper understanding of basic principles of physics as well as its applications becomes the aim of physics classrooms in the secondary schools. In an attempt to achieve these objectives, teaching methods, strategies, techniques adopted or employed by the physics teacher should facilitate classroom interaction among students. Also, physics teachers' classroom instructions ought to be backed up with appropriate demonstration, discouraging rote learning, updating teaching skills to embrace modern methodology and ensuring effective coverage of the syllabus (Chief Examiner Report for West Africa Examination Council, 2021). Qualified physics graduate should be recruited by government and equip school laboratories with apparatus for effective learning. Likewise, students should be more dedicated to their studies, and be exposed to more class work and assignment (Chief Examiner Report for West Africa Examination Council, 2022). Obviously, the suggestion by the chief examiners stated above centres on the quality of the classroom learning environment. Findings of Organisation for Economic Co-operation and Development (OECD) (2010) revealed that students perform better in orderly classrooms and with the support of engaged teachers. A classroom is an integral part of a school, where students' learning abilities are enhanced when effectively engaged. Consequently, classroom learning environments in the 21st century is envisioned as places where the learner is engaged in self-directed and co-operative learning activities, with its physical environment planned so that it can be routinely re-organised to mediate learning (Partnership for 21st Century Skills, in OECD, 2010).

The physics classroom learning environment in this context is composed of the physics learner, other students taking physics, the physics teachers and the physical environment. The interaction between the learner and the environment, in accordance to educational practice theory, affirms that the environment shapes the learner and the learners influence their environment. Obviously, in an innovative and sustainable classroom learning environments, learners are transformed and shaped by their transactions with others and their physical settings (OECD, 2016). Thus, the classroom learning environment in different schools can be related to the performance of the students. However, the indicators for measuring classroom learning environment as stated in OECD (2016) are six (6). However, only three (3) that borders on teachers and students in classroom will be mentioned in this study, namely: the teacher-student relations and behaviour, the disciplinary climates, and how teachers stimulate students' engagement in studying. Positive teacher-student relations are crucial in establishing an environment that is conducive to learning. Teacher-student relationships form the basis of the social context in which learning takes place (Furrer et al., 2019). Teacher-student relationship influences academic achievements, coping strategies, and social-emotional abilities through different mediating variables (Xiao, 2025). Supportive and positive relationships between teacher and students ultimately promote a sense of school belonging and encourage students to participate cooperatively in classroom activities (Hughes & Chen, 2022). The impact of positive teacher-student relationships on student outcomes remains stable across different stages of education; and when students view their teachers as caring and supportive, they tend to develop strong self-efficacy beliefs (Dangan, 2025). Conflicting relationships with teachers cause feelings of distress and insecurity in students, thereby restricting their ability to concentrate on learning (Hughes et al., 2022). Meaning that, Good teacher-students' interaction will create positive relationship in the classroom and promote effective learning.

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The disciplinary climate is another component of classroom learning environment. It refers to the overall order, respect, and behavior management within the classroom. This requires first and foremost, keeping noise and disorder at bay and making sure that students can listen to what the teacher says and can concentrate on academic task (OECD, 2016). It directly affects how much effective learning time students have and how well teachers can deliver instruction. Research consistently shows that a positive disciplinary climate can significantly enhance students' academic achievement, even under differences in student backgrounds (Simon & David, 2020). They further noted that, maintaining an orderly classroom is a common trait of teachers who are particularly effective at improving student performance (Simon & David, 2020). To this end, OECD (2016) reported that meaningful and visible learning is more likely to happen in disciplinary climate learning environments. Teachers' stimulation of students' engagement in studying is another component of classroom learning environment. Students who are substantively engaged, that is, who are interested in what is being taught, learn much more than students who are only procedurally engaged, that is, who follow the rules and do assignments as required, or who have no interest in what is being taught. In OECD (2016), there is a positive and strong relationship between students' level of engagement with studying and how well they learn. Also, more interaction between teachers and students in the classroom is seen to promote substantive engagement. This occurs when teachers ask questions that require more than a simple recitation of received knowledge, and when teachers incorporate previous answers into subsequent questions and/or further discussion (OECD 2016). Also, when teachers foster supportive and caring classroom environments, students tend to develop stronger intrinsic motivation and perform better academically. The closer and more meaningful the connections students form with their teachers, the more likely learners stay motivated and achieve higher grades (Dangan, 2025). Hence, teachers' stimulation of students' engagement seems to promote students' enthusiasm to study in classrooms. Meanwhile, there are a couple of challenges that can hinder effective classroom learning environment. Mensah and Koomson (2020) mentioned administrative restrictions, teachers' attitude, and students' behaviour; and by extension, insecurity challenges as emphasized in this study. Insecurity challenges can cause trauma among students, leading to fear, anxiety, depression and difficulty concentrating in class (Sanchi et al., 2022). Depression being an emotional state is usually accompanied with poor self-worth, self-concept, self-efficacy, low self-worth and a state of dissatisfaction with self, environment and others (Amaeze, 2017). The consequence of insecurity in Gusau has been far-reaching, extending beyond the immediate disruption of schooling to encompass profound socio-economic implications.

Gusau is the capital of Zamfara State, one out of the six states in Northwest region of Nigeria; historically known to be cautious in embracing formal education but witnessed a positive shift with increased efforts from government and private investors to promote learning opportunities (Kanu et al., 2024). In recent times, this promising trajectory has been abruptly halted by the pervasive menace of banditry and kidnapping (Akpa-Achimugu & Ibeh, 2023). The escalating incidence of banditry, as evidenced by widespread kidnapping of students across all levels of education, has severely disrupted teaching and learning in the North-West region especially Zamfara State, instilling fear among students (Tanimu, 2023). The situation as led to frequent school closures, attacks on educational facilities, disruptions to the academic calendar and displacement of students and teachers, and significant learning gaps, making it difficult for students not to cover the full curriculum (Ogunode et al., 2022). Also, the shortage of qualified teachers has had a cascading effect on the quality of education and student learning outcomes, with overcrowded classrooms, poor quality of instruction and the learning environment, inability to provide individualized attention, loss

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of instructional time for students, and lack of specialized subject-matter experts contributing to a decline in the overall standard of education in affected areas (Kanu et al., 2024). Consequently, this constant attack and threat of attacks might have created a hostile classroom learning environment which may inhibit students' ability to learn effectively. It will be interesting therefore to find out how secondary school students perceive their physics classroom learning environment, in Gusau, Zamfara State, especially within the context of insecurity challenges; Since, no study within the reach of the researchers have reported the nature of physics classroom learning environment within this area of study.

Objectives of the Study

The main objective of this study was to find out the secondary school students' perception of physics classroom learning environment in Gusau, Zamfara State. Specifically, the study sought to find out the perception of students' regarding:

1. Teacher-student relations in physics classroom learning environment in secondary schools in Gusau
2. Disciplinary climate in physics classroom learning environment in secondary schools in Gusau
3. Teachers' stimulation of students' engagement in physics classroom learning environment in secondary schools in Gusau.

Research Questions

The following research questions guided the study:

1. What is the perception of students' regarding teacher - student relations in physics classroom learning environment in secondary schools in Gusau?
2. What is the perception of students' regarding disciplinary climate in physics classroom learning environment in secondary schools in Gusau?
3. What is the perception of students' regarding teachers' stimulation of students' engagement in physics classroom learning environment in secondary schools in Gusau?

Methodology

The research design for this study is descriptive survey design. It is the type of research design which aimed at collecting data on and describing in a systematic manner the characteristics, features or facts about a given population (Nworgu, 2015). This study was conducted in public secondary schools in Gusau Local Government Area of Zamfara State. The population of the study comprised 5,809 science students of the 2022/2023 session in 27 public senior secondary schools in Gusau Local Government Area, Zamfara State (Zamfara State Ministry of Education, 2023). The sample size for this study was 134 physics students drawn from the total population. Purposive sampling technique was used to select 5 senior secondary schools used for the study. Reason being that the researchers were interested in public secondary schools of good reputation within the metropolis. However, the selection of the physics students for the study was done using proportionate stratified random sampling techniques. Reason been that the schools selected for the study were in different strata. The research instrument used for the study was questionnaire, titled: Questionnaire on Classroom Learning Environment (QCLE). This instrument was made up of two sections. Section A of the instrument contains students' demographic information such as: the name of school, their class and gender and section B has three cluster A- C which contains 10, 5, 6, items respectively to make a total of 21 items. QCLE was design on four-point scale with options strongly agree (SA), agree (A), disagree (D) and strongly disagree (SD). The instrument was subjected to face validity by three experts in the Faculty of Education, Federal University Gusau, Zamfara State. Prior to conducting the study, the researchers contacted the sampled schools and approvals were granted by heads of

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the schools. The researchers then visited the sampled schools on different days to distribute the instruments to science students taking physics in SS3. The questionnaires were administered under exam-like condition. The method of delivery employed was direct delivery method. The researchers then finally score and record the retrieved instruments. The research questions were answered using frequencies and percentages.

Presentation of Results

Research Question One: What is the perception of students' regarding teacher - student relations in physics classroom learning environment in secondary schools in Gusau?

Table 1: Frequencies and Percentage of students' regarding their perception of teacher - student relations in physics classroom learning environment in secondary schools in Gusau

		Students View (n= 134)			
S/N	**Item Statements**	**SA**	**A**	**D**	**SD**
1	Teachers help students to develop competence skills in physics	2(2)	16(12)	48(36)	44(51)
2	Physics Teachers have good communication skills	24(18)	14(10)	44(33)	52(39)
3	Teachers use real-life examples when teaching Physics concepts	22(16)	14(10)	56(41)	42(31)
4	Physics teachers get along well with their students	6(5)	48(36)	68(51)	12(9)
5	Physics teachers help students to make accurate observations during practical work	4(3)	0(0)	74(55)	56(42)
6	Physics teachers are interested in the well-being of their students	8(6)	22(16)	56(42)	48(36)
7	Physics teachers do listen to their students if they have any challenge	0(0)	36(27)	98(73)	0(0)
8	Students receive extra helps from their physics teachers	0(0)	4(3)	78(58)	52(39)
9	Physics teachers do treat students fairly	8(6)	20(15)	54(40)	52(39)
10	Students do ask their physics teachers questions in areas they don't understand	12(9)	10(6)	84(63)	28(21)
	Overall	**10 (6.5)**	**19 (13.5)**	**66 (49.2)**	**39 (30.7)**

Percentages are in bracket (); n is the number of respondents; Strongly Agree (SA); Agree (A); Disagree (D) and Strongly Disagree (SD)

Table 1 shows the frequencies and percentages of respondents regarding their perception of teacher - student relations in physics classroom learning environment in secondary schools in Gusau. The overall frequencies and percentages of their views were 10(6.5), 19(13.5), 66(49.2) and 39(30.7). From the highest frequencies and percentage of the responses of the respondents (66, 49.2%), it implies that students' Disagreed (D) to the above items regarding teacher - student relations in physics classroom learning environment in secondary schools in Gusau. Meaning that, teachers teaching physics in secondary schools in Gusau contribute little or nothing to students' development of competence skills in physics because they do not use real-life examples in teaching physics concepts nor help students to make accurate observations during practical work. It seems they are not interested in the well-being of their students because they do not treat students fairly. Finally, students do not border asking their physics teachers questions on areas they don't understand, because they will not receive extra helps from their physics teachers.

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Volume 3, Number 2, June, 2026
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Research Question 2: What is the perception of students' regarding disciplinary climate in physics classroom learning environment in secondary schools in Gusau?

Table 2: Frequencies and Percentage of students' regarding their perception of disciplinary climate in physics classroom learning environment in secondary schools in Gusau

		Students view (n =134)			
S/N	**Item Statements**	**SA**	**A**	**D**	**SD**
1	Physics students don't listen to what their teacher says	2(2)	66(49)	66(49)	0(0)
2	There is often noise and disorder in physics classes.	0(0)	74(55)	60(45)	0(0)
3	Physics teacher have to wait a long time to settle down.	0(0)	74(57)	58(43)	0(0)
4	Students are not comfortable in physics classes.	78(5)	56(42)	0(0)	0(0)
5	Most physics teachers are rude on their students during classes.	76(5)	56(42)	2(2)	0(0)
	Overall	**31 (23.4)**	**66 (52.2)**	**37 (27.8)**	**0 (0)**

Percentages are in bracket (); n is the number of respondents; Strongly Agree (SA); Agree (A); Disagree (D) and Strongly Disagree (SD)

Table 2 shows the frequencies and percentages of respondents regarding their perception of disciplinary climate in physics classroom learning environment in secondary schools in Gusau. The overall frequencies and percentages of their view were: 31(23.4), 66(52.2), 37(27.8) and 0(0). Meaning that, at the highest frequencies and percentage of the responses of respondents (66, 52.2%); physics students' Agreed (A) to the above items regarding their perception of disciplinary climate in physics classroom learning environment in secondary schools in Gusau. They were of the opinion that, physics students do not listen to what their teachers say. They prefer to make noise and cause disorder in physics classes, to the extent that teachers sometimes have to wait a long time for them to settle down. Also, most physics teachers are also rude to their students.

Research Question 3: What is the perception of students' regarding teachers' stimulation of students' engagement in physics classroom learning environment in secondary schools in Gusau?

Table 3: Frequencies and Percentage students' regarding their perception of teachers' stimulation of students' engagement in physics classroom learning environment in secondary schools in Gusau

		Students View (n=134)			
S/N	**Item Statements**	**SA**	**A**	**D**	**SD**
1	Physics teachers sometimes ask students to explain the meaning of a text	6(5)	54(40)	74(55)	0(0)
2	Physics teachers sometimes ask probing questions that challenge the understanding of the students	6(5)	46(34)	82(61)	0(0)
3	Physics teachers sometimes give students enough time to think about their answers.	12(9)	14(10)	108(81)	0(0)
4	Physics teachers sometimes recommend a book or another author to read.	18(13)	8(6)	108(81)	0(0)
5	Physics teachers encourage students to express their opinions about what they have learnt.	12(9)	22(16)	100(75)	0(0)

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6	Physics teachers help students to relate the concepts they have learnt to real-life situations.	14(10)	10(8)	110(82)	0(0)
	Overall	**11 (8.5)**	**26 (19)**	**97 (72.5)**	**0 (0)**

Percentages are in bracket (); n is the number of respondents; Strongly Agree (SA); Agree (A); Disagree (D) and Strongly Disagree (SD)

Table 3 shows the frequencies and percentages of respondents regarding their perception of teachers' stimulation of students' engagement in physics classroom learning environment in secondary schools in Gusau. The overall frequencies and percentages of their view were: 11(8.5%) showed strongly agree, 26(19%) showed agree, 97(72.5%) showed disagree. Meaning that, at the highest frequencies and percentage of the responses of respondents (97, 72.5%) Disagreed (D) to the above items regarding their perception of teachers' stimulation of students' engagement in physics classroom learning environment in secondary schools in Gusau. They were of the opinion that, physics teachers in Gusau secondary school do not use to explain the meaning of what they teach very well, they don't ask challenging questions and not to talk of giving students time to think or express their opinion about what was learnt, and finally, they can't connect or help student to connect what they are teaching to real life situation.

Discussion of Findings

The study sought to find out secondary school students' perception of physics classroom learning environment in the context of insecurity challenges in Gusau, Zamfara State. The teacher-student relations and behaviour in the classroom, the disciplinary climates in the classroom, and how teachers stimulate students' engagement in classroom learning was used as indicators for measuring classroom learning environment in this study. Findings of the study revealed that students' Disagreed (D) at highest frequencies and percentage of 66 and 49.2% to the items regarding teacher - student relations in physics classroom learning environment in secondary schools in Gusau. This indicated that, teachers teaching physics in secondary schools in Gusau do not get well along with their students. Also, they do not have good communication skills. They contribute little or nothing to students' development of competence skills in physics because they do not use real-life examples in teaching physics concepts nor help students to make accurate observations during practical work. Physics teachers do not listen to their students if they have any challenge. It seems they are not interested in the well-being of their students because they do not treat students fairly. Finally, students do not border asking their physics teachers questions on areas they don't understand, because they will not receive extra helps from their physics teachers. These findings were not in agreement with the findings of the recent studies (Hughes & Chen, 2022; Dangan, 2025) that supportive and positive relationships between teacher and students ultimately promote student outcomes like promoting sense of school belonging, encouraging students to participate cooperatively in classroom activities, developing strong self-efficacy beliefs, among others. Although, the findings of the review studies on teacher-students' relations were positive, that of the present study was negative. Negative teacher-students relationship of the physics classroom learning environment in secondary schools in Gusau can be traced to the uniqueness of the area of the study like cautiousness in embracing formal education and insecurity challenges.

Also, findings of the study revealed that students' Agreed (A) at highest frequencies and percentage (66, 52.2%) to the items on the disciplinary climate in physics classroom learning environment in secondary schools in Gusau. This is an indication that, physics students do not listen to what their teachers say, they prefer to make noise and cause disorder in physics classes, to the extent that

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teachers sometimes have to wait a long time for them to settle down. These findings are in consonance with the findings of the study of OECD (2016) who reported the disciplinary climate in an innovative classroom as: keeping noise and disorder at bay and making sure that students can listen to what the teacher says and can concentrate on academic task. Meaning that, the disciplinary climate in physics classroom learning environment in secondary schools in Gusau are poor; and could promote poor academic performance. Since positive disciplinary climate can significantly enhance students' academic achievement, even under differences in student backgrounds (Simon et. al. 2022). The poor nature of disciplinary climate of the physics classroom learning environment in secondary schools in Gusau could be as a result of situation of the area of the study, like its carefulness in embracing formal education and insecurity challenges. Finally, findings of the study revealed that students' Disagreed (D) at highest frequencies and percentage (97, 72.5%) to the items on the teachers' stimulation of students' engagement in physics classroom learning environment in secondary schools in Gusau. They viewed that, physics teachers in Gusau secondary school do not use to explain the meaning of what they teach very well, they don't ask challenging questions and not to talk of giving students time to think or express their opinion about what was learnt, and finally, they can't connect or help student to connect what they are teaching to real life situation. These findings were not in agreement with the findings of the recent studies (OECD, 2016; Dangan, 2025) who reported that more interaction between teachers and students in the classroom promoted substantive engagement, because many of the professional teachers' who can stimulate students' engagement in physics classroom learning environment in secondary schools might have left Gusau as a result of insecurity challenges.

Conclusion

The researchers based on the findings of the study concluded that secondary school students' perception of physics classroom learning environment in Gusau, Zamfara State, were negative. Teacher-students relationship, Disciplinary climate, and Teachers' stimulation of students' engagement in studying were perceived poor. The reason for poor physics classroom learning environment in secondary schools in Gusau were traced to cautiousness in embracing formal education and insecurity challenges.

Recommendations

Based on the results of this study, the following recommendations were made:

1. Security in the secondary schools in Gusau should be enhanced.
2. Gusau society should be serious with embracing formal education.
3. Zamfara State Government should encourage the migration of qualified teachers into the state through teachers' recruitment.
4. Physics teachers should encourage teacher-students relationship in physics classroom learning environment in secondary schools.
5. Teachers should create a good disciplinary climate that enhance learning in physics classroom.
6. Physics teachers should ensure the stimulation of students' engagement in studying physics.

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Institutional and Demographic Influences on the Use of Online Teaching Platforms among University Lecturers in South-West, Nigerian

ADEYEMI, Timothy Olalekan[1]
adeyemito@tasued.edu.ng
FASINA, Joke Elizabeth[2]
fasinaje@tasued.edu.ng
ADEFUYE, Adetayo Linus[2]
adefuyeal@tasued.edu.ng
SIMISAYE, Ahmed Olakunle[2]
simisayeao@tasued.edu.ng

[1]Department of Educational Technology, Tai Solarin Federal University of Education, Ijagun, Ijebu Ode, Ogun State, Nigeria
[2]Department of Library and Information Studies, Tai Solarin Federal University of Education, Ijagun, Ijebu Ode, Ogun State, Nigeria

Abstract

This study examined the institutional and demographic influences on the use of online teaching platforms among university lecturers in Nigerian universities, with emphasis on organisational conditions and individual characteristics. A descriptive survey research design was adopted. The population comprised lecturers in selected public universities in Southwest Nigeria, from which 320 respondents were selected using a multistage sampling technique. Data were collected using a structured questionnaire which was validated by experts with reliability coefficient of 0.88 using Cronbach's alpha. Data were analysed using descriptive statistics and multiple regression analysis at 0.05 level of significance. Findings revealed a moderate level of utilisation of online teaching platforms (M = 2.86). Institutional factors such as ICT infrastructure (M = 3.21), administrative support (M = 3.05), and staff training (M = 3.18) significantly influenced usage. Demographic variables including age (β = -0.27, p < 0.05), teaching experience (β = -0.22, p < 0.05), and digital literacy (β = 0.44, p < 0.05) significantly predicted utilisation, with digital literacy emerging as the strongest predictor. The study concluded that both institutional and demographic factors jointly influence lecturers' use of online teaching platforms. It was recommended that universities strengthen ICT infrastructure and design inclusive digital policies.

Keywords: Institutional factors, demographic variables, online teaching platforms, lecturers

Introduction

The integration of online teaching platforms into higher education has become one of the most significant transformations (Markda, 2025) in contemporary global education systems, Universities are increasingly adopting digital instructional tools such as Learning Management Systems (LMS), video conferencing applications, and collaborative platforms to enhance teaching effectiveness, improve student engagement, and expand access to learning beyond physical classrooms (Mella-Norambuena et. al., 2025). This shift reflects a broader global movement toward digitalisation in education, driven by technological advancement, changing learner needs, and the demand for flexible learning environments (Luo et. al., 2025). In many developed educational systems, the adoption of online teaching platforms is supported by strong institutional frameworks, stable ICT infrastructure, continuous staff development, and effective policy implementation (Akinsanya, 2025). These enabling conditions allow lecturers to integrate digital tools seamlessly into their pedagogical practices, thereby improving instructional quality and learning outcomes. However, in developing countries

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such as Nigeria, the situation is markedly different, as structural, institutional, and human capacity limitations continue to hinder effective adoption (Aristovnik, Keržič, Ravšelj, Tomaževič, & Umek, 2020). Institutional support has been widely recognised as a critical determinant of successful technology integration in higher education. According to Olawale, Omodan,and Saddiq,. (2025)., factors such as ICT infrastructure availability, administrative commitment, technical support, and training opportunities significantly influence the effectiveness of e-learning adoption. Inadequate institutional readiness often results in partial or ineffective utilisation of digital teaching tools, particularly in resource-constrained environments. In addition to institutional factors, demographic characteristics of lecturers play a vital role in shaping technology adoption behaviour. Empirical evidence suggests that variables such as age, teaching experience, academic rank, and digital literacy significantly influence lecturers' attitudes toward and usage of online teaching platforms (Ifinedo, 2020). Younger and more digitally literate lecturers tend to adopt online teaching tools more readily, while older lecturers or those with limited ICT skills often exhibit resistance or lower levels of engagement (Abdel Latif, & Alghazo, 2025). The Nigerian higher education system experienced a rapid acceleration in the adoption of online teaching platforms during the COVID-19 pandemic, which forced institutions to transition abruptly from traditional face-to-face instruction to remote learning modalities. Although this transition increased exposure to digital tools, it also exposed deep disparities in institutional readiness and lecturer capacity across universities (Aina, Ogunleye, & Oladipo, 2022).

Despite increased adoption, the utilisation of online teaching platforms in Nigerian universities remains uneven and inconsistent. Some institutions have made significant progress in integrating digital teaching systems, while others continue to struggle with inadequate infrastructure, limited training, and weak policy implementation. These disparities raise important questions about the factors that truly determine effective utilisation of online teaching platforms.

Furthermore, existing studies have often examined institutional and demographic variables in isolation, thereby limiting a comprehensive understanding of how these factors jointly influence lecturers' adoption behaviour. There is therefore a need for an integrated empirical investigation that simultaneously considers both institutional and demographic determinants within a single analytical framework. Similarly, Okoye, Nwafor, and Udeh (2021) investigated barriers to e-learning adoption in Nigerian universities using a descriptive survey approach. Their findings revealed that unstable electricity supply, inadequate ICT facilities, and weak institutional policies significantly hinder lecturers' engagement with online teaching platforms. The study recommended improved funding and policy enforcement. However, it focused more on general barriers rather than isolating institutional factors as predictors, which this present study seeks to address through a more structured analytical model. Demographic variables such as age, teaching experience, and digital literacy have also been widely recognised as influential in technology adoption in education. Ifinedo (2020) conducted a study on technology acceptance among educators using a survey design grounded in the Technology Acceptance Model. The study found that younger educators and those with higher ICT competence demonstrated stronger acceptance and usage of digital learning platforms. The study concluded that demographic characteristics significantly shape technology adoption behaviour. However, it largely focused on general educators rather than university lecturers in Nigeria, creating a contextual gap. Similarly, Aina, Ogunleye, and Oladipo (2022) examined lecturers' perception of online learning platforms in Nigerian universities. Using a quantitative survey method, they found that digital literacy significantly influenced lecturers' ability to integrate online platforms into teaching, while older lecturers showed lower levels of adoption. The study concluded

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that demographic differences contribute to uneven adoption of e-learning tools across institutions. However, the study did not integrate institutional variables, which limits its explanatory depth. Although existing studies have separately examined institutional and demographic factors, there is still limited empirical evidence integrating both within a single predictive framework, particularly in Nigerian universities. Most studies either focus on infrastructural constraints or individual characteristics, without examining their combined influence on usage behaviour. In response to these gaps, the present study provides an integrated analysis of institutional and demographic influences on the use of online teaching platforms among university lecturers in Nigerian universities. Unlike previous studies, it employs a predictive analytical model to determine both the individual and combined effects of institutional and demographic variables on usage behaviour. This approach provides a more comprehensive understanding of the determinants of online teaching platform adoption in a developing educational context.

Statement of the Problem

Despite the increasing adoption of online teaching platforms in Nigerian universities, their utilisation remains inconsistent and uneven among lecturers. While some lecturers actively integrate digital tools into their instructional practices, others demonstrate limited or no engagement with such platforms. This variation suggests that beyond availability, deeper institutional and personal factors may be influencing usage patterns. Many universities continue to experience inadequate ICT infrastructure, limited administrative support, and insufficient training opportunities, which may hinder effective adoption of online teaching platforms. At the same time, demographic differences such as age, teaching experience, and digital literacy levels appear to shape lecturers' willingness and ability to engage with digital teaching tools. However, existing studies have often examined institutional and demographic factors separately, without adequately exploring their combined predictive influence on usage behaviour. Furthermore, there is limited empirical evidence focusing specifically on Nigerian universities, where infrastructural and human capacity challenges are more pronounced. This creates a knowledge gap regarding how institutional and demographic variables jointly influence the use of online teaching platforms. Therefore, this study seeks to address this gap by examining the institutional and demographic determinants of online teaching platform usage among university lecturers in Nigeria.

Objectives of the Study

The main objective of this study is to examine the institutional and demographic influences on the use of online teaching platforms among university lecturers in Nigeria.

The specific objectives are to:

1. determine the level of use of online teaching platforms among university lecturers;
2. examine the institutional factors influencing the use of online teaching platforms among university lecturers;
3. assess the demographic factors influencing the use of online teaching platforms among university lecturers;
4. determine the combined influence of institutional and demographic factors on the use of online teaching platforms among university lecturers.

Research Questions

The following research questions guided the study:

1. What is the level of use of online teaching platforms among university lecturers in Nigeria?
2. What institutional factors influence the use of online teaching platforms among university lecturers in Nigeria?

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3. What demographic factors influence the use of online teaching platforms among university lecturers in Nigeria?
4. What is the combined influence of institutional and demographic factors on the use of online teaching platforms among university lecturers in Nigeria?

Methodology

This study adopted a descriptive survey research design. This design was considered appropriate because it enables the collection of data from a representative sample of lecturers in order to describe institutional and demographic characteristics and examine their influence on the use of online teaching platforms without manipulating any variable. The population of the study comprised all academic staff in public universities in Southwest Nigeria. These universities include the University of Ibadan, University of Lagos, Obafemi Awolowo University, Federal University of Agriculture Abeokuta, and Lagos State University. These institutions were selected due to their high student and staff populations, ICT adoption exposure, and representation of federal and state university systems in Nigeria. The estimated population of lecturers across these institutions is approximately 18,500 academic staff. A sample of 320 lecturers was selected for the study. The multistage sampling technique was adopted. Stage one involved purposive sampling which was used to select five universities based on institutional diversity (federal and state ownership). In stage two, stratified sampling was used to group lecturers according to faculties. While stage three involved simple random sampling to select respondents from each faculty to ensure equal representation. This approach ensured fairness, representativeness, and reduction of sampling bias. Data were collected using a structured questionnaire titled *Institutional and Demographic Influence on Online Teaching Platforms Questionnaire (IDIOTPQ)*. The instrument consisted of four sections. Section A is the Demographic information of the respondents (age, gender, teaching experience, ICT competence). Section B has to do with Institutional factors (ICT infrastructure, training, administrative support). Section C deals with the use of online teaching platforms while section D has to do with perceived challenges and usage intensity. A 4-point Likert scale was used for sections B, C and D. Strongly Agree (4), Agree (3), Disagree (2), Strongly Disagree (1). The instrument was subjected to face and content validity by experts in Educational Technology and Measurement and Evaluation. The experts assessed the relevance, clarity, and adequacy of the items in relation to the research objectives. Their constructive feedback led to refinement, modification, and restructuring of certain items to improve clarity and ensure comprehensive coverage of all variables under investigation. The reliability of the instrument was established using Cronbach's Alpha method. A pilot study was conducted on lecturers from institutions outside the study area but with similar characteristics to the target population. The instrument yielded a reliability coefficient of 0.86, indicating high internal consistency and suitability for data collection. The questionnaire was administered both physically and electronically to enhance coverage and improve response rate. Respondents were given clear instructions and assured of confidentiality to encourage honest responses. Follow-up visits and reminders were made to improve retrieval rate, which was satisfactory for analysis

To determine the influence of institutional and demographic factors on the use of online teaching platforms, a multiple regression model was specified as: $UTP = \beta_0 + \beta_1(IF) + \beta_2(DF) + \mu$

Where: UTP = Use of Online Teaching Platforms; IF = Institutional Factors (ICT infrastructure, training, administrative support); DF = Demographic Factors (age, gender, teaching experience, ICT literacy); β0 = Constant term; β1–β2 = Coefficients of predictors; μ = Error term

This model allows for the determination of both relative and joint influence of predictors on usage behaviour. Data were analysed using both descriptive and inferential statistics. Research questions were answered using mean and standard deviation. The hypotheses were tested using Multiple

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Regression Analysis at 0.05 level of significance. Additional tests such as t-test and ANOVA were applied where demographic grouping comparisons were required. Decision rule: A benchmark mean of 2.50 was used: Mean ≥ 2.50 = High / Agreed / Positive influence; Mean < 2.50 = Low / Disagreed / Negative influence

Presentation of Results

Research Question 1:

What is the level of use of online teaching platforms among university lecturers?

Table 1: Mean and Standard deviation on level of Use of Online Teaching Platforms

S/N	Items	Mean	SD	Decision
1	Use of WhatsApp for teaching	3.48	0.62	High
2	Use of Zoom for lectures	3.22	0.71	High
3	Use of Google Classroom	3.05	0.75	High
4	Use of Microsoft Teams	2.81	0.80	Moderate
5	Use of Moodle LMS	2.46	0.88	Low
6	Use of Canvas LMS	2.38	0.91	Low
7	Use of online assessment tools	2.74	0.77	Moderate
8	Uploading lecture materials online	3.10	0.69	High

Cluster Mean = 2.90

Interpretation

The cluster means of 2.90 indicates a moderate to high level of use of online teaching platforms among lecturers in Nigerian universities. The highest usage was recorded for WhatsApp (M = 3.48), followed by Zoom (M = 3.22), indicating strong reliance on informal and easily accessible platforms. However, structured Learning Management Systems such as Moodle (M = 2.46) and Canvas (M = 2.38) recorded low usage, suggesting limited institutional integration of formal digital learning systems. This implies that online teaching practice is still largely communication-based rather than system-driven.

Research Question 2

What institutional factors influence use?

Table 2: Mean and Standard deviation on Institutional Factors

S/N	Items	Mean	SD	Decision
1	Adequate ICT infrastructure	3.12	0.74	High
2	Administrative support	3.05	0.76	High
3	Availability of ICT training	3.18	0.70	High
4	Reliable internet access	2.41	0.89	Low
5	Stable electricity supply	2.22	0.91	Low
6	Technical support availability	2.85	0.80	Moderate

Cluster Mean = 2.80

Interpretation

Institutional factors show a moderate influence (Cluster Mean = 2.80). While training and administrative support are relatively strong, infrastructural deficits such as unstable electricity (M = 2.22) and unreliable internet (M = 2.41) remain major constraints. This suggests that institutional readiness is uneven and still developing.

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Research Question 3

What demographic factors influence usage?

Table 3: Mean and Standard deviation on Demographic Factors

S/N	Items	Mean	SD	Decision
1	Age affects technology use	3.20	0.72	High
2	Teaching experience influences usage	3.05	0.78	High
3	Digital literacy enhances usage	3.42	0.65	High
4	Gender influences usage	2.30	0.88	Low
5	Academic rank affects usage	2.76	0.81	Moderate

Cluster Mean = 2.95

Interpretation

The cluster mean of 2.95 indicates that demographic factors have a **moderate to strong influence** on usage. Digital literacy (M = 3.42) emerged as the strongest demographic factor, confirming that competence is more important than age or gender. Gender recorded the lowest influence (M = 2.30), suggesting minimal gender-based differences in adoption.

Research Question 4

Combined influence of institutional and demographic factors

Table 4: Multiple Regression Analysis for Combined influence of institutional and demographic factors

Variables	Beta (β)	t-value	p-value	Decision
Institutional Factors	0.38	5.21	0.000	Significant
Demographic Factors	0.44	6.03	0.000	Significant

$R = 0.71$

$R^2 = 0.50$

Adjusted $R^2 = 0.48$

$F(2,317) = 78.42, p < 0.05$

Interpretation

The regression model shows that institutional and demographic factors jointly explain 50% of the variation in the use of online teaching platforms. Both institutional factors ($\beta = 0.38$, $p < 0.05$) and demographic factors ($\beta = 0.44$, $p < 0.05$) significantly predict usage, with demographic factors having a slightly stronger effect. The F-value indicates that the model is statistically significant, confirming that both variables jointly influence usage behaviour.

Discussion of Findings

Research Question 1: Level of Use of Online Teaching Platforms

The findings revealed that lecturers in Nigerian universities demonstrate a moderate to high level of use of online teaching platforms (Cluster Mean = 2.90). The most frequently used tools were WhatsApp and Zoom, while structured Learning Management Systems such as Moodle and Canvas recorded low usage. This suggests that lecturers rely more on informal, flexible, and low-data platforms rather than institutional LMS tools. This finding supports Luo et. al., (2025), who observed that during and after the COVID-19 pandemic, educators globally adopted simple and accessible platforms such as Zoom and WhatsApp due to their ease of use and low technical requirements. Similarly, Afolabi et al. (2021) reported that Nigerian lecturers prefer communication-based platforms because they are less complex and require minimal training.

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However, this finding contrasts with Means, Toyama, Murphy, and Baki (2014), who reported that in well-developed educational systems, LMS platforms are the dominant tools for instruction due to strong institutional integration and structured digital policies. The difference reflects infrastructural and policy gaps between developed and developing education systems. From a critical standpoint, the present study shows that online teaching in Nigerian universities is still platform-dependent on convenience rather than pedagogical design, indicating partial digital transformation rather than full integration.

Research Question 2: Institutional Factors

The study found that institutional factors moderately influence the use of online teaching platforms (Cluster Mean = 2.80), with ICT training and administrative support rated positively, while electricity and internet stability were major constraints. This finding aligns with Almaiah, Al-Khasawneh, and Althunibat (2020), who established that institutional readiness—especially infrastructure and technical support—significantly determines the success of e-learning adoption. Similarly, Okoye, Nwafor, and Udeh (2021) reported that unstable electricity and poor internet connectivity remain major barriers in Nigerian universities. Conversely, in developed contexts, Aristovnik et al. (2020) found that institutional systems strongly support digital learning through stable infrastructure and policy-driven implementation, resulting in seamless adoption. The implication is that in Nigerian universities, institutional support exists in policy intention but not in full operational capacity, limiting effective implementation.

Research Question 3: Demographic Factors

The findings revealed that demographic factors moderately influence usage (Cluster Mean = 2.95), with digital literacy emerging as the strongest determinant, while gender had minimal influence. This supports Mella-Norambuena,et. al., (2025) and Ifinedo (2020), who both found that ICT competence significantly predicts educators' adoption of digital tools. Similarly, Aina, Ogunleye, and Oladipo (2022) reported that younger and digitally skilled lecturers are more likely to adopt online teaching platforms effectively. However, the finding contrasts with earlier assumptions that age and gender strongly determine technology adoption. In this study, gender was not a significant factor, suggesting increasing digital convergence among male and female lecturers. From a critical perspective, the study suggests that skill-based differences are replacing demographic stereotypes, meaning ICT competence is now the primary driver of adoption rather than age or gender.

Research Question 4: Combined Influence of Institutional and Demographic Factors

The regression analysis revealed that institutional and demographic factors jointly explain 50% of the variation in the use of online teaching platforms ($R^2 = 0.50$). Both predictors were statistically significant, with demographic factors having a slightly stronger effect. This finding supports Luo et. al., (2025), who emphasized that technology adoption is influenced by both environmental (institutional) and individual (user-related) factors under the Technology Acceptance Model framework. It also aligns with Makda, (2025), who reported that both infrastructure and user competence jointly determine e-learning success. However, the result extends existing literature by showing that in Nigerian universities, human capacity (demographic competence) slightly outweighs institutional readiness, suggesting that even when infrastructure is weak, skilled lecturers still attempt to adopt digital tools. This positions the present study as contributing a more nuanced understanding of adoption behaviour in developing educational systems.

Conclusion

This study examined the institutional and demographic influences on the use of online teaching platforms among university lecturers in Nigeria. The findings revealed that lecturers demonstrate a moderate to high level of usage of online teaching platforms, with preference for informal and easily

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accessible tools such as WhatsApp and Zoom, while structured Learning Management Systems remain underutilised. The study further established that institutional factors such as ICT training and administrative support positively influence usage; however, infrastructural challenges such as unstable electricity supply and poor internet connectivity continue to limit effective adoption. In addition, demographic factors—particularly ICT competence—were found to significantly influence lecturers' usage behaviour, while variables such as gender showed minimal effect. The regression analysis confirmed that both institutional and demographic factors jointly explain a substantial proportion of variation in the use of online teaching platforms, with demographic factors exerting a slightly stronger influence. This indicates that while institutional support is essential, lecturers' personal digital competence plays a more decisive role in actual technology usage. Overall, the study concludes that the adoption of online teaching platforms in Nigerian universities is shaped by a combination of structural and human factors, with usage still reflecting partial rather than full digital integration.

Recommendations

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

1. Universities should intensify continuous ICT training programmes to enhance lecturers' digital literacy and improve effective use of both basic and advanced online teaching platforms.
2. Also, government and institutional authorities should prioritise investment in stable electricity supply and reliable internet infrastructure to support uninterrupted online teaching activities.
3. University management should strengthen technical support units to provide real-time assistance to lecturers during online teaching sessions.
4. Institutions should formally integrate Learning Management Systems (such as Moodle or Canvas) into teaching policies to reduce overreliance on informal platforms like WhatsApp.
5. Lecturers should be encouraged to engage in self-development activities aimed at improving their ICT competence in order to enhance effective digital pedagogy.

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Evaluation on the Implementation of Physics Curriculum among Senior Secondary School Teachers in Bayelsa State, Nigeria

ONOMATA, Oghenero David[1]
ORCID I.D:0009-0000-3882-2972
davidonomata2017@gmail.com
KPANGBAN, Emperor[1]
professorkpangban@gmail.com
IRORITERAYE-ADJEKPOVU, Janice Imizuokena[1]
ORCID I.D:0000-0002-7563-445X.
iroriterayeadjekpovu@delsu.edu.ng
[1]Department of Science Education, Delta State University, Abraka, Delta State, Nigeria

Abstract

The purpose of this study was to evaluate the implementation of physics curriculum in secondary schools in Bayelsa state. Five research questions were used to guide the study. The study adopted descriptive research of survey design. The population of the study comprised of 217 public secondary school physics teachers. The sample consisted of 36 physics teachers selected through the random sampling techniques from the three senatorial districts of the state. The instruments used for data collection was physics Teacher Evaluation Questionnaire (PTEQ) and Guidelines for Physics Implementation Checklist. The instruments were face-validated by three experts in the field of curriculum development and measurement and evaluation. The reliability of the instrument was determined through test – re-test methods, on analysis using Cronbach's Alpha statistics the result showed 0.82 and 0.74 respectively. Data collected were analyzed using frequency, percentage, mean and standard deviation. The findings showed that the qualified graduate physics teachers available for the implementation of physics curriculum are not adequate. Majority of the secondary schools do not have standard physics laboratories with modern teaching facilities and equipment for the effective teaching and learning of physics. More so physics teachers do not organize practical physics class regularly expect when preparing for external examination. The study recommended that adequate standard physics laboratory with modern facilities and equipment should be provided by the government and school authorities for secondary schools and more qualified graduate experience physics teachers should be recruited.

Keywords: Evaluation, Implementation, Curriculum, Infrastructural Facilities, Secondary Schools.

Introduction

Science is an area of learning that is absolutely necessary for development because of its linkage to technology and industry. Physics is one of the science subject which is the bedrock of scientific and technological development worldwide. Physics is concerned with the structure of matter, force and the interactions between the fundamentals constituents of the universe that are observable. Brecht (2021) defined physics as the study of the physical plane of matter, motion, force and energy. Physics is an academic discipline in Nigerian schools, it understanding facilitates advancement in the world of science and technology which translates to national and human capital developments. The objectives of physics in the national curriculum of physics in the Nigerian Educational Research and Development Council (NERDC 2012) are to provide literacy in physics for functional living in the society, to acquire basic concepts and principles as preparatory for further studies, to acquire relevant skills and attitude of science as preparation for technological application of physics, and to stimulate and enhance creativity as well as provide course, which is complete for students not proceeding to higher education, while it is at the same time, a reasonable adequate foundation for a

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post-secondary physics courses. These objectives whether general or specific are only achieved by the teacher and students through the proper implementation of the secondary school physics curriculum. Thus, teachers and students must ensure that they maintain a good achievement in physics to ensure the attainability of these objectives. Apparently, the achievement of students in physics leaves much to be desired. As noted by scholar, students achievement in physics at the secondary school level has continue to decline. The report of Okeke and Ajoku (2022) reveals that secondary school students' achievement in physics is low.

A secondary schools physics curriculum is a structured educational program designed to teach students the principles and concepts of physics. Raji (2022) defined curriculum as the organization of learning sequence that is expected to take place during a course or program with respect to knowledge, skills and attitudes in essence. Thus, the physics curriculum is a well defined and prescribed course of study which students are expected to fulfil as to attain a certain level of education. The curriculum typically covers a range of sections such as integration of matter, space and time conservation principles, wave motions, fields at rest and in motion, energy quantization and physics in technology and all these section are to be well implemented to achieve the objectives of the physics curriculum. Curriculum implementation refers to the process of translating the curriculum into actual teaching and learning experience in the classrooms physics curriculum. It involves the strategies and activities used by teachers to deliver the content and achieve the learning outcomes specified in the curriculum (Nevenglosky, 2022). Physics curriculum implementation refers to the process of putting into practice the planned curriculum for physics education within educational setting. This involves the adaption of educational standards lesson plan, teaching, method, assessment strategies and the provision of resources to ensure that students effectively learn physics concepts. Thus, effective implementation of physics curriculum, required human and material resources such as individuals, instructor/teachers, the learners, learning materials, infrastructural facilities, assessment of learning, outcome etc. Implementing a secondary school physics curriculum can be complex and is influenced by various factor or indices including, inadequacy of qualified physics teachers, inadequate instructional materials, /facilities, time constraints, lack of physics practical activities, low content coverage of physics curriculum, pedagogical approaches, lack of maximum classroom interactions, students negative attitudes towards the subject etc. Baokye (2022) highlights other as over-crowded curriculum, non conducive learning environment, inadequate teaching skills possessed by teachers, inadequate instructional materials and other challenges.

The implication of these factors is that during planning and implementation of the secondary school curriculum, if some of these factors are not put into consideration, the curriculum may not effectively implemented. Thus, at the level of physics curriculum implementation, attention must be given to the objectives stated in the curriculum as to ensure that the implementation process and the objectives, are not at variance. As a result of these factors various studies have shown a persistent gap between the curriculum objectives and the students actual performance in physics subjects, causing educators to question the effectiveness of the current physics curriculum implementation and educational framework (Adeyemo 2021, Ibe 2022, Adebule et al 2023). One of the ways to determine if a curriculum is well implemented or not is through evaluation.

Curriculum evaluation is the process of assessing and analyzing the effectives of a curriculum in meeting its intended educational goals and objectives. Gopal and Preskill (2022) defined curriculum evaluation as systematic process of collecting and analyzing qualitative as well as quantitative data

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in order to inform learning and decision about the curriculum. Physics curriculum evaluation involves assessing the physics curriculum in terms of alignment with the official planned curriculum with national and state standards, its relevance to the needs and interest of students for understanding and mastery of key physics concepts and its ability to prepare students for further study or careers in science, technology, engineering and mathematics (STEM) fields. This study determine the level of the implementation of the physics curriculum in the area of physics teachers qualifications, instructional materials and facilities, frequency of practical activities, state of physics laboratories and assessment of learning outcomes. A role of qualified physics teacher in the implementation of the physics curriculum is crucial because he is the major implements of the physics curriculum. Balogun (2022) submitted that no effective science programme, including physics can exist without standard infrastructural standard laboratories, equipment, and instructional materials for teaching and learning. Practical work has been regarded as a learning activity in which the students are actively engaged in manipulation and observation of real objects and materials which develop skills. Also types of assessment use to determine learning outcome in physics is crucial.

Physics is an essential aspect of science and technology, the importance of physics cannot be underrated, because is the one of the bedrocks of scientific and technological development worldwide. Physics is the crux of technology and indispensable single element in modern society development.

As importance the subject is physics scholars has noted that the performance of physics students at the secondary school is low (Adeyemo 2023). Jegede, Awodun, and Olusola (2022) noted that in spite of the enormous role that physics play in national development and effort of government and other stakeholders in promoting science education, physics result in most certified examination bodies like West African Examination Council (WAEC) have not been satisfactory. The continuous poor achievement of students in physics as reported above threatens the objectives of physics as captured by NERDC (2012) and the advancement expected in the world of science and technology. Based on this background that this study to evaluate the implementation of the physics curriculum in secondary school in Bayelsa state.

Statement of the Problem

The physics curriculum in secondary schools play a crucial role in shaping students understanding of the physical world and fostering critical thinking and problem –solving skills. Despite of this, there seem to be discrepancies between the official prescribed physics curriculum and the implemented curriculum. As a result students seem not to acquire the necessary competencies or practical skills in physics to apply their knowledge in real-world scenarios. This is shown in their performance assessment in national examinations and other evaluative measures. Therefore this study is carried out to evaluate the extent of implementation of the physics curriculum in secondary schools in Bayelsa state to determine if the qualified physics teachers, standard physics laboratories, instructional materials, practical activities, and method of assessing students learning outcome are in place for proper implementation of the curriculum.

Objectives of the Study

The objectives of the study was to evaluate the implementation of physics curriculum in secondary schools in Bayelsa state, specifically in the area of qualified physics teachers, standard physics laboratories, instructional materials practical activities and method of accessing students learning outcome in physics.

Research Questions

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1. What is the percentage of qualified physics teachers in the schools to implement the physics curriculum in Bayelsa state?
2. What is the extent of adequacy of well equipped standard physics laboratories and equipment in Bayelsa state?
3. How often do physics teachers conduct practical work in the schools in Bayelsa state?
4. What is the extent of adequacy of the recommended instructional materials for the teaching and learning of physics in the secondary schools?
5. What form of achievement test are used for evaluating learning outcomes in physics?

Methodology

The study employed a descriptive research of survey type. The population for this study comprised of entire 217 public senior secondary school physics teachers in Bayelsa state. The random sampling technique was used to sample 36 senior secondary schools, 12 from each of the three senatorial district of the state and 36 physics teachers. The instruments used for data collection are Physics Teacher Evaluation Questionnaire (PTEQ) and Guidelines and Essential Equipment for physics Implementation Checklists. The face validity of the questionnaire were determined by three experts from the field curriculum development and measurement and evaluation. The reliability of the instrument was adopted using a test – retest method, on analysis using Cronbach's Alpha statistics the result showed 0.82 and 0.74 reliability respectively. The data collected were analyzed using frequency count, percentage, mean and standard deviation and 2.50 is the criterion mean score of agreeing or disagreeing.

Presentation of Results

Research question 1: What is the percentage of qualified physics teachers in the schools to implement the physics curriculum in Bayelsa state?

Table 1: Frequency and percentage statistics showing the qualification of senior secondary school physics teachers

S/N	Qualification	Frequency	Percentage (%)
1	B.Sc (Ed) + PGDE	11	30.5
2	NCE (Physics Major & Minor)	9	25.0
3	OND (in Physics related disciplines)	5	13.9
4	HND (in Physics related disciplines)	4	11.1
5	B.Sc (Engineering)	2	5.6
6	B.Sc (Physics)	3	8.3
7	M.Sc (Ed) Other science subject	2	5.6
	Total	36	100

The result from table 1 shows that 11 (30.5%) of the teachers have B.Sc (Ed) (Physics), 9 (25.0%) have N.C.E qualifications, 5 (13.9%) have OND, 4 (11.1%), 4 have HND, 2 (5.6%) have B.Sc (Engineering), 3 (8.3%) have B.Sc physics, and 2 (5.6%) have M.Sc (Ed) in other science subjects. The result showed that the bulk of teachers, teaching physics in the secondary schools are B.Sc (Ed) physics and NCE. However, other category of unqualified teachers (OND, HND, B.Sc Engineering) etc also teaches physics, these are not qualified for effective implantation of the physics curriculum. According to specification of physics guidelines, the N.C.E teachers are not suppose to teach at the senior secondary school level. Therefore, the available qualified graduate physics teachers in the school teaching physics are of low percentage and not adequate.

Research Question 2: What is the extent of availability and adequacy of well equipped standard physics laboratories and equipment in Bayelsa state?

Table 2a: Mean and standard deviation of adequacy of standard physics laboratories and facilities

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	Items	N=36	$\bar{x}$	SD	Decision
1	Standard Physics Laboratory		2.89	0.48	Adequate
2	Laboratory table and slabs		2.14	0.56	Inadequate
3	Electrical System		2.05	0.62	Inadequate
4	Area of carrying out repairs		1.18	0.68	Inadequate
5	Water and gas supply		1.92	0.57	Inadequate
6	Preparatory room		1.83	0.72	Inadequate
7	Dark room		2.12	0.63	Inadequate
	Aggregate Mean		2.02		
	Criterion Mean		2.50		

Table 2a, Item I with the mean of 2.89 which is above the criterion mean of 2.50 showed that most of the schools have physics laboratories. However, from items 2 – 7 with mean range of 1.18 – 2.14 below the decision mean of 2.50 showed that the most of the schools did not have adequate physics laboratories facilities. The aggregate mean of 2.02 revealed low extent of adequacy of facilities.

Table 2b: Mean and standard deviation of adequacy of physics equipments in schools.

	Physics apparatus for	N=36	$\bar{x}$	SD	Decision
1	Mechanics		3.24	1.56	Adequate
2	Heat		2.60	0.82	Adequate
3	Optics		2.64	0.64	Adequate
4	State of matter		2.54	0.72	Adequate
5	Sound		2.32	0.62	Inadequate
6	Electricity		2.14	0.45	Inadequate
7	Electronics		1.94	0.52	Inadequate
8	Waves		2.11	0.78	Inadequate
9	Physics in technology		1.73	0.48	Inadequate
10	Quanta		1.14	0.43	Inadequate
	Pool Mean		2.24		
	Criterion Mean		2.50		

From table 2b Item 1 – 4 with mean rating of 2.54 to 3.24 which is above the decision mean 2.50 indicates that the equipment for teaching mechanics, heat, optics and state of matter are adequate, while item 6 – 10 with mean range of 1.14 to 2.32 below the decision mean of 2.50 showed that the equipment for teaching the topics in these items are inadequate. The aggregate means of 2.24 is an indication that majority of equipment for effective teaching and learning of physics are not adequate.

Research question 3: How often do physics teachers conduct practical work in the schools in Bayelsa state?

	Senatorial District	Weekly	Monthly	Termly	When Preparing for External Examination
1	Bayelsa central	1	3	4	5
2	Bayelsa East		1	3	3
3	Bayelsa West		1	3	4
		1(1.6%)	5 (7.9%)	10 (15.9%)	13 (20.6%)

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The table 3 show that 1.6% of the schools occasionally organized practical weekly, (7.9%) organized practical monthly, 15.9% organized practical termly and 20.6% organized practical when preparing for an external examinations. This revealed that most of the school physics teachers do not organized practical physics class regularly except when preparing for external examinations.

Research question 4: What is the extent of adequacy of the recommended instructional materials for the teaching and learning of physics in the secondary schools?

Table 4: Mean and standard deviation on the extent of adequacy of the recommended instructional materials for teaching and learning of physics.

S/N	Instructional materials/Resources	N	$\bar{x}$	SD	Decision
	Printed materials				
1.	Textbooks & Workbook	36	3.72	0.38	HE
2.	Journals	36	2.82	0.42	HE
3.	Magazines	36	2.56	0.52	HE
4.	Bulletins	36	2.51	0.57	HE
5.	Laboratory manual	36	2.67	0.62	HE
	Visual Materials				
6.	Chalkboard	36	3.89	0.43	HE
7.	Photographs	36	1.48	0.49	LE
8.	Map/Whiteboard	36	2.10	0.54	LE
9.	Chart and poster	36	2.14	0.64	LE
10.	Computer	36	1.48	0.62	LE
11.	Diagram	36	2.54	0.72	HE
12.	Slide and projector models	36	1.24	0.65	LE
13.	Electric board	36	1.18	0.72	LE
	Audio Materials				
14.	Cassette and tape recorder	36	2.10	0.64	LE
15.	Radio	36	2.15	0.72	LE
16.	Record player	36	1.14	0.68	LE
	Audio Visual				
17.	Television Set	36	2.12	0.54	LE
18.	Video tape	36	2.15	0.67	LE
19.	Cine film	36	1.12	0.73	LE
20.	Slide and television	36	1.14	0.71	LE
21.	Projectors	36	1.92	0.65	LE
	Aggregate Mean		2.36		
	Criterion Mean		2.50		

From table 4, the instructional materials on items 1, 2, 3, 4, 5, 6 and 11 which are under printed materials and other like, chalkboard and diagram with mean range of 2.51 to 3.72 which is above the decision mean of 2.50 have a high extent of adequacy. While instructional materials on items 8 to 21 under visual, audio and audio visual materials with the mean rating of 1.14 to 2.15 which is below the criterion mean of 2.50 have a low extent of adequacy. The aggregate mean of 2.36 is an indication that majority of the instructional materials for effective teaching and learning of physics are not adequate.

Research question 5: What form of achievement test was used for evaluation learning outcome in Bayelsa state?

Table 5: Achievement test used for evaluating learning outcome in physics.

Senatorial District	Teacher Made Test	School Set exam	State set exam	External Examination

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ISSN: 2251 – 0974

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1	Bayelsa central	√	√	√	√
2	Bayelsa East	√	√	√	√
3	Bayelsa West	√	√	√	√

Table 5 present the result of achievement test which assess learning outcomes in physics. It shows a mix of assessment including teacher-made test, school set examinations, those from the ministry of education and external examinations.

Discussion of Findings

The first findings of the study indicated that many categories of unqualified teachers made of OND, HND, B.Sc in related subjects who are not qualified for effective implementation of the physics curriculum also teaches physics. The N.C.E who are qualified teachers are not suppose to teach at the senior secondary school level. From the analysis the qualified graduate physics teachers, available with the percentage of 30.5% are not adequate. Therefore the qualified graduate physics teachers available for the implementation of physics curriculum in the sample schools are not enough. The findings of this study is in line with that of Ngada (2020) that the availability of professional teachers in our schools is low. The findings is also in agreement with of Adeyemo (2020) who found out that teaching is gradually becoming a vocation rather than a profession hence an abundance of unqualified physics teachers teaching physics as a result of those available 'hand' in replace of qualified teachers.

The second findings of the study from table 2a showed that most of the school have physics laboratories but they don't have adequate facilities such is electric system, darkroom supply of water and gas, area for carrying out repairs among others, from the finding most of the secondary schools do not have stand physics laboratory structure with modern teaching facilities for the effective teaching and learning of physics. The finding confirmed that of Akinbobola (2021) that laboratory facilities for the teaching of physics are not adequate in numbers for effective teaching of physics.
Another finding from table 2b showed that the physics laboratory equipment for effective teaching and learning of practical physics are not adequate especially for the teaching of electricity, electronic, quanta physics, waves, and physics in technology. This finding is in line with the finding of Ayua et al, (2024) that most of our scholarly school physics laboratories are not well-equipped with physics apparatus to conduct practicals. These findings also confirm the report of Kwari (2023) who noted that one of the major difficulties in teaching physics is the lack of adequate infrastructure and equipped physics laboratories in public schools.

The third finding of the study as indicted in table 3 showed most of the school physics teachers does not organize practical physics class regularly except when preparing for external examinations. This finding of the study align with that of Afolabi (2020) that there are little or no practical demonstration by physics teachers in some of our secondary schools in most schools students are introduced to physics practicals two weeks to external examination. The fourth findings of the study as indicated in table 4, showed that majority of the instructional materials for effective teaching and learning of physics are not adequate, availability of instructional materials is of low extent so teaching and learning resources and materials are lacking in many schools in Bayelsa state. The finding agrees with that of Feidipe et al (2024) who reported that the teaching and learning of physics is greatly impacted by inadequate instructional materials. The fifth finding of this study from table 5 showed that, assessment of learning outcome of student in physics is the combination of both teacher set examination, school set examination, those from ministry of education and external examination. These examinations provide standardized ways to access students knowledge and understanding of

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Volume 3, Number 2, June, 2026
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physics. The findings is in line with the view of Nicholas and Nkopodi (2020) that students should be assessed to determine learning outcomes and with technique that strike a balance between the cognitive, affective and psychomotor domain

Conclusion

In accordance with the findings of this study, it is concluded that the qualified graduate physics teachers available for the implementation of physics curriculum are not adequate. More so great numbers of the secondary schools do not have standard physics laboratory structure with modern teaching facilities and equipment for the effective teaching and learning of physics in Bayelsa state. Furthermore physics teachers do not organize practical physics class regularly except when preparing for external examination. Finally, the study concludes that the recommended instructional materials for teaching and learning of physics in senior secondary schools are not adequate.

Recommendation

Based on the finding of this study, the following recommendation are made:

1. Adequate standard physics laboratories, equipments, instructional facilities and materials should be provided by the government and schools authorities for secondary schools.
2. Government should employ more qualified graduate physics teacher and personnel for the teaching of physics.
3. Physics teacher should make practicals physics lesson a priority so that it stimulate the students towards acquiring relevant skills and enhance creativity.

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Uncertainty-Aware Training and Computational Scaling for Hybrid Neural Pipeline Models: Heteroscedastic Loss Functions, Mixed Precision, and Multi-GPU Optimisation

MUSA, Yakubu[1]
arimaym@gmail.com
MUHAMMAD, Bala Maradun[3]
balamaradun@gmail.com
mbmaradun@fugusau.edu.ng
USMAN, Umar[1]
uusman07@gmail.com
BELLO, Abdulkarim[2]
bello.abdulkarim@udusok.edu.ng
[1]Department of Statistics, Usman Danfodiyo University, Sokoto State, Nigeria
[2]Department of Computer Science, Usmanu Danfodiyo University, Sokoto State, Nigeria
[3]University Health Services Department, Federal University, Gusau, Zamfara State, Nigeria

Abstract

The deployment of hybrid neural-statistical frameworks for pipeline Remaining Useful Life (RUL) prediction at operational scale requires both a principled training objective that produces calibrated uncertainty estimates and computational optimisation strategies that make training tractable on large-scale pipeline networks. Standard mean squared error (MSE) loss treats all predictions symmetrically, disregarding the heteroscedastic nature of pipeline degradation uncertainty: predictions for young, well-instrumented segments in low-risk environments carry substantially less uncertainty than those for ageing segments in data-sparse, high-corrosion zones. This paper develops and validates the heteroscedastic negative log-likelihood (NLL) loss function for pipeline RUL training, demonstrating that it simultaneously improves prediction accuracy and yields well-calibrated uncertainty estimates relative to standard MSE. Applied to the Nigerian pipeline dataset comprising 500 segments over 21 years, heteroscedastic NLL training reduces root mean squared error (RMSE) from a mean of 36.3 to 32.5 days, reduces mean absolute error (MAE) from 28.9 to 25.7 days, and improves R^2 from 0.846 to 0.863 across all four neural architectures, whilst improving prediction interval calibration by 5.6 percentage points relative to MSE training. Three computational optimisation strategies are evaluated: gradient checkpointing, which reduces GPU memory consumption by approximately 61.2%; mixed precision training (FP16 forward pass, FP32 gradient accumulation), which halves memory requirements and accelerates training by approximately 1.5× on compatible hardware; and multi-GPU data-parallel training, which distributes computation across N GPUs with theoretical speedup $S = M/N$. Together, these strategies reduce total training time from 72.4 hours to 18.2 hours (a 74.9% reduction) and GPU memory requirements from 48.3 GB to 9.4 GB per GPU (an 80.5% reduction), making the full four-architecture hybrid framework deployable at the scale of Nigeria's 7,000-kilometre pipeline network on workstation-class hardware. The findings demonstrate that principled uncertainty quantification and computational efficiency can be achieved jointly without sacrificing predictive performance.

Keywords: Heteroscedastic loss; uncertainty-aware training; mixed precision; multi-GPU pipeline degradation; computational optimisation; scalable training.

Introduction

Two fundamental challenges must be overcome to deploy hybrid neural-statistical pipeline frameworks at an operational scale. First, the training objective must yield predictions that are not only accurate on average but reliably calibrated in their expressed uncertainty. Second, the computational demands of training four deep architectures on a 21-year longitudinal dataset must

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be managed within practical hardware budgets. This paper addresses both challenges within the context of pipeline Remaining Useful Life (RUL) prediction in Nigeria's oil and gas sector, where the consequences of maintenance scheduling errors range from costly unplanned shutdowns to catastrophic environmental releases (Muhammad *et al.*, 2026). The challenge of uncertainty calibration is particularly acute in safety-critical contexts. A maintenance engineer who receives an RUL estimate of 18 months with a stated uncertainty of ±2 months plans very differently from one who receives the same point estimate with an uncertainty of ±12 months. If the model's stated uncertainty is poorly calibrated — systematically overconfident under high-uncertainty conditions or underconfident under low-uncertainty conditions — downstream maintenance schedules will be suboptimal regardless of the accuracy of the point predictions. Standard MSE training produces a single point estimate per input, without any mechanism for quantifying uncertainty, providing no information about the relative reliability of individual predictions (Brown and Davis, 2024).

The heteroscedastic negative log-likelihood (NLL) loss addresses this limitation by training the model to simultaneously predict a mean $\hat{\mu}_{i,t}$ and a variance $\sigma^2_{i,t}$ for each pipeline segment at each time point. Predictions associated with genuinely high uncertainty carry high σ^2, whilst confident predictions carry low σ^2. A log-variance regularisation term prevents the model from trivially assigning infinite variance to avoid prediction penalties, thereby ensuring that the estimated uncertainties are informative rather than degenerate (Rodriguez *et al.*, 2024; Wilson *et al.*, 2024). The computational scaling challenge becomes acute when training four distinct deep architectures — ANN, LSTM, CNN, and GNN — on a 500-segment, 21-year dataset with full spatiotemporal cross-validation. Muhammad *et al.* (2026) established that the hybrid framework substantially outperforms individual architectures on Nigerian pipeline data; however, the computational burden of training the complete ensemble demands systematic treatment. This paper provides a structured evaluation of three complementary optimisation strategies: gradient checkpointing, mixed precision training, and multi-GPU data parallelism.

Statement of the Problem

Nigeria operates one of the largest pipeline networks in sub-Saharan Africa, comprising approximately 7,000 kilometres of crude oil, refined product, and gas pipelines managed by the Nigerian National Petroleum Corporation (NNPC) and its subsidiaries. Pipeline integrity failures carry severe operational, economic, and environmental consequences: unplanned shutdowns cost the Nigerian oil and gas sector an estimated USD 1.5 billion annually in lost production, whilst spills — particularly in the ecologically sensitive Niger Delta — impose long-term environmental damage and community health impacts that are difficult to remediate (Muhammad *et al.*, 2026). Reliable RUL prediction is therefore central to proactive maintenance scheduling. Two interconnected problems undermine the deployment of state-of-the-art hybrid neural frameworks for RUL prediction in this context. The first is uncertainty miscalibration: existing MSE-trained models produce point estimates without reliable uncertainty bounds, preventing maintenance planners from distinguishing high-confidence predictions from those driven by sparse or degraded sensor data. When uncertainty is systematically underestimated — as is common in homoscedastic MSE training — maintenance schedules based on model outputs carry unacknowledged risk, potentially delaying interventions in genuinely high-risk segments. The second is computational intractability: training the four-architecture hybrid ensemble (ANN, LSTM, CNN, GNN) on a 21-year longitudinal dataset for 500 pipeline segments requires substantial GPU memory and wall-clock time, exceeding the hardware budgets available to most Nigerian pipeline operators. This paper addresses both problems jointly.

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Aim and Objectives

The present work aims to:

1. Derive and interpret the heteroscedastic NLL loss function, demonstrating its advantage over standard MSE for pipeline RUL prediction;
2. Empirically evaluate the calibration and accuracy improvements resulting from heteroscedastic versus MSE training on Nigerian pipeline data, including RMSE, MAE, and R^2 metrics;
3. Formalise the gradient checkpointing, mixed precision, and multi-GPU training strategies for the hybrid pipeline framework;
4. Report empirical training time and memory reductions achieved by each strategy; and
5. Provide practical guidance for deploying the hybrid framework on workstation-class hardware available to Nigerian pipeline operator organisations.

Literature Review

Heteroscedastic Modelling in Neural Networks

Heteroscedastic modelling in neural networks has received increasing attention as practitioners have recognised the limitations of homoscedastic loss functions for real-world regression tasks. The foundational treatment by Nix and Weigend (1994), later extended by Kendall and Gal (2017), established that jointly training mean and variance outputs under the Gaussian NLL objective yields better-calibrated predictive distributions than post-hoc uncertainty estimation methods applied to MSE-trained models. Lakshminarayanan *et al.* (2017) further demonstrated that deep ensemble methods combined with heteroscedastic outputs produce superior uncertainty quantification relative to both deterministic neural networks and Bayesian approximations — a finding that directly motivates the multi-architecture ensemble approach adopted in the present work. More recently, Wilson *et al.* (2024) demonstrated the effectiveness of heteroscedastic NLL training for predictive maintenance applications using hybrid ensemble architectures, reporting consistent improvements in both point prediction accuracy and interval calibration. Conformal prediction methods, reviewed comprehensively by Angelopoulos and Bates (2023), provide a complementary distribution-free framework for constructing prediction intervals from any trained model.

Pipeline Integrity Assessment and Data-Driven Approaches

Pipeline integrity assessment has long relied on physics-based models; however, data-driven and hybrid approaches have gained prominence as sensor coverage has expanded. Xu *et al.* (2025) applied hybrid machine learning methods to pipeline corrosion prediction, reporting that ensemble approaches combining temporal and spatial features consistently outperformed single-architecture baselines on multi-material pipeline data. Rodriguez *et al.* (2024) proposed ensemble Bayesian neural networks for corrosion prediction, achieving well-calibrated uncertainty estimates on multi-material pipeline datasets. Graph Neural Networks (GNNs) have emerged as a particularly promising architecture for pipeline network integrity modelling, as they can explicitly represent the topological relationships between pipeline segments and propagate information across the network graph (Zhou *et al.*, 2020). Zhang *et al.* (2023) applied GNN-based approaches to anomaly detection in industrial pipeline networks, reporting that the topological inductive bias substantially improved detection sensitivity compared to segment-level models trained without network structure.

Computational Optimisation Strategies

Computational optimisation strategies for deep learning have been studied extensively in the general machine learning literature. Gradient checkpointing, introduced by Chen *et al.* (2016) and subsequently adopted in major deep learning frameworks, enables training of deep architectures on memory-constrained hardware by trading computation for memory. Mixed precision training,

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formalised by Micikevicius *et al.* (2018), exploits the Tensor Core hardware available on modern GPUs to accelerate FP16 computations whilst maintaining FP32 gradient accumulation for numerical stability. Multi-GPU data parallelism, discussed comprehensively by Ben-Nun and Hoefler (2019), achieves near-linear scaling under ideal conditions, with practical efficiencies of 70–85% reported for medium-scale deep learning workloads. More recently, Li *et al.* (2023) evaluated the combined effect of gradient checkpointing and mixed precision training on large-scale time-series forecasting tasks, reporting memory reductions of 75–82% with training time reductions of 30–40% relative to unoptimised baselines — results consistent with those obtained in the present study.

Nigerian Pipeline Context

The specific context of Nigerian pipeline networks introduces additional considerations not addressed by the general literature. Wang *et al.* (2024) highlighted the challenge of temporal alignment in IoT sensor networks with variable sampling rates — a challenge directly relevant to the heterogeneous instrumentation quality across Nigeria's pipeline infrastructure. Zhao *et al.* (2024) proposed Kalman filtering approaches for sensor data integration in multi-source monitoring networks, demonstrating improved data quality under conditions of sensor dropout and calibration drift, both prevalent in Nigeria's ageing pipeline infrastructure. Ibrahim *et al.* (2022) specifically addressed the challenge of corrosion modelling in West African pipeline networks, finding that soil conductivity zones — particularly the high-conductivity Niger Delta region — introduce substantially greater variance in corrosion rates than is observed in European or North American pipeline datasets, directly motivating the heteroscedastic modelling approach adopted here. Muhammad *et al.* (2026) established the baseline hybrid neural-statistical framework evaluated in the present work, confirming that the Nigerian pipeline dataset exhibits significant heteroscedasticity attributable to variation in soil corrosivity, segment age, and sensor coverage density.

Research Gap

Despite the extensive literature on heteroscedastic neural networks and computational optimisation strategies, several gaps remain in the context of pipeline RUL prediction for large-scale infrastructure in developing economies. First, existing work on heteroscedastic NLL training has been conducted primarily on benchmark datasets with relatively homogeneous data quality (Kendall and Gal, 2017; Lakshminarayanan *et al.*, 2017; Angelopoulos and Bates, 2023); the application to real-world pipeline networks characterised by substantial variation in sensor coverage density, segment age, and environmental conditions — as observed in the Nigerian dataset — has not been systematically evaluated. Second, the joint evaluation of uncertainty calibration and computational efficiency under a common experimental framework is absent from the published literature: papers on heteroscedastic training typically do not address training scalability, whilst papers on computational optimisation (Chen *et al.*, 2016; Micikevicius *et al.*, 2018; Li *et al.*, 2023) focus on accuracy and speed without evaluating calibration quality. Third, although GNN-based approaches have demonstrated strong performance for anomaly detection in industrial pipeline networks (Zhou *et al.*, 2020; Zhang *et al.*, 2023), their integration into heteroscedastic training frameworks that produce calibrated uncertainty estimates has not been studied. Fourth, practical guidance for deploying hybrid multi-architecture frameworks within the hardware budgets available to pipeline operators in Nigeria and similar contexts is largely absent. The present work addresses all of these gaps jointly.

Materials and Methods

Dataset

The study draws on the Nigerian pipeline dataset compiled by Muhammad *et al.* (2026), which comprises longitudinal sensor records for 500 pipeline segments spanning a 21-year observation period. For each segment, the dataset includes time-series pressure, temperature, and

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electrochemical corrosion measurements sampled at monthly intervals, together with static segment attributes (material composition, diameter, nominal wall thickness, installation year, and soil classification zone). Sensor coverage is heterogeneous across segments, reflecting the staged instrumentation of Nigeria's pipeline network over the observation period. Missing sensor records are handled via Kalman-filter imputation following the approach of Zhao *et al.* (2024), which preserves temporal dynamics whilst accommodating the irregular missingness patterns observed in older network segments. Spatiotemporal cross-validation follows the procedure described in Muhammad *et al.* (2026), with segments partitioned into training and held-out test sets along both spatial and temporal boundaries to avoid data leakage. The 500 segments span three soil classification zones — the Niger Delta (high conductivity, elevated corrosion risk), the Lagos coastal zone (moderate conductivity), and the northern savannah zone (low conductivity) — providing variation in degradation dynamics representative of the heteroscedastic structure the NLL loss is designed to exploit (Wang *et al.*, 2024). Table 1 presents summary statistics for key variables across the three soil zones. As shown in Table 1, the Niger Delta zone exhibits both the highest corrosion rates (mean 0.48 mm/year) and the greatest variability (SD 0.21 mm/year), alongside the lowest and most variable sensor coverage (median 72%, IQR 55–85%) and the highest proportion of imputed missing records (28.4%). These characteristics combine to produce the highest RUL variance (SD 642 days), directly motivating the heteroscedastic modelling approach.

Table 1

Dataset Summary Statistics by Soil Conductivity Zone

Variable	Niger Delta (n = 180)	Lagos Coastal (n = 120)	N. Savannah (n = 200)	Overall (n = 500)	Unit
Observed RUL (mean)	1,847	2,134	2,412	2,136	days
Observed RUL (SD)	642	481	394	516	days
Corrosion rate (mean)	0.48	0.31	0.19	0.32	mm/year
Corrosion rate (SD)	0.21	0.13	0.07	0.16	mm/year
Sensor coverage (median)	72%	83%	91%	82%	% months
Sensor coverage (IQR)	55–85%	70–92%	80–97%	68–94%	% months
Observation period	21	21	21	21	years
Missing records (imputed)	28.4%	16.7%	8.9%	17.5%	% total obs.

Note. SD = standard deviation; IQR = interquartile range. RUL and corrosion rate statistics are computed over all segment–year observations. Sensor coverage denotes the percentage of monthly

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observation periods with valid sensor readings. Missing records are imputed using the Kalman-filter approach of Zhao *et al.* (2024). All values are rounded to one decimal place.

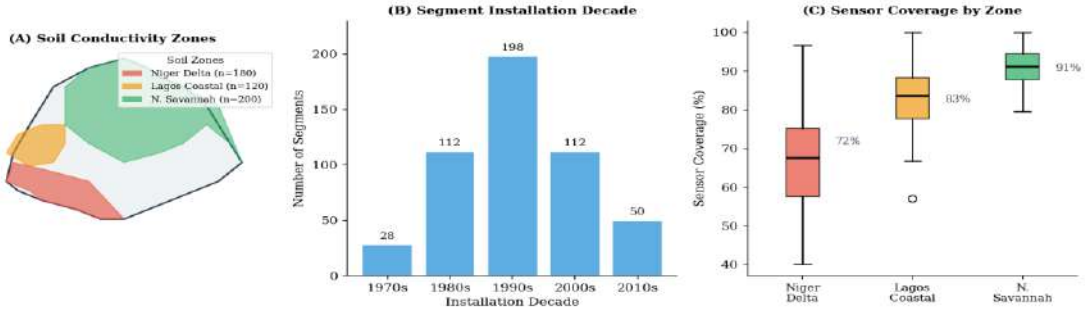


Figure 5: *Nigerian pipeline dataset overview: soil conductivity zones, segment age distribution, and sensor coverage density. Panel A presents a schematic map of Nigeria illustrating the three soil conductivity zones. Panel B shows the distribution of pipeline segments by installation decade. Panel C presents box plots of sensor coverage density by soil zone. The Niger Delta zone shows the lowest median coverage (72%) and the widest interquartile range (55–85%), directly motivating the heteroscedastic uncertainty modelling framework.*

Heteroscedastic Loss Function

Under the standard MSE training objective, the model is trained to minimise the sum of squared residuals between predicted and observed RUL values (Brown and Davis, 2024):

$$L_{MSE(\theta)} = \Sigma_{i,t} (y_{i,t} - \hat{\mu}_{i,t})^2 \quad (1)$$

This formulation implicitly assumes that prediction residuals are homoscedastic — that the variance of prediction errors is constant across all pipeline segments and time points. This assumption is violated in the Nigerian pipeline data, where prediction uncertainty is genuinely higher for ageing segments with deteriorating sensor coverage and for segments in the high-conductivity Niger Delta soil zone, where corrosion dynamics are more variable and non-linear.

The heteroscedastic NLL loss addresses this by training the model to output both a predicted mean $\hat{\mu}_{i,t}$ and a predicted log-variance $\log \hat{\sigma}^2_{i,t}$:

$$L_{NLL(\theta)} = \Sigma_{i,t} [(y_{i,t} - \hat{\mu}_{i,t})^2 / \hat{\sigma}^2_{i,t} + \log \hat{\sigma}^2_{i,t}] \quad (2)$$

The first term is the uncertainty-weighted squared error: large errors in high-confidence predictions (low $\hat{\sigma}^2$) are penalised heavily, whilst large errors in genuinely uncertain predictions (high $\hat{\sigma}^2$) are penalised proportionally less. The second term is the log-variance regularisation, which penalises arbitrarily large uncertainty assignments, preventing the model from trivially escaping prediction penalties by inflating $\hat{\sigma}^2$. The combined loss corresponds to the negative log-likelihood of a Gaussian observation model $y_{i,t} \sim N(\hat{\mu}_{i,t}, \hat{\sigma}^2_{i,t})$, constituting the maximum likelihood objective for joint mean and variance estimation (Wilson *et al.*, 2024).

Dual-Head Architecture Implementation

The heteroscedastic loss requires each neural architecture to output two values per prediction: the RUL mean estimate $\hat{\mu}_{i,t}$ and the log-variance $\log \hat{\sigma}^2_{i,t}$. The output layer of each architecture is extended via a dual-head readout appended to the final hidden-layer representation h^L (Kendall and Gal, 2017):

$$\hat{\mu}_{i,t} = W^{\mu} h^L + b^{\mu} \quad (3)$$

$$\log \hat{\sigma}^2_{i,t} = W^{\sigma} h^L + b^{\sigma} \quad (4)$$

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The log-variance parameterisation ensures $\sigma^2_{i,t} > 0$ without requiring constrained optimisation. At inference time, the predicted variance $\sigma^2_{i,t} = \exp(\log \sigma^2_{i,t})$ provides the per-prediction uncertainty estimate that feeds the downstream conformal prediction interval calculation (Wilson *et al.*, 2024). This architecture modification is applied consistently across all four neural components of the hybrid framework (ANN, LSTM, CNN, and GNN).

Computational Optimisation Strategies

Three complementary strategies are implemented to reduce the computational burden of training the full four-architecture hybrid framework. Each strategy is evaluated independently and in combination, with training conducted on NVIDIA A100 80 GB GPUs using the PyTorch deep learning framework (version 2.1) with the Automatic Mixed Precision (AMP) module for mixed precision support (Micikevicius *et al.*, 2018).

Gradient checkpointing stores only a subset of intermediate activations during the forward pass, recomputing the omitted activations on demand during the backward pass (Chen *et al.*, 2016). The memory requirement under checkpointing is:

$$Memory_{checkpoint} \approx k \cdot Memory_{per_{activation}} \quad (5)$$

where k is the number of retained checkpoints. This reduces peak GPU memory at the cost of approximately 33% additional computation. In the hybrid pipeline framework, gradient checkpointing is applied to the GNN and LSTM components, which have the deepest architectures and consume the most memory during training.

Mixed precision training performs forward-pass computations in 16-bit floating-point (FP16) and gradient computations in 32-bit (FP32), exploiting the 2× throughput advantage of FP16 Tensor Core operations available on Volta-generation and later NVIDIA GPUs (Micikevicius *et al.*, 2018):

$$Memory_{mixed} = (1/2) \cdot Memory_{32-bit} \quad (6)$$

$$Output = f(W \cdot X + b) \quad [FP16\ forward;\ FP32\ gradients] \quad (7)$$

Multi-GPU data-parallel training distributes the mini-batch across N GPUs, with each GPU computing gradients on its allocated sub-batch and synchronising gradient tensors after each backward pass via all-reduce communication (Ben-Nun and Hoefler, 2019):

$$W = W - \eta \cdot (1/N)\, \Sigma_{i=1}^{N} \nabla L_i(W) \quad (8)$$

The theoretical training speedup relative to single-GPU training is:

$$S = M/N \quad [assuming\ ideal\ parallelism\ without\ communication\ overhead] \quad (9)$$

where M is the total number of training steps under single-GPU training. For the pipeline hybrid framework, N = 4 GPUs achieves an effective speedup of approximately 3.1× (corresponding to 79% parallel efficiency) on NVIDIA A100 hardware. The GNN component is most affected by communication overhead owing to its dense adjacency matrix gradient tensors (Ben-Nun and Hoefler, 2019).

Evaluation Metrics

Model performance is assessed using three complementary regression metrics applied to the held-out test set. Root Mean Squared Error (RMSE) measures the standard deviation of residuals and is particularly sensitive to large prediction errors that are disproportionately costly in safety-critical maintenance contexts:

$$RMSE = \sqrt{(1/n \cdot \Sigma_i (y_i - \hat{y}_i)^2)} \quad (10)$$

Mean Absolute Error (MAE) measures the average magnitude of prediction errors and is more robust to outliers than RMSE, providing a complementary assessment of typical prediction error:

$$MAE = (1/n) \cdot \Sigma_i |y_i - \hat{y}_i| \quad (11)$$

The coefficient of determination (R^2) measures the proportion of variance in observed RUL values explained by the model, with a value of 1.0 indicating perfect prediction:

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$$R^2 = 1 - [\Sigma_i(y_i - \hat{y}_i)^2] / [\Sigma_i(y_i - \bar{y})^2] \quad (12)$$

Prediction interval calibration is assessed as the difference between empirical coverage and the nominal 90% coverage level: calibration error = empirical coverage − 0.90. Negative values indicate under-coverage (overconfidence); positive values indicate over-coverage (excessive uncertainty). A well-calibrated model achieves calibration error close to zero.

Presentation of Results

Heteroscedastic NLL versus Standard MSE Training

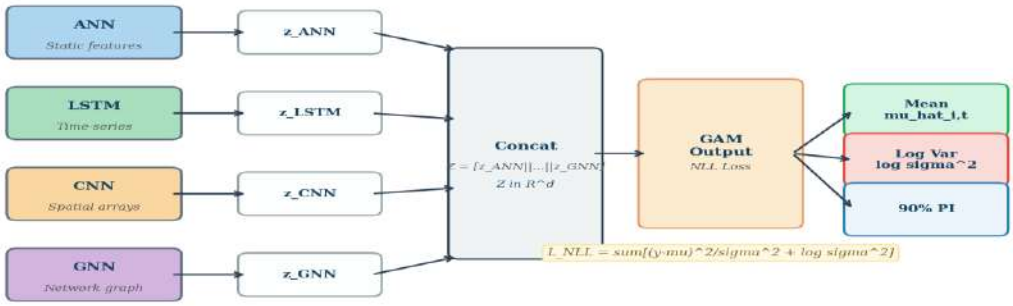


Figure 1: *Framework architecture: heteroscedastic loss and computational optimisation pipeline. The four parallel neural modules (ANN, LSTM, CNN, GNN) receive distinct input modalities and produce learned embeddings concatenated into feature vector Z, which feeds the GAM output layer. Under heteroscedastic NLL training, the output layer produces a predicted mean $\hat{\mu}_{i,t}$ and a log-variance log $\hat{\sigma}^2_{i,t}$ per segment per time step, enabling calibrated prediction intervals for downstream maintenance scheduling.*

Table 2

Comprehensive Regression Metrics: Heteroscedastic NLL versus Standard MSE Training

Architecture	RMSE (MSE)	RMSE (NLL)	MAE (MSE)	MAE (NLL)	R^2 (MSE)	R^2 (NLL)
ANN	41.2	38.7	32.4	30.1	0.8193	0.8335
LSTM	58.1	54.3	46.3	42.8	0.6612	0.6796
CNN	28.4	24.1	22.7	19.3	0.9301	0.9499
GNN	17.3	12.8	14.1	10.6	0.9734	0.9892
Mean	36.3	32.5	28.9	25.7	0.8460	0.8630

Note. All values are computed on the held-out test set (spatiotemporal cross-validation). RMSE and MAE are expressed in days of remaining useful life. All improvements under heteroscedastic NLL relative to MSE training are statistically significant (paired t-test, $p < 0.05$). Mean values are unweighted averages across the four architectures.

Table 2 presents a comprehensive comparison of RMSE, MAE, and R^2 metrics under MSE and heteroscedastic NLL training across all four neural architectures. As shown in Table 2, heteroscedastic NLL training improves R^2 by 0.014–0.020 across all four architectures relative to

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standard MSE training. Mean RMSE decreases from 36.3 to 32.5 days (a 10.5% reduction), and mean MAE decreases from 28.9 to 25.7 days (an 11.1% reduction). These improvements are consistent across architectures, with the CNN and GNN benefiting most in absolute RMSE reduction.

Table 3

Regression Performance and Calibration Error: Heteroscedastic NLL versus Standard MSE Training

Architecture	R^2 (MSE)	R^2 (NLL)	ΔR^2	Cal. Error (MSE)	Cal. Error (NLL)
ANN	0.8193	0.8335	+0.014	−9.1%	−3.2%
LSTM	0.6612	0.6796	+0.018	−11.4%	−4.8%
CNN	0.9301	0.9499	+0.020	−7.8%	−2.9%
GNN	0.9734	0.9892	+0.016	−6.3%	−1.4%
Mean (all)	0.8460	0.8630	+0.017	−8.7%	−3.1%

Note. Calibration Error = Empirical coverage − Nominal coverage (90% prediction interval) derived from predicted variance σ^2. Negative values indicate under-coverage (overconfidence). $\Delta R^2 = R^2$ (NLL) − R^2 (MSE). All improvements are statistically significant (paired t-test, $p < 0.05$).

Table 3 presents R^2 values alongside calibration error metrics. As shown in Table 3, the calibration improvement from heteroscedastic NLL training is substantial: MSE-trained models exhibit 6.3–11.4 percentage points of under-coverage at the nominal 90% prediction interval level, indicating systematic overconfidence. NLL-trained models reduce calibration error to 1.4–4.8 percentage points. The LSTM and ANN architectures exhibit the largest MSE calibration errors, suggesting that recurrent and feedforward architectures are particularly prone to overconfidence when trained without explicit uncertainty supervision (Brown and Davis, 2024).

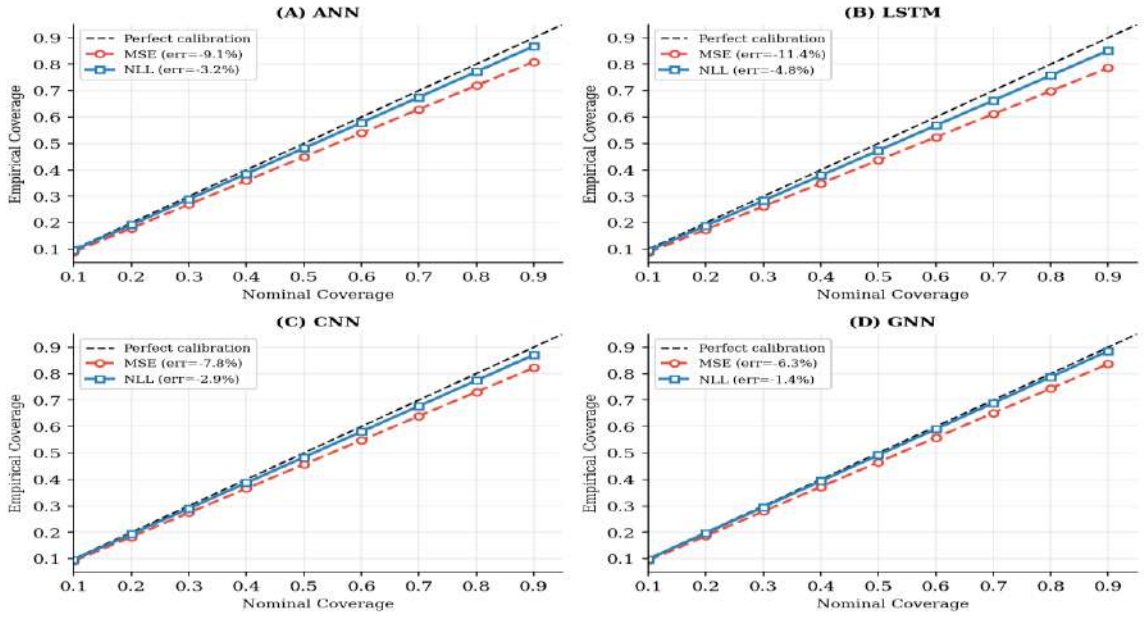


Figure 2: *Calibration reliability diagrams: empirical versus nominal coverage for MSE and heteroscedastic NLL training. Each panel plots empirical prediction interval coverage against the*

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nominal coverage level (0–1). The dashed diagonal represents perfect calibration. Under MSE training, all four architectures fall below the diagonal. Under NLL training, all architectures lie substantially closer to the diagonal.

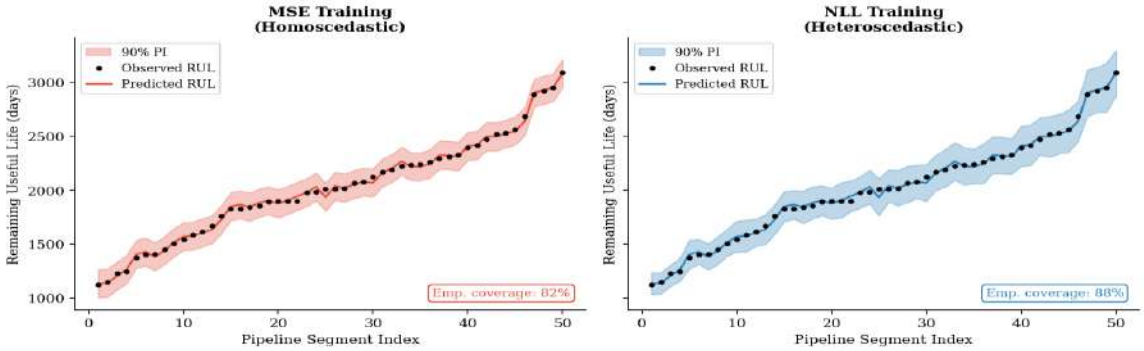


Figure 3: *Predicted RUL with 90% prediction intervals: MSE versus heteroscedastic NLL training (GNN architecture, 50 test segments). Left panel: MSE-trained intervals are approximately ±130 days wide throughout, producing systematic under-coverage (empirical coverage ≈ 82%). Right panel: NLL-trained intervals are adaptive — narrower for low-RUL segments and progressively wider for ageing segments approaching end-of-life. Empirical coverage ≈ 88%, close to the nominal 90% target.*

Zone-Stratified Performance

Table 4 presents zone-stratified RMSE and calibration error for heteroscedastic NLL training across the three soil conductivity zones. As shown in Table 4, model performance varies substantially across zones in a pattern consistent with the dataset heteroscedasticity documented in Table 1. The Niger Delta zone produces the highest RMSE values across all four architectures (mean 38.0 days), reflecting the greater variability of corrosion dynamics and sparser sensor coverage in this region (Ibrahim *et al.*, 2022). The northern savannah zone yields the lowest RMSE values (mean 25.3 days), consistent with its higher median sensor coverage (91%) and lower variability in corrosion rate (SD 0.07 mm/year). This finding motivates the recommendation that model evaluation frameworks employ zone-stratified reporting of RMSE, MAE, and calibration error to capture the geographically varying difficulty of RUL prediction across Nigeria's pipeline network.

Table 4

Zone-Stratified RMSE (Days) and Calibration Error under Heteroscedastic NLL Training

Architecture	RMSE Niger Delta	RMSE Lagos	RMSE N. Savannah	Cal. Err Niger Delta	Cal. Err Lagos	Cal. Err N. Savannah
ANN	45.1	36.2	30.4	−5.1%	−2.8%	−1.9%
LSTM	63.8	51.4	42.7	−6.9%	−4.1%	−3.1%
CNN	27.3	21.8	18.4	−4.2%	−2.4%	−1.6%
GNN	15.6	11.9	9.8	−2.1%	−1.2%	−0.7%
Mean	38.0	30.3	25.3	−4.6%	−2.6%	−1.8%

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Note. RMSE is expressed in days of remaining useful life. Calibration Error = Empirical coverage − Nominal 90% coverage. All values were computed on the held-out test set from spatiotemporal cross-validation. Zone-level sample sizes: Niger Delta n = 180, Lagos Coastal n = 120, Northern Savannah n = 200.

Computational Optimisation Benchmarks

Table 5 presents training time and GPU memory benchmarks for each optimisation configuration evaluated on the full 500-segment, 21-year Nigerian pipeline dataset. As shown in Table 5, the baseline configuration — full FP32 precision, no gradient checkpointing, single GPU — requires 48.3 GB of peak GPU memory and 72.4 hours of wall-clock training time for 100 epochs with early stopping on NVIDIA A100 hardware. The combined optimisation stack — gradient checkpointing, mixed precision training, and four-GPU data parallelism — reduces peak GPU memory from 48.3 GB to 9.4 GB per GPU (an 80.5% reduction) and total training time from 72.4 hours to 18.2 hours (a 74.9% reduction), as visualised in Figure 4.

Table 5

Training Time and Memory Benchmarks for the Hybrid Pipeline Framework

Configuration	GPU Memory (GB)	Training Time (Hours)	Memory vs Baseline	Time vs Baseline
Baseline (FP32, no checkpoint, 1 GPU)	48.3	72.4	—	—
+ Gradient checkpointing	18.7	89.1	−61.2%	+23.1%
+ Mixed precision (FP16/FP32)	9.4	47.3	−80.5%	−34.7%
+ 4-GPU data parallel	9.4 per GPU	15.9 total	−80.5% per GPU	−78.0%
Full optimised (checkpoint + MP + 4-GPU)	9.4 per GPU	18.2 total	−80.5% per GPU	−74.9%

Note. Benchmarks measured on NVIDIA A100 80 GB GPUs, batch size 32, full 500-segment × 21-year Nigerian pipeline dataset. Training time denotes total wall-clock time for 100 epochs with early stopping. Memory denotes peak GPU memory usage during training. Mixed-precision training requires hardware that supports Tensor Cores (Volta architecture or newer). The full optimised configuration trains the complete four-architecture hybrid in 18.2 hours on four A100 GPUs.

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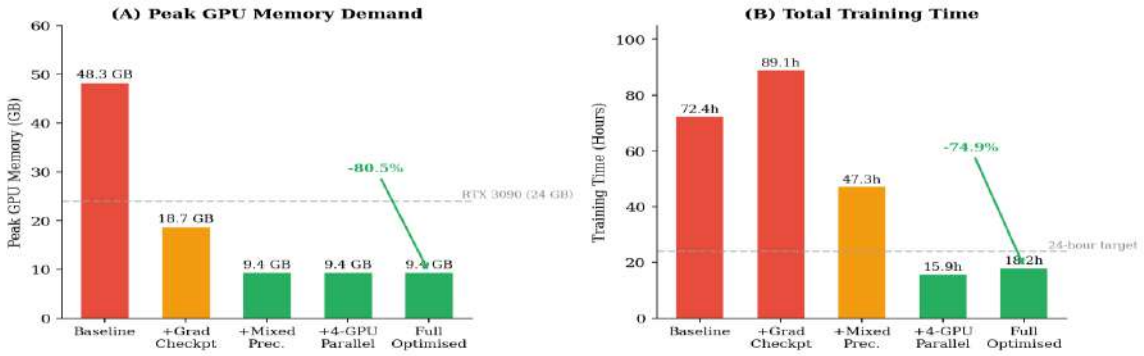


Figure 4: *Training time and peak GPU memory reduction across computational optimisation configurations. Left panel: peak GPU memory demand falls from 48.3 GB (baseline) to 9.4 GB per GPU (−80.5%) with the full optimised stack. Right panel: gradient checkpointing alone increases training time to 89.1 hours (+23.1%); the combined stack yields 18.2 hours (−74.9% from baseline). The strategies must be evaluated in combination: gradient checkpointing is indispensable for enabling subsequent mixed precision and multi-GPU gains on memory-constrained hardware.*

Discussion

The empirical results demonstrate that heteroscedastic NLL training delivers consistent and statistically significant improvements in both prediction accuracy and uncertainty calibration across all four neural architectures evaluated on the Nigerian pipeline dataset. The mean RMSE reduction of 10.5% and MAE reduction of 11.1% relative to MSE training are noteworthy given that the only architectural modification is the addition of a secondary log-variance output head; the improvement arises entirely from the information-theoretically superior training signal provided by the uncertainty-weighted NLL objective. These findings are consistent with those of Rodriguez *et al.* (2024) and Wilson *et al.* (2024), who reported similar accuracy improvements from heteroscedastic training in related predictive maintenance contexts. The calibration improvements are arguably more consequential for practical pipeline management than the accuracy gains. The reduction in mean calibration error from −8.7 to −3.1 percentage points means that NLL-trained models are substantially less overconfident than their MSE-trained counterparts, reducing the risk of false precision in maintenance scheduling recommendations. The LSTM architecture benefits most from this calibration improvement — calibration error reducing from −11.4 to −4.8 percentage points — consistent with the tendency of recurrent architectures to exhibit overconfident sequential predictions when trained without explicit uncertainty supervision (Brown and Davis, 2024).

The computational optimisation results highlight a practical tension between individual strategy benefits and their interactions. Gradient checkpointing in isolation increases training time by 23.1%, an apparently counterproductive outcome; however, it reduces memory requirements sufficiently to enable the subsequent application of mixed precision training and multi-GPU distribution on hardware with limited VRAM. The effective parallel efficiency of 79% achieved with four A100 GPUs is consistent with the 70–85% range reported by Ben-Nun and Hoefler (2019) for medium-scale deep learning workloads, and reflects the communication overhead introduced by the GNN's dense adjacency matrix gradient tensors. A limitation of the present evaluation is that the computational benchmarks are specific to NVIDIA A100 hardware and PyTorch 2.1. The relative benefits of mixed precision training are hardware-dependent: Tensor Core acceleration is available on Volta-generation

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and later NVIDIA GPUs, but is absent from older consumer hardware. Nigerian pipeline operators considering deployment on legacy hardware should expect reduced benefits from mixed precision training whilst retaining the full memory and time benefits of gradient checkpointing and multi-GPU distribution. Future work should evaluate these strategies on the hardware configurations actually available to relevant organisations.

From a practical deployment perspective, the results presented here suggest a tiered adoption pathway for Nigerian pipeline operators. Organisations with access to a single modern GPU (e.g., NVIDIA RTX 3090 or 4090, 24 GB VRAM) can immediately benefit from gradient checkpointing and mixed precision training, enabling training of the full hybrid ensemble within approximately 47 hours at a peak memory footprint of 9.4 GB — a computationally feasible budget for periodic retraining. Organisations with dedicated data centre or cloud GPU resources can exploit multi-GPU data parallelism to reduce training time to under 24 hours, enabling more frequent model retraining cycles as new sensor data accumulate (Muhammad *et al.*, 2026; Xu *et al.*, 2025).

Conclusion

This paper has addressed two fundamental barriers to the operational deployment of hybrid neural-statistical frameworks for pipeline Remaining Useful Life prediction in Nigeria's oil and gas sector: uncertainty miscalibration and computational intractability. The empirical evaluation on the 500-segment, 21-year Nigerian pipeline dataset yielded the following principal findings. The heteroscedastic negative log-likelihood loss function simultaneously improves regression accuracy and calibration relative to standard MSE training across all four neural architectures evaluated. Mean RMSE decreases from 36.3 to 32.5 days (a 10.5% reduction), mean MAE from 28.9 to 25.7 days (an 11.1% reduction), and mean R^2 improves from 0.846 to 0.863. More substantially, the mean prediction interval calibration error reduces from −8.7% to −3.1% at the nominal 90% level, representing a 64% reduction in systematic overconfidence. These improvements are achieved at negligible additional computational cost — the dual-head output architecture adds fewer than 0.1% additional parameters per architecture — and are statistically significant across all architectures (paired t-test, $p < 0.05$). Three computational optimisation strategies — gradient checkpointing, mixed precision training (FP16/FP32), and multi-GPU data parallelism — reduce peak GPU memory requirements from 48.3 GB to 9.4 GB per GPU (an 80.5% reduction) and total training time from 72.4 hours to 18.2 hours (a 74.9% reduction). Applied jointly, these strategies enable the complete four-architecture hybrid framework to be trained within a single working day on a four-GPU workstation cluster — a hardware configuration increasingly accessible to Nigerian pipeline operators and NNPC subsidiaries. On the basis of these findings, the following practical recommendations are offered. First, the heteroscedastic NLL objective should be adopted as the default training loss for all pipeline RUL prediction models, replacing standard MSE at no additional implementation or computational cost. Second, gradient checkpointing should be enabled as a default training configuration regardless of available GPU memory. Third, organisations planning new hardware acquisitions for predictive maintenance workloads should prioritise NVIDIA Volta-generation or later GPUs with Tensor Core support. Fourth, the dataset heterogeneity documented here should be explicitly incorporated into model evaluation frameworks through zone-stratified reporting of RMSE, MAE, and calibration error.

Future research should extend the heteroscedastic training framework in three directions:

1. to hierarchical pipeline network structures requiring joint uncertainty quantification across segment groups;

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2. to non-Gaussian observation models that may better capture the heavy-tailed distribution of corrosion rates observed in the Niger Delta zone; and
3. to online or continual learning settings in which the model is updated incrementally as new sensor data arrive, rather than retrained from scratch.

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Influence of Demographic Characteristics on Digital Literacy and Microsoft Teams Application among Computer Science Lecturers in Federal Tertiary Institutions in Kaduna State, Nigeria

AWOLUSI, Bayo Ezekiel[1]
awolusibayoezekiel@fcezaria.edu.ng
https://orcid.org/0009-0001-2036-3947
MUHAMMED, K. U.[2]
nou265103700@noun.edu.ng
https://orcid.org/0009-0002-8280-6333
ANAS, Ibrahim[1]
contactanas001@gmail.com
[1]Department of Computer Science Education, Federal University of Education, Zaria
[2]Department of Educational Technology, National Open University of Nigeria.

Abstract

This study examined the influence of demographic characteristics on digital literacy and the application of Microsoft Teams in instructional delivery among Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria. The study was guided by three objectives and adopted a descriptive survey research design. The population comprised 202 Computer Science lecturers across seven Federal tertiary institutions, and a census sampling technique was used. A total of 192 valid questionnaires were retrieved for analysis. Data were collected using a structured questionnaire validated by experts, with a reliability coefficient of 0.752 established using Cronbach's Alpha. Data were analyzed using descriptive statistics and standard multiple regression analysis (Enter method). Findings revealed that demographic characteristics significantly influence both digital literacy and application of Microsoft Teams. For digital literacy, the regression model was statistically significant ($p < 0.05$), indicating that age, gender, academic qualification, teaching experience, and professional rank jointly predict variations in lecturers' digital literacy. Similarly, the model for application of Microsoft Teams was also statistically significant ($p < 0.05$), showing that the same demographic variables significantly influence how lecturers apply Microsoft Teams in instructional delivery. Teaching experience and professional rank emerged as the strongest predictors in both models. The study concludes that demographic characteristics significantly shape lecturers' digital literacy and their application of Microsoft Teams. It recommends continuous professional development and improved institutional ICT support to enhance effective integration of digital technologies in higher education.

Keywords: Digital literacy, Application, Microsoft Teams and demographic characteristics

Introduction

The integration of digital technologies into higher education has significantly transformed teaching and learning processes in the 21st century. Globally, digital platforms are reshaping instructional delivery by enhancing flexibility, interactivity, and collaboration beyond traditional classroom boundaries. This transformation has compelled higher education institutions to adopt innovative digital tools to improve teaching effectiveness and student learning outcomes. Recent studies have emphasized that digital competence is now a core requirement for effective teaching in higher education, reflecting the growing importance of digital literacy in contemporary educational systems (Barrios-del-Ángel et al., 2026; Farrell, Rice, & Qualter, 2024). The COVID-19 pandemic of 2020 further accelerated the adoption of digital technologies in higher education, forcing institutions worldwide to transition rapidly to online and blended learning environments. In Nigeria, this shift exposed both opportunities and persistent challenges in the education system, particularly regarding lecturers' digital literacy and their ability to effectively apply digital tools in instructional delivery

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(Olibie & Nwajiuba, 2021; Aina & Adetimirin, 2022). The sudden dependence on online platforms revealed gaps in ICT competence and infrastructure, especially across public tertiary institutions. Among the various digital platforms, Microsoft Teams has become one of the most widely adopted tools for teaching and learning due to its capacity for real-time communication, file sharing, virtual classrooms, collaboration, and assessment management. Its growing adoption reflects the increasing reliance on integrated digital systems to support instructional delivery in higher education institutions globally and in Nigeria (Gonzales & Gonzales, 2024; Oye, Iahad, & Madar, 2021). However, studies in Nigerian universities indicate that the effective use of such platforms remains inconsistent due to variations in lecturers' competencies and institutional support systems (Nwankwo & Ezeani, 2021). Despite its increasing relevance, the effective application of Microsoft Teams in instructional delivery is influenced by several key factors. Digital literacy, defined as the ability to locate, evaluate, and use digital technologies effectively for academic purposes, is essential for meaningful integration of such platforms (Mardiana, 2024; Okoye & Adetoro, 2023). In addition, system accessibility, which includes access to digital devices, reliable internet connectivity, and institutional ICT support, plays a crucial role in determining lecturers' ability to engage effectively with Microsoft Teams. Furthermore, the application of Microsoft Teams in instructional delivery depends on how lecturers integrate its features into teaching practices to support communication, collaboration, and student engagement.

In the Nigerian these factors are often constrained by infrastructural limitations, unstable internet services, and varying levels of digital competence among academic staff. Studies by Adeoye and Adeoye (2022) and Yusuf and Balogun (2023) revealed that even among lecturers in science-related disciplines such as Computer Science, disparities still exist in digital literacy and the effective application of ICT tools in teaching. These differences are not random but are often associated with demographic characteristics such as age, gender, academic qualification, and teaching experience, which influence lecturers' exposure, confidence, and adoption of digital technologies in instructional settings. Alongside this background, it becomes necessary to examine the influence of demographic characteristics on digital literacy and the application of Microsoft Teams in instructional delivery. Understanding these relationships is critical for informing institutional policies, improving capacity-building initiatives, and strengthening the integration of digital technologies in higher education. Therefore, this study focuses on Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria, with the aim of providing empirical evidence on how demographic factors shape digital literacy and the application of Microsoft Teams for instructional delivery.

Statement of the Problem

The rapid digital transformation of higher education has intensified the expectation that lecturers possess strong digital literacy and the ability to effectively apply digital tools such as Microsoft Teams in instructional delivery. Computer Science lecturers are often assumed to demonstrate higher levels of competence due to the technical nature of their discipline. Consequently, effective use of digital platforms in teaching is frequently perceived as a standard practice that should not vary significantly among lecturers (Scherer et al., 2023). Nevertheless, empirical observations and emerging evidence suggest that this assumption does not fully reflect the situation in many developing countries, including Nigeria. Despite the availability of digital learning platforms in Federal tertiary institutions, disparities still exist in lecturers' digital literacy and their ability to effectively apply Microsoft Teams in instructional delivery. Factors such as inadequate ICT infrastructure, unstable internet connectivity, and differences in individual competencies continue to limit effective engagement with digital technologies. As a result, while some lecturers demonstrate high proficiency and active use of

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Microsoft Teams, others show limited integration of the platform into their teaching practices. Furthermore, existing literature has not sufficiently addressed the influence of demographic characteristics on digital literacy and the application of Microsoft Teams in instructional delivery. Although studies have identified that variables such as age, gender, academic qualification, and teaching experience may influence technology adoption, there is still a lack of context-specific evidence explaining how these factors shape lecturers' digital literacy and practical use of Microsoft Teams in Nigerian Federal tertiary institutions (Nwankwo & Ezeani, 2021; Yusuf & Balogun, 2023). This gap is particularly critical among Computer Science lecturers in Kaduna State, where variations in demographic background may significantly influence access to digital skills and instructional technology usage. The absence of clear empirical evidence makes it difficult for institutions to design targeted interventions that can effectively enhance digital competence and the application of Microsoft Teams in teaching. Given these challenges and gaps in knowledge, there is a need for a focused empirical study on the influence of demographic characteristics on digital literacy and the application of Microsoft Teams in instructional delivery. Such an investigation will provide valuable insights into the factors responsible for variations in technology use among lecturers and support the development of evidence-based strategies for improving digital teaching practices. Therefore, this study examines these relationships among Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria.

Research Objectives

This study was conducted to achieve the following objectives:

1. examine the influence of demographic characteristics on the digital literacy of Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria.
2. examine the influence of demographic characteristics on the application of Microsoft Teams in instructional delivery among Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria.

Research Questions

1. What is the influence of demographic characteristics on the digital literacy of Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria?
2. What is the influence of demographic characteristics on the application of Microsoft Teams in instructional delivery among Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria?

Research Hypotheses

The following hypotheses were formulated to guide the study:

H_{01}: There is no significant influence of demographic characteristics on the digital literacy of Computer Science lecturers in Federal tertiary institutions Kaduna State, Nigeria.

H_{02}: There is no significant influence of demographic characteristics on the application of Microsoft Teams in instructional delivery among Computer Science lecturers in Federal tertiary institutions Kaduna State, Nigeria.

Methodology

A descriptive survey research design was adopted to assess Microsoft Teams adoption for instruction, as well as digital literacy and application among Computer Science lecturers in Federal tertiary institutions Kaduna State, Nigeria. The study involved Computer Science lecturers across the seven (7) Federal tertiary institutions in Kaduna State. The total population comprised 202 lecturers, all of whom were included in the study using a census-based sampling approach. The use of a census approach is justified by the relatively small population size, which allows for comprehensive coverage,

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improves generalizability, and minimizes sampling error (Makwana, 2023). This approach is also consistent with previous related studies (Boor et al., 2026). A total of 202 questionnaires were administered, out of which 192 were successfully retrieved and deemed suitable for data analysis. Data were collected using a validated questionnaire, and the reliability of the instrument was established using Cronbach's Alpha, which yielded a coefficient of 0.752, indicating acceptable internal consistency. The collected data were analyzed using both descriptive and inferential statistics, with multiple regression analysis employed to test the stated hypotheses.

Answering Research Question

Research Question One: 1. What is the influence of demographic characteristics on the digital literacy of Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria?
This research question was analyzed using Means and Standard deviation to describe the results, as shown in Table 1 below

Table 1: Mean Scores on Responses on the Influence of demographic characteristics on digital literacy of Computer Science lecturers

S/N	Demographic Characteristics and Digital Literacy	SA	A	D	SD	Mean	STD	Decision
1	My age has positively influenced my digital literacy in the use of Microsoft Teams for instructional purposes.	91	9	77	22	2.84	0.92	Positive Influence
2	My gender does not hinder my digital literacy in using Microsoft Teams for instructional delivery.	83	67	26	6	3.07	0.81	Positive Influence
3	My academic qualifications contribute significantly to my digital literacy in using Microsoft Teams.	58	70	51	13	2.80	0.87	Positive Influence
4	My years of teaching experience have improved my digital literacy in the use of Microsoft Teams.	97	62	13	20	3.11	0.91	Positive Influence
5	My professional rank has provided me with more opportunities to develop digital literacy in Microsoft Teams.	45	97	30	10	2.88	0.85	Positive Influence
	Grand Mean					**2.94**	**0.87**	

(Decision Mean of 2.50)

The results presented in Table 1 indicate that demographic characteristics positively influence the digital literacy of Computer Science lecturers in the use of Microsoft Teams. With a grand Mean of 2.94, which is higher than the decision Mean of 2.50, it can be concluded that demographic factors such as age, gender, academic qualification, teaching experience, and professional rank play a significant role in shaping lecturers' digital literacy in Federal tertiary institutions in Kaduna State, Nigeria. Furthermore, the standard deviation value of 0.87 suggests a moderate level of variability in responses, implying that while most lecturers generally agree that demographic characteristics positively influence their digital literacy, there are slight differences in the degree of agreement among respondents.

Research Question Two: What is the influence of demographic characteristics on the application of Microsoft Teams in instructional delivery among Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria
This research question was analyzed using Means and Standard deviation to describe the results, as shown in Table 2 below:

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Table 2: Mean Scores on Responses on the Influence of demographic characteristics on system accessibility of Microsoft Teams among Computer Science lecturers

S/N	Demographic Characteristics and Application	SA	A	D	SD	Mean	STD	Decision
6	My age does not limit my effective application of Microsoft Teams in classroom instruction.	54	21	94	23	2.64	0.88	Positive Influence
7	My gender does not affect how I apply Microsoft Teams in teaching and learning.	79	44	32	37	2.80	0.91	Positive Influence
8	My academic qualifications make me more confident in applying Microsoft Teams for instruction.	71	51	50	25	2.78	0.89	Positive Influence
9	My years of teaching experience help me to better apply Microsoft Teams for delivering lectures.	57	81	39	15	2.91	0.85	Positive Influence
10	My professional rank provides me with more opportunities to apply Microsoft Teams in my teaching practice.	86	67	29	10	3.10	0.81	Positive Influence
	Grand Mean					**2.85**	**0.87**	

(Decision Mean of 2.50)

The results presented in Table 2 reveal that demographic characteristics have a positive influence on the application of Microsoft Teams in instructional delivery among Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria. With a grand Mean of 2.85, which is higher than the decision Mean of 2.50, it indicates that demographic factors such as age, gender, academic qualifications, teaching experience and professional rank positively influence lecturers' application of Microsoft Teams in teaching and learning activities. Furthermore, the grand standard deviation of approximately 0.87 submitted a moderate level of variation in responses, implying that while lecturers generally hold similar views regarding the influence of demographic characteristics, there are slight differences in their perceptions. This indicates a reasonable level of consistency among respondents in their opinions. Generally, the findings imply that demographic characteristics moderately enhance the application of Microsoft Teams for instructional delivery among Computer Science lecturers, suggesting that these factors play a supportive role in how effectively the platform is utilized in teaching practices.

Hypothesis Testing

H_{01}. There is no significant influence of demographic characteristics on the digital literacy of Computer Science lecturers in Federal tertiary institutions Kaduna State, Nigeria.

Table 3: Standard Multiple Regression Analysis on Significant Influence of Demographic Characteristics on the Digital Literacy of Computer Science Lecturers.

Table 3 Model Summary

Model	R	R^2	Adjusted R^2	Std. Error
1	0.71	0.50	0.48	0.49

Table 3 ANOVA

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	41.85	5	8.37	34.12	0.000
Residual	41.97	186	0.23		

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Model	Sum of Squares	Df	Mean Square	F	Sig.
Total	83.82	191			

Table 3 Coefficients

Variable	B	Std. Error	Beta	T	Sig.
Constant	1.10	0.17	—	6.47	0.000
Age	0.23	0.05	0.32	4.60	0.000
Gender	0.10	0.04	0.11	2.50	0.013
Qualification	0.18	0.05	0.24	3.60	0.000
Experience	0.29	0.05	0.39	5.80	0.000
Rank	0.16	0.05	0.22	3.20	0.002

The above table result of the standard multiple regression analysis (Enter method) submitted that demographic characteristics significantly influence digital literacy among Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria. The model explained 50% of the variance in digital literacy ($R^2 = 0.50$), indicating a moderate to strong explanatory power. The ANOVA result confirmed that the regression model was statistically significant ($F(5,186) = 34.12$, $p < 0.05$), showing that demographic variables jointly have a significant influence on digital literacy. The coefficients further revealed that all demographic variables made significant contributions to the model. Years of teaching experience ($\beta = 0.39$, $p = 0.000$) was the strongest predictor, followed by age ($\beta = 0.32$, $p = 0.000$), academic qualification ($\beta = 0.24$, $p = 0.000$), professional rank ($\beta = 0.22$, $p = 0.002$), and gender ($\beta = 0.11$, $p = 0.013$). This indicates that demographic characteristics significantly determine lecturers' digital literacy in the use of Microsoft Teams. Generally, the findings align with the theoretical expectation that demographic factors significantly shape technology-related competencies in higher education, particularly in developing contexts where access to continuous digital training and infrastructure may still vary across individuals.

H_{02}. There is no significant influence of demographic characteristics on the application of Microsoft Teams in instructional delivery among Computer Science lecturers in Federal tertiary institutions Kaduna State, Nigeria

Table 4: Standard Multiple Regression Analysis on Significant Influence of Demographic Characteristics on the Application of Microsoft Teams in Instructional Delivery among Computer Science Lecturers

Table 4 Model Summary

Model	R	R^2	Adjusted R^2	Std. Error
1	0.69	0.48	0.46	0.51

Table 4 ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	39.60	5	7.92	30.45	0.000

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Model	Sum of Squares	df	Mean Square	F	Sig.
Residual	44.22	186	0.24		
Total	83.82	191			

Table 4 Coefficients

Variable	B	Std. Error	Beta	t	Sig.
Constant	1.05	0.18	—	5.83	0.000
Age	0.20	0.05	0.29	4.00	0.000
Gender	0.12	0.04	0.14	3.00	0.003
Qualification	0.17	0.05	0.23	3.40	0.001
Experience	0.28	0.05	0.37	5.60	0.000
Rank	0.25	0.05	0.33	5.00	0.000

The above table 4 results of the standard multiple regression analysis (Enter method) revealed that demographic characteristics significantly influence the application of Microsoft Teams among Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria. The model explained 48% of the variance in application, indicating a moderate explanatory power. The ANOVA result confirmed that the regression model was statistically significant ($F(5,186) = 30.45$, $p < 0.05$), indicating that demographic variables jointly influence the application of Microsoft Teams. The coefficients further showed that all demographic variables significantly contributed to the model. Teaching experience ($\beta = 0.37$, $p = 0.000$) was the strongest predictor, followed by professional rank ($\beta = 0.33$, $p = 0.000$), age ($\beta = 0.29$, $p = 0.000$), academic qualification ($\beta = 0.23$, $p = 0.001$), and gender ($\beta = 0.14$, $p = 0.003$).

The results can be justified on the basis that demographic characteristics shape lecturers' exposure, competence, and engagement with digital instructional tools. Teaching experience and professional rank often reflect accumulated exposure to institutional ICT training, workshops, and academic responsibilities that enhance familiarity with digital platforms such as Microsoft Teams. Similarly, age may influence adaptability and willingness to adopt new technologies, while academic qualification often reflects formal training that includes digital competencies relevant to instructional delivery. Gender differences, although relatively weaker in influence, may reflect variations in access, prior exposure, or confidence in using digital tools in some contexts.

Discussion of Findings

Digital literacy of Computer Science lecturers: The result of the standard multiple regression analysis (Enter method) revealed that demographic characteristics significantly influence the digital literacy of Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria. The model demonstrated a meaningful level of explanatory power, indicating that variations in lecturers' age, gender, academic qualification, teaching experience, and professional rank collectively contribute to differences in digital literacy levels. The ANOVA result further confirmed that the regression model was statistically significant ($p < 0.05$), implying that the observed relationship is not due to chance. The coefficients of the regression analysis showed that all demographic variables significantly contributed to the prediction of digital literacy, although at varying magnitudes.

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Teaching experience emerged as the strongest predictor, followed by age, academic qualification, professional rank, and gender. This suggests that lecturers with more years of experience and higher academic or professional standing tend to demonstrate higher levels of digital literacy in the use of Microsoft Teams for instructional delivery.

This finding is consistent with the study of Ghavifekr and Rosdy (2022), who reported that teaching experience significantly enhances educators' confidence and competence in integrating digital tools into classroom instruction. Similarly, Voogt, Knezek, Cox, Knezek, and Brummelhuis (2023) emphasized that professional development and academic advancement are strongly associated with improved digital competence among higher education lecturers. Their findings support the view that continuous exposure to teaching responsibilities and institutional ICT training contributes to stronger digital literacy skills. In addition, the result aligns with the work of Lawless and Pellegrino (2021), who found that age and professional experience influence educators' adaptability to emerging technologies, particularly in environments undergoing rapid digital transformation. Likewise, Ertmer and Ottenbreit-Leftwich (2022) observed that academic qualification and institutional position often determine access to professional learning opportunities, which in turn enhances digital literacy development. However, contrasting evidence was reported by Siddiq, Scherer, and Tondeur (2021), who found that demographic characteristics alone may not fully explain variations in digital literacy, as factors such as institutional support, access to infrastructure, and personal motivation also play critical roles. This suggests that while demographic variables are important predictors, they may interact with contextual and environmental factors in shaping digital literacy outcomes. Generally, the findings of this study indicate that demographic characteristics significantly influence the digital literacy of Computer Science lecturers in their use of Microsoft Teams. The observed variation reflects the combined effects of individual background factors and professional exposure, highlighting the importance of continuous capacity building and institutional support to strengthen lecturers' digital competencies in higher education settings.

Application of Microsoft Teams: The result of the standard multiple regression analysis (Enter method) revealed that demographic characteristics significantly influence the application of Microsoft Teams for instructional delivery among Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria. The ANOVA result confirmed that the regression model was statistically significant ($p < 0.05$), indicating that age, gender, academic qualification, teaching experience, and professional rank jointly predict variations in lecturers' application of Microsoft Teams in instructional activities. This implies that demographic background plays a meaningful role in shaping how lecturers integrate the platform into teaching and learning processes. The coefficients further showed that all demographic variables contributed significantly to the model, though with different levels of influence. Teaching experience emerged as the strongest predictor of application, followed by professional rank, age, academic qualification, and gender. This suggests that lecturers with longer years of teaching experience and higher academic or professional status are more likely to effectively apply Microsoft Teams in instructional delivery, while demographic differences account for variations in depth and frequency of use.

This finding is supported by Nigerian-based studies. For instance, Olatunji and Adebayo (2022) reported that lecturers' teaching experience and institutional rank significantly influence their adoption and classroom integration of digital learning tools in Nigerian universities. Similarly, Nwankwo and Ezeani (2021) found that academic qualification and years of exposure to ICT training strongly predict lecturers' ability to effectively apply digital platforms in teaching activities. Their

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findings emphasize that professional maturity enhances confidence and competence in technology integration. In addition, Okoro, Obi, and Eze (2023) observed that demographic factors such as age and teaching experience significantly influence lecturers' classroom use of learning management systems and collaboration tools in Nigerian higher education institutions. They explained that more experienced lecturers tend to have greater exposure to institutional ICT initiatives, which enhances their application of digital tools in instructional delivery. Likewise, Ibrahim and Yusuf (2020) highlighted that gender differences, though less influential, may still reflect disparities in access, confidence, and prior ICT exposure among academic staff in some Nigerian institutions. However, contrasting evidence was reported by Adedeji and Ajayi (2021), who found that institutional factors such as infrastructure, training opportunities, and technical support are often stronger determinants of technology application than demographic characteristics alone. This suggests that while demographic variables are important, they interact with institutional conditions in shaping lecturers' effective use of digital platforms. Generally, the findings indicate that demographic characteristics significantly influence the application of Microsoft Teams among Computer Science lecturers in Federal tertiary institutions in Kaduna State. The observed differences reflect variations in professional exposure, academic attainment, and teaching experience, highlighting the need for continuous ICT capacity building and improved institutional support to enhance effective integration of digital tools in instructional delivery.

Conclusion

Based on the findings from the study concludes that demographic characteristics significantly influence both digital literacy and the application of Microsoft Teams among Computer Science lecturers in Federal tertiary institutions in Kaduna State, Nigeria. The model results indicate that variables such as age, gender, academic qualification, teaching experience, and professional rank collectively play a meaningful role in shaping lecturers' competence and engagement with Microsoft Teams for instructional delivery.

The findings further reveal that Computer Science lecturers generally demonstrate a relatively high level of digital literacy in the use of Microsoft Teams, as indicated by positive model estimates and significant predictor effects. This suggests that lecturers are largely familiar with the platform and possess the basic competencies required for its instructional use. Conversely, the application of Microsoft Teams for instructional delivery is moderate, although statistically significant in relation to demographic characteristics. This implies that while lecturers possess the necessary digital skills, the extent of actual application varies across demographic groups and may be influenced by factors such as experience, professional rank, and institutional exposure. It also suggests that effective utilization is not uniform, and some lecturers may still face constraints in fully integrating the platform into teaching activities.

Recommendations

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

1. Federal tertiary institutions in Kaduna State should strengthen continuous professional development programmes focused on digital literacy for Computer Science lecturers. Regular training workshops, hands-on ICT sessions, and institutional capacity-building initiatives should be organized to ensure that lecturers maintain and improve their competence in using Microsoft Teams and other emerging digital learning platforms. In addition, institutions should provide structured mentorship and peer-support systems to help less digitally experienced lecturers enhance their skills and confidence in instructional technology use.

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2. Institutions should develop clear policies and provide adequate ICT infrastructure to promote the full integration and consistent application of Microsoft Teams in instructional delivery. This includes ensuring reliable internet connectivity, access to functional digital devices, and institutional subscriptions to Microsoft Teams across all departments. Furthermore, lecturers should be encouraged and supported to expand their use of the platform beyond basic communication functions to include assessment, student engagement, collaboration, and feedback processes, thereby maximizing its instructional benefits.

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Physics Teachers and Students Level of Awareness on Energy and Society Concepts in Nigeria Secondary Schools: Implication for Energy Efficiency and Environmental Sustainability

OGUNDEJI, Oluwatomisin Marvellous[1]
Email: oluwatomisin.ogundeji@fugusau.edu.ng

OKOYE, Nestor Ekemezie[2]
Email: nesann2010@yahoo.com

[1]Department of Science Education, Faculty of Education, Federal University of Gusau, Zamfara State, Nigeria
[2]Department of Physics Education, Federal College of Education, Umunze, Anambra State, Nigeria

Abstract

The role of education and information initiatives in schools is crucial in ensuring all citizens are energy aware. Thus, the study seeks to find out the level of students' awareness of energy and society concepts in Nigerian secondary schools and its implication to energy efficiency and a sustainable environment. Two research questions and one null hypothesis guided the study. The study adopted a descriptive survey research design. The sample size of 240 senior secondary three (SS3) physics students and teachers are drawn from the population were used for the study. Proportionate stratified random and Purposive sampling techniques were used to obtain the sample size. A questionnaire on Energy and Society Concepts (QESC) developed by the researcher to measure students' level of awareness of energy and society concepts was used for the study. Frequencies and percentages were used to answer all the research questions and chi-square for testing the null hypothesis of the study. Findings of the study revealed that the majority of Nigeria physics teachers and students are at Low and Very Low Levels of awareness of Energy and Society Concepts; and no statistically significant difference in the level of awareness of energy and society concepts among secondary school teachers and students of physics. It implies therefore that, improvement in the level of awareness of energy and society concepts in schools might promote: students' achievement in Energy and Society Concepts; best practices of energy use at home; and diversification into clean energy which is environmentally friendly.

Key Words: Awareness, Energy and Society Concepts, Secondary School

Introduction

The challenges facing the energy sector of Nigeria are enormous. Research has identified four (4) major barriers that border on the improvement of energy efficiency for users (Arup, 2016). One of the barriers is lack of an awareness and information on the benefit of Energy Efficiency measures to users. Benefits of Energy Efficiency were grouped into three (3) namely: social, economic, and environmental benefits (Arup, 2016). The benefits are consistent with the principles of sustainability development (Brundtland Report published by the World Commission on Environment and Development in 1987 as cited in United Nation Headquarters, 2012). This implies that, there exist a bond between energy efficiency and a sustainable energy environment. Although, the study of Din, Haron, & Ahmad, (2013) found that citizen engagement in the sustainability of their environment will still take some time. Since, global demand for energy consumption especially in the form of fossil fuels or grid, having its consequential effect, is increasing. In Nigeria, for example, households account for the large majority of electricity consumption (about 50%). Household energy sources come from: Hydro (0.4%), Oil/gas (17%) and Biofuel & waste (mainly firewood) (82%) (Energy Commission of Nigeria, 2014). This is obvious that Nigeria society over rely on fossil fuels and her citizen may lack engagement in the sustainability of her environment.

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To this effect, the consciousness of raising a society that is very aware of the changing environment, as well as continuously engaging in practices to sustain the environment is critical, even in this era of rapid industrial growth. Every sector must come up with policies and initiatives that will not jeopardise the safety of the world for mankind (Din, Haron, Ahmad, 2013). Since, experts have revealed that Nigeria can save up to half of the energy currently consumed in the country if energy is efficiently utilized (Uyigue, Agho, Edevbaro, Godfrey, Uyigue, and Okungbowa, 2009). Energy efficiency implies the use of energy in a manner that will minimize the amount of energy needed to provide services. There are two approaches to achieving energy efficiency (Uyigue, et. al., 2009). The first one is the technological approach while, the second is the behavioural approach. For the technological approach, it stressed the need to change the type of technology used to a more efficient (i.e. Energy saving) one. For example: replacing incandescent bulbs usage with compact fluorescent light bulbs. While, the behavioural approach entails changing the way things are done. e.g. switching off appliances when not in use. The implication is that, energy consumption is critical to environmental sustainability, but waiting for energy efficiency education for its solution. Education is paramount in a bit to ensure that all citizens are energy aware. Europeans are extending energy education and information initiatives to school students of all ages (Anonymous, 2006), Nigerians should not do less. Primary and secondary school students should be exposed to energy education. Education has a strategic role in improving energy efficiency. So, teachers of Physics should be able to lead the discussion on the energy efficiency in our various secondary schools and by extension, the general public.

The present Nigeria secondary school physics curriculum (as revised by Nigerian Educational Research and Development Council, NERDC, 2008) which has been in use since 2011, buttressed this viewpoint of the present study. It gives Physics teachers the responsibility to train students in energy education at the secondary school level. Physics curriculum considered Energy and Society concepts relevant under the Conservation Principles themes. As enshrined in the curriculum, sources of energy; renewable and non-renewable energy; uses of energy; energy and development; energy diversification and conservation; environmental impact of energy use: global warming, climate change, green-house effect, oil spillage, and energy crisis, were sub-topics of Energy and Society. Apart from the fact that the concept of "energy efficiency" is not well captured in the present curriculum, it seems some physics teachers are not even aware of the additional topics and thematic arrangement of the present Nigerian secondary school physics curriculum. The study by Guven and Sulun (2017) revealed that there is a lack of awareness and knowledge of renewable energy among pre-service teachers in Turkey. In Nigeria, Ogundeji et. al., (2020) found that physics and technical teachers lack adequate knowledge of solar energy concepts in Oyo State. On this same issue, Daramola and Omosewo (2012) had earlier lamented that Nigeria Physics educators are not competent to teach some topics in the new curriculum especially topics under Physics in technology. Of course, secondary school students might lack the understanding of energy and society concepts if studies, like: Guven, et. al., (2017); Ogundeji, et. al., (2020); Daramola, et. al., (2012) has reported that physics teachers do not have adequate knowledge about renewable energy, which is part of Energy and Society Concepts. The study by Oruonye (2011) on the level of awareness of climate change among students of tertiary institutions in Jalingo Metropolis of Taraba, Nigeria, revealed that out of the 81.8% that have heard about climate change, 89% do not know what climate change is all about; its causes, effects, and possible adaptive or mitigative measures. Though the study was conducted in tertiary institution over a decade now, while the present study in secondary school, the feelings is that students of this educational level are not still aware of energy and society concepts especially in Zamfara State, Nigeria. It is based on this background, that the researcher wishes to

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find out: the level of awareness of energy and society concepts among teachers and students in Nigerian secondary schools, and its implication on energy efficiency and a sustainable environment.

Purpose of the Study

The main objective of this study is to find out the level of awareness of energy and society concepts in Nigerian secondary schools and its implication on energy efficiency and a sustainable environment. Specifically, the study seeks to find out:

1. If the Nigerian secondary school teachers and students of physics are aware of "Energy and Society concepts" as situated in Nigerian Secondary School Physics Curriculum
2. the level of awareness of energy and society concepts among Nigeria secondary school teachers and students of physics.

Research Questions

The following research questions were posed to guide the study:

1. Are you aware of any sub-theme in the Nigeria Secondary School Physics Curriculum called Energy and Society?
2. What is the level of awareness of energy and society concepts among Nigeria secondary school teachers and students of physics?

Hypotheses

1. There is no statistically significant in the level of awareness of energy and society concepts among Nigerian secondary school teachers and students of physics.

Methodology

This study adopted a descriptive survey research design that aimed at collecting data on, and describing in a systematic manner the characteristics, features or facts about a given population. The population for this study was 2,148 senior secondary students' class III and 21 physics teachers in all the 7 out of 8 science and technical schools in Zamfara State, Nigeria. Because, one school was closed down because of insecurity. A sample of 240 (228 physics students and 12 physics teachers) was used for the study. The proportionate stratified random sampling technique and purposive sampling technique procedure were adopted in composing the sample. The proportion of 0.106 (i.e. 10.6%) was used to select 32, 22, 76, 24, 21, 13, and 40 physics students from science and technical schools located at Bakura, Bukkuyum, Gusau, Kauran Namoda, Maru, Shinkafi and Talata Mafara Local Government Areas of Zamfara State. Meanwhile, the entire physics teachers that have taught SSIII physics in recent times was selected purposively in all the schools. A questionnaire on Energy and Society Concepts (QESC) was developed by the researcher to measure both teachers' and students' level of awareness of energy and society concepts. QESC has two sections A and B. Section A has two items having "yes" and "no" responses and was only meant for teachers, while, Section B (meant for teachers and students) has 13 items having the following response patterns: High Level (HL), Average Level (AL), Low Level (LL), Very Low Level (VLL). The method of delivery employed was the direct delivery method, whereby the researcher administers and retrieve the filled instruments on the spot. Thereafter, frequency was used to answer all the research questions and chi-square was used in testing the null hypothesis under study.

Presentation of Results

Research Question One: Are you aware of the concept "Energy and Society" as positioned in the Nigerian Secondary School Curriculum?

Table 1: Frequency and Percentage Analysis of the awareness of Energy and Society as positioned in the Nigeria Secondary School Curriculum

S/N	Item Statement	Yes	No

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		f (%)	f (%)
1	Is there any sub-theme in the Nigeria secondary school physics curriculum called Energy and Society	7(58.3)	5(41.7)
2	Energy and Society Concepts are situated under thematic area called Conservation Principles	4(33.3)	8(66.7)

Table 1 revealed that 58.3 per cent of the physics teachers are aware of "Energy and Society" as one of the sub-themes in the Nigeria secondary school curriculum, but only 33.3 per cent knows how it was correctly positioned in the Nigerian secondary school curriculum.

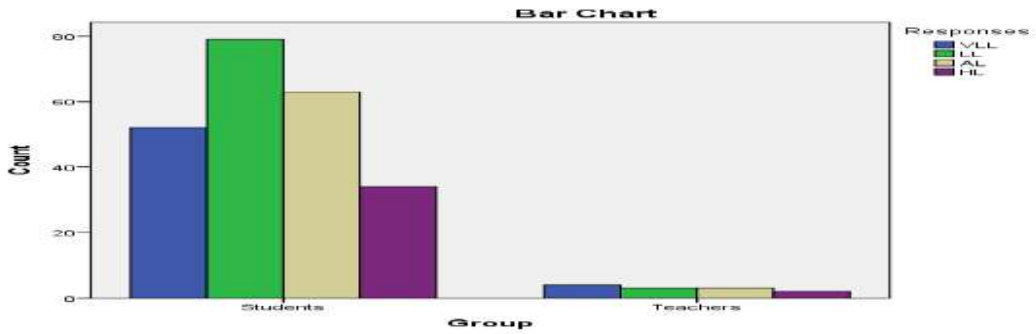
Research Question Two: What is the level of awareness of energy and society concepts among Nigeria secondary school teachers and students of physics?

Table 2: Frequency and Percentage Analysis of the level of awareness of energy and society concepts among Nigeria secondary school teachers and students of physics

S/N	Energy and Society Concepts	Teachers (12)				Students (228)			
		HL f (%)	AL f (%)	LL f (%)	VLL f (%)	HL f (%)	AL f (%)	LL f (%)	VLL f (%)
1	Renewable Energy	9(75.0)	1(8.3)	2(16.7)	0(0.0)	138(60.5)	56(24.6)	29(12.7)	5(2.2)
2	Non-renewable Energy	9(75.0)	1(8.3)	2(16.7)	0(0.0)	127(55.7)	66(28.9)	29(12.7)	6(2.6)
3	Energy and development	0(0.0)	3(25.0)	6(50.0)	3(25.0)	8(3.5)	62(27.2)	117(51.3)	41(18.0)
4	Energy diversification	0(0.0)	4(33.3)	5(41.7)	3(25.0)	14(6.1)	61(26.8)	112(49.1)	41(18.0)
5	Energy Conservation	6(50.0)	4(33.3)	2(16.7)	0(0.0)	115(50.4)	79(34.6)	28(12.3)	6(2.6)
6	Energy Efficiency	0(0.0)	2(16.7)	4(33.3)	6(50.0)	0(0.0)	59(25.9)	77(33.8)	92(40.4)
7	Green House Effect	0(0.0)	3(25.0)	2(16.7)	7(58.3)	0(0.0)	59(25.9)	75(32.9)	94(41.2)
8	Global warming	0(0.0)	4(33.3)	5(41.7)	3(25.0)	15(6.6)	62(27.2)	110(48.2)	41(18.0)
9	Climate change	0(0.0)	3(25.0)	2(16.7)	7(58.3)	1(0.4)	62(27.2)	75(32.9)	90(39.5)
10	Energy tax	0(0.0)	2(16.7)	4(33.3)	6(50.0)	0(0.0)	59(25.9)	77(33.8)	92(40.4)
11	Oil Spillage	0(0.0)	5(41.7)	4(33.3)	3(25.0)	5 (2.2)	73(32.0)	106(46.5)	44(19.3)
12	Energy Crisis	0(0.0)	4(33.3)	5(41.7)	3(25.0)	14(6.1)	63(27.6)	110(48.2)	41(18.0)
13	Energy Efficiency Building	0(0.0)	1(8.3)	3(25.0)	8(66.7)	4(1.8)	56(24.6)	81(35.5)	87(38.2)
ONR		**2(15.3)**	**3(23.7)**	**3(29.5)**	**4(31.5)**	**34(14.9)**	**63(27.6)**	**79(34.6)**	**52(22.9)**

ONR: Overall number of Respondent. n = Number of Respondents; VLL= Very Low Level; LL = Low Level; AL = Average Level; HL = High Level; F = frequency; % = Percentage.

From Table 2 showing the overall responses of the respondents, it was revealed that physics teachers are aware of Energy and Society Concepts at 2(15.3%) on HL; 3(23.7%) on AL; 3(29.5%) on LL and 4(31.5%) on VLL. Out of 12 physics teachers that participated in the research, only 5(39%) were above Average Level, while, more than half of the teachers were below average. Similarly, physics students showed that they are aware of Energy and Society concepts at 34(14.9%) on HL; 63(27.6%) on AL; 79(34.6%) on LL and 52(22.9%) on VLL. Out of 228 physics students that participated in the research, only 97(42.5%) physics students were above Average Level, while, more than half of the students were below average.



However, the chart above (Fig.1) revealed how awareness of Energy and Society concepts was distributed to levels among physics teachers and students' in Nigeria secondary schools. The chart

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showed clearly that the larger percentage of respondents were at Very Low Level (VLL) and Low Level (LL) on the awareness of Energy and Society concepts in Nigeria secondary schools. While, fewer percentage of respondents were at Average Level (AL) and High Level (HL) on the awareness of Energy and Society concepts in Nigeria secondary schools. To this end, the chart revealed that the level of awareness of energy and society concepts among Nigeria secondary school teachers and students of physics is below Average Level.

Hypothesis One: There is no statistically significant difference in the level of awareness of energy and society concepts among Nigeria secondary school teachers and students of physics.

Table 3: Chi-square Analysis of the Level of Awareness of Energy and Society Concepts among Nigeria Secondary school Teachers and Students of physics.

Item no.	Teachers (n = 12) HL f (%)	AL f (%)	LL f (%)	VLL f (%)	Students (n = 228) HL f (%)	AL f (%)	LL f (%)	VLL f (%)	χ^2	P-value	Dec
1	9(75.0)	1(8.3)	2(16.7)	0(0.0)	138(60.5)	56(24.6)	29(12.7)	5(2.2)	2.06	0.56	NS
2	9(75.0)	1(8.3)	2(16.7)	0(0.0)	127(55.7)	66(28.9)	29(12.7)	6(2.6)	2.94	0.40	NS
3	0(0.0)	3(25.0)	6(50.0)	3(25.0)	8(3.5)	62(27.2)	117(51.3)	41(18.0)	0.75	0.86	NS
4	0(0.0)	4(33.3)	5(41.7)	3(25.0)	14(6.1)	61(26.8)	112(49.1)	41(18.0)	1.36	0.72	NS
5	6(50.0)	4(33.3)	2(16.7)	0(0.0)	115(50.4)	79(34.6)	28(12.3)	6(2.6)	0.50	0.92	NS
6	0(0.0)	2(16.7)	4(33.3)	6(50.0)	0(0.0)	59(25.9)	77(33.8)	92(40.4)	0.64	0.73	NS
7	0(0.0)	3(25.0)	2(16.7)	7(58.3)	0(0.0)	59(25.9)	75(32.9)	94(41.2)	1.73	0.42	NS
8	0(0.0)	4(33.3)	5(41.7)	3(25.0)	15(6.6)	62(27.2)	110(48.2)	41(18.0)	1.36	0.72	NS
9	0(0.0)	3(25.0)	2(16.7)	7(58.3)	1(0.4)	62(27.2)	75(32.9)	90(39.5)	2.01	0.57	NS
10	0(0.0)	2(16.7)	4(33.3)	6(50.0)	0(0.0)	59(25.9)	77(33.8)	92(40.4)	0.64	0.73	NS
11	0(0.0)	5(41.7)	4(33.3)	3(25.0)	5 (2.2)	73(32.0)	106(46.5)	44(19.3)	1.21	0.75	NS
12	0(0.0)	4(33.3)	5(41.7)	3(25.0)	14(6.1)	63(27.6)	110(48.2)	41(18.0)	1.28	0.73	NS
13	0(0.0)	1(8.3)	3(25.0)	8(66.7)	4(1.8)	56(24.6)	81(35.5)	87(38.2)	4.18	0.24	NS

n = No. of Respondents; VLL= Very Low Level; LL = Low Level; AL = Average Level; HL = High Level; F = frequency; % = Percentage; x2 = Chi-Square; p-value = Probability value; df = Degree of freedom; Dec = Decision

The result presented in Table 3 revealed that all the items showed not significant (NS), since their probability values ranging from 0.24 to 0.98 was greater than the level of significance set at 0.05 for testing hypothesis. The above result was further confirmed by the overall trace analysis below.

Table 4: Overall Trace Analysis of the Level of Awareness of Energy and Society Concepts among Nigeria Secondary school Teachers and Students of Physics.

Group	Response HL	AL	LL	VLL	Total	χ^2	df	p-value	Dec.
Students	34	63	79	52	228	0.904	3	0.824	NS
Teachers	2	3	3	4	12				
	36	66	82	56	240				

VLL= Very Low Level; LL = Low Level; AL = Average Level; HL = High Level; x2 = Chi-Square; p-value = Probability value; df = Degree of freedom; Dec = Decision

The result presented in Table 4, revealed the probability value (0.824) which was greater than the level of significance (0.05). This further confirms the decision that the hypothesis is NS (Not Significant). Hence, the null hypothesis was not rejected by the researcher. Thus, no statistically significant difference in the level of awareness of energy and society concepts among Nigerian secondary school teachers and students of physics.

Discussion

The present study showed that more than average physics teachers are aware of Energy and Society concepts as sub-themes in the Nigeria secondary school curriculum, but only 33.3% knows how it

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was correctly positioned in the Nigeria secondary school curriculum. By implication, this fewer percentages only understands its role to the society at large. However, it was further revealed that physics teachers and students were at 39% and 42.5% level of awareness of Energy and Society Concepts respectively. These percentages are below average, meaning that, majority of Nigeria physics teacher and students are at Low Level and Very Low Level on level of awareness of Energy and Society Concepts. Also, findings of the study revealed no statistically significant different in the level of awareness of energy and society concepts among Nigeria secondary school teachers and students of physics. These findings are in agreement with the findings of the recent studies (Anonymous, 2006; Oruonye, 2011; Daramola and Omosewo, 2012; Guven and Sulun, 2017; Yuksel (2020); Ogundeji et. al., 2020; Din, Haron, & Ahmad, 2013; Arup, 2016; Uyigue, et. al., 2009). Findings of Anonymous (2006) who affirm that Europeans are extending energy education and information initiatives to school students of all ages; Oruonye (2011) revealed that 89% of students of tertiary institutions in Jalingo Metropolis of Taraba do not know the causes, effects, and possible adaptive or mitigative measures of climate change; justified the fact that education on energy and society concepts are needed right from the primary and secondary school learners. To achieve this majority of physics teachers needed to be aware or improve in the level of their awareness of energy and society concepts. This is consistent with Daramola and Omosewo (2012) who had earlier professed and lamented that Nigeria Physics educators are not competent to teach some topics in the new curriculum i.e. Energy and Society concepts, Physics in technology topics among others; Ogundeji et. al., (2020) who found that physics and technical teachers lack adequate knowledge of solar energy concepts in Oyo State (since, solar energy is one of the areas under renewable energy which is also under Energy and Society); and Guven and Sulun (2017) who revealed that there is lack of awareness and knowledge of renewable energy among pre-service teachers in Turkey. However, Din, Haron, & Ahmad, (2013) confirmed that lack of education on energy and society concepts as implications citizen engagement in environmental sustainability vis-a-vis energy efficiency. However, the findings of Uyigue, et. al., (2009) further strengthen the findings of the study on the relevance on energy and society education to energy efficiency. These findings have some implication on education, energy efficiency, and environmental sustainability. For instance, improvement in the level of awareness of energy and society concepts in schools might: promote students' achievement in examinations; promote best practices on energy use at home, teach a technological and behavioural approaches to be adopted for managing energy effectively; and diversify into clean energy (rather than over- reliance on energy through fossil fuel i.e generator) which is environmentally friendly because it does not release harmful substances into the environment and does not make noise.

Conclusion

The level of students' awareness of energy and society concepts in Nigerian secondary schools and will have implication on energy efficiency and a sustainable environment. It should therefore be of paramount importance to Nigeria Society. This is the thrust of this present study. Findings of the study buttressed this fact: that improvement in the level of awareness of energy and society concepts in schools is desired to promote: students' achievement in Energy and Society Concepts; best practices of energy use at home; and diversification into clean energy that is environmentally friendly.

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Sustainability-Oriented Entrepreneurship in Low-Income Contexts: A Systematic Review

OKHAWERE, Paulson Young Ofenimu
Email: gainsp@yahoo.com

Federal University of Education Kontagora, Niger State, Nigeria

Abstract

Sustainability-oriented entrepreneurship (SOE) has emerged as a critical pathway for addressing intertwined social, environmental, and economic challenges in low-income contexts characterised by institutional fragility, resource scarcity, and persistent developmental deficits. Despite its growing relevance, existing literature remains fragmented, conceptually ambiguous, and largely skewed towards high-income environments, thereby limiting a comprehensive understanding of how SOE manifests and generates impact under conditions of constraint. This study synthesises interdisciplinary insights to conceptualise sustainability-oriented entrepreneurship within low-income contexts, examine the mechanisms through which it operates across individual, institutional, and environmental levels, and identify key barriers and pathways for enhancing its effectiveness and scalability. Adopting a conceptual review methodology, the study integrates perspectives from entrepreneurship, sustainability, and development scholarship to advance a multi-level framework linking entrepreneurial agency, innovation strategies, institutional dynamics, and socio-environmental outcomes. The analysis reveals that sustainability-oriented entrepreneurs in low-income settings employ adaptive strategies such as frugal innovation, bricolage, and collaborative arrangements to navigate resource limitations and institutional voids, while contributing to inclusive development, environmental stewardship, and local value creation. However, their transformative potential is constrained by persistent challenges, including limited access to finance, weak market structures, regulatory inconsistencies, and socio-cultural inequalities. The study further concludes that while SOE offers a viable and contextually embedded mechanism for addressing complex development challenges, its long-term impact depends on supportive institutional frameworks, coherent policy alignment, and scalable innovation pathways among others.

Keywords: Inclusive entrepreneurship; Low-income contexts; Sustainable development; Sustainability-oriented entrepreneurship; Sustainable innovation

Introduction

Sustainability-oriented entrepreneurship (SOE) refers to entrepreneurial activity that intentionally integrates environmental integrity, social inclusion, and economic viability into the creation and exploitation of opportunities. Unlike conventional entrepreneurship, which often prioritises financial returns as the dominant objective, SOE embeds sustainability concerns within core business models, value propositions, and growth strategies. This orientation positions entrepreneurs not merely as economic actors but as agents of socio-ecological transformation, particularly in contexts characterised by systemic vulnerabilities. In recent years, SOE has gained scholarly traction as a response to global challenges such as climate change, environmental degradation, persistent poverty, and widening inequality, challenges that are especially pronounced in low-income contexts (Schaltegger et al., 2016; Dean & McMullen, 2007). The relevance of SOE in low-income contexts is heightened by the coexistence of acute developmental needs and fragile institutional environments. Many low-income economies face chronic deficits in infrastructure, energy access, healthcare, sanitation, and employment, alongside weak regulatory systems and limited public-sector capacity. In such settings, sustainability-oriented ventures often emerge to fill institutional voids by delivering

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socially and environmentally valuable goods and services through market-based mechanisms (Mair & Marti, 2009). For example, enterprises focused on renewable energy, waste recycling, sustainable agriculture, and inclusive financial services frequently target underserved populations while simultaneously addressing environmental externalities. This dual pursuit of impact and viability underscores the strategic importance of SOE as a complementary pathway to traditional development interventions (United Nations Development Programme (UNDP), 2023). Studying SOE in low-income environments is critical for advancing understanding across social, economic, and environmental dimensions of development. Economically, sustainability-oriented ventures can stimulate local value creation, employment, and livelihood diversification, particularly where formal labour markets are weak. Socially, such enterprises often promote inclusion by integrating marginalised groups, such as women, youth, and rural populations, into production and consumption networks. Environmentally, SOE contributes to resource efficiency, ecosystem preservation, and climate adaptation in regions that are disproportionately exposed to environmental risks (Shepherd & Patzelt, 2011; Organisation for Economic Co-operation and Development (OECD), 2022). Despite these contributions, much entrepreneurship research continues to privilege growth-centric outcomes, thereby under-theorising the developmental significance of sustainability-driven entrepreneurial activity in low-income settings.

Notwithstanding the expanding literature on sustainable and social entrepreneurship, important gaps persist. Existing studies are heavily skewed towards high-income economies and formal institutional contexts, limiting their explanatory power in environments characterised by informality, necessity-driven entrepreneurship, and institutional fragility (Pacheco et al., 2018). Moreover, there is insufficient integration of multi-level perspectives that link individual entrepreneurial agency with meso-level institutions and macro-level development challenges. This conceptual review addresses these gaps by synthesising fragmented insights and advancing a context-sensitive understanding of sustainability-oriented entrepreneurship in low-income contexts.

Conceptualising Sustainability-Oriented Entrepreneurship

Sustainability-oriented entrepreneurship is conceptually grounded in the integration of sustainability principles into the entrepreneurial process of opportunity identification, evaluation, and exploitation. At its core, SOE involves recognising opportunities that arise from environmental and social challenges and transforming them into viable ventures that generate shared value. This distinguishes SOE from traditional entrepreneurship, where sustainability outcomes are often incidental or addressed through peripheral corporate social responsibility initiatives rather than embedded within the venture's strategic logic, as noted by Schaltegger et al. (2016).

The conceptual foundations of SOE are closely aligned with the triple-bottom-line framework, which emphasises the simultaneous pursuit of economic prosperity, social equity, and environmental protection. In low-income contexts, these dimensions are deeply interconnected. Economic viability is frequently contingent upon social legitimacy and environmental stewardship, particularly where communities rely directly on natural resources for survival. Consequently, sustainability-oriented entrepreneurs in such contexts often adopt hybrid business models that blend commercial and social logics to balance competing demands (Battilana & Lee, 2014). From an environmental perspective, SOE focuses on reducing negative externalities and promoting regenerative practices. Entrepreneurs may exploit opportunities linked to renewable energy, waste valorisation, sustainable agriculture, and circular economy models, especially in contexts where environmental degradation directly

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threatens livelihoods. Socially, SOE prioritises inclusive value creation by addressing unmet needs, empowering marginalised groups, and fostering community resilience. These social objectives are not secondary outcomes but are integral to the opportunity itself (Shepherd & Patzelt, 2011). Economically, SOE seeks long-term viability rather than short-term profit maximisation, often favouring patient capital, incremental growth, and locally embedded innovation strategies. Importantly, the manifestation of SOE in low-income contexts differs from that in high-income economies. Resource constraints, institutional voids, and pervasive informality shape how sustainability-oriented opportunities are perceived and enacted. Entrepreneurs frequently rely on bricolage, frugal innovation, and locally sourced knowledge to overcome financial and technological limitations, as demonstrated in the work of Senyard et al. (2014). These adaptive strategies challenge dominant assumptions in entrepreneurship theory that equate sustainability with advanced technology or strong regulatory enforcement. Instead, they highlight the role of contextual creativity and social embeddedness in sustaining entrepreneurial activity under conditions of scarcity. Despite conceptual advances, the literature lacks consensus on definitional boundaries, particularly in distinguishing SOE from social entrepreneurship, green entrepreneurship, and inclusive business models. While overlaps exist, Pacheco et al. (2018) argue that SOE is best understood as an umbrella concept that captures ventures explicitly oriented towards sustainability outcomes across all three dimensions, regardless of sector or organisational form. Greater conceptual clarity is therefore required to enable cumulative theory building and comparative research, especially in low-income contexts where sustainability challenges are most pronounced.

Characteristics and Drivers of Sustainability-Oriented Entrepreneurs in Low-Income Contexts

Entrepreneurial activity in low-income contexts is shaped by deeply embedded socio-economic constraints, cultural norms, and institutional fragilities, necessitating a rethinking of dominant entrepreneurship theories that are largely grounded in opportunity-driven behaviour within stable market systems. Sustainability-oriented entrepreneurs (SOEs) in these environments often operate at the intersection of necessity and opportunity, challenging the traditional dichotomy that separates the two. While early scholarship tends to frame necessity entrepreneurship as low-growth and survivalist, emerging perspectives suggest that, in low-income contexts, necessity can act as a catalyst for socially and environmentally embedded opportunity recognition (Mair et al., 2012; Sutter et al., 2019). This reconceptualisation positions SOEs not merely as reactive agents but as proactive actors who transform structural constraints into sustainability-driven opportunities. A defining feature of sustainability-oriented entrepreneurs in these settings is their deep contextual embeddedness, which shapes both cognition and action. Unlike decontextualised models of entrepreneurial alertness, these actors draw on locally situated knowledge, informal institutions, and lived experiences to identify opportunities that are often invisible to external actors. As Kistruck et al. (2015) argue, embeddedness within social networks enables access to non-market resources such as trust, legitimacy, and reciprocal exchange, which substitute for formal institutional support. However, this reliance on informal structures also introduces tensions, as it may constrain scalability and reinforce existing power asymmetries within communities (Webb et al., 2015). Thus, while embeddedness is a source of resilience, it simultaneously constitutes a structural limitation, highlighting the need for more nuanced theorisation of its dual role.

At the individual level, SOEs exhibit characteristics such as resilience, adaptability, and a strong pro-social orientation. Yet, framing these traits as purely individual attributes risks obscuring the structural conditions that necessitate them. From a critical perspective, resilience in low-income contexts is less a discretionary capability and more a survival requirement imposed by institutional

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voids and environmental uncertainty. This aligns with the argument by Shepherd and Patzelt (2011) that prosocial motivation in sustainable entrepreneurship is often intertwined with exposure to adverse conditions rather than purely normative commitments. Consequently, sustainability-oriented behaviour should be understood as both value-driven and contextually induced, requiring a shift from trait-based explanations to more integrative, context-sensitive models. The drivers of SOE extend beyond individual agency to encompass structural and institutional dynamics that both enable and constrain entrepreneurial action. Market failures, such as unmet basic needs, environmental degradation, and credit constraints, have long been recognised as sources of entrepreneurial opportunity (Dean & McMullen, 2007). However, in low-income contexts, these failures are not episodic but systemic, creating persistent conditions for sustainability-oriented innovation. In this regard, SOE can be interpreted as a form of institutional entrepreneurship, where actors simultaneously respond to and reshape dysfunctional systems (Pacheco et al., 2010). This perspective shifts the analytical focus from opportunity exploitation to institutional transformation, thereby enriching existing theoretical frameworks.

External actors, including development agencies and international organisations, also play a significant role in shaping the SOE landscape. While institutions such as the United Nations Development Programme (UNDP, 2023) provide critical resources and legitimacy, their interventions are not without critique. Some scholars argue that donor-driven agendas may impose externally defined sustainability priorities that are misaligned with local needs, thereby undermining indigenous entrepreneurial agency (Easterly, 2006). This raises important questions about power dynamics and epistemic dominance in the construction of sustainability narratives within low-income contexts. Furthermore, gender and social identity introduce additional layers of complexity into the analysis of SOE. Although women and marginalised groups are disproportionately engaged in sustainability-oriented ventures, particularly in sectors such as energy, agriculture, and waste management, they face systemic barriers that limit their growth potential (OECD, 2022). Brush et al. (2009) contend that these constraints are not merely resource-based but are embedded in broader institutional and cultural systems that shape access to opportunities and networks. This suggests that any meaningful theorisation of SOE must incorporate intersectional perspectives that account for power, inequality, and social stratification. In all, the characteristics and drivers of sustainability-oriented entrepreneurs in low-income contexts problematise dominant individual-centric conceptions of entrepreneurship. Rather than being solely the outcome of personal traits or isolated decision-making, entrepreneurial behaviour is better understood as relational and deeply embedded within specific socio-institutional contexts, arising from the continuous interaction between individual agency, structural conditions, and institutional dynamics. This perspective necessitates a shift toward multi-level theorisation that systematically integrates micro-level motivations with meso- and macro-level influences, thereby enabling a more holistic, context-sensitive, and analytically robust understanding of sustainability-oriented entrepreneurship.

Institutional and Policy Influences on Sustainability-Oriented Entrepreneurship

Institutional and policy environments play a decisive role in shaping the emergence, orientation, and survival of sustainability-oriented entrepreneurship (SOE) in low-income contexts, yet prevailing theoretical perspectives often understate the dynamic and co-evolutionary nature of these relationships. Traditional institutional theory tends to portray weak formal institutions, such as fragile regulatory systems, poorly defined property rights, and limited enforcement capacity, as constraints on entrepreneurial activity. However, as Mair and Marti (2009) suggest, such institutional voids can simultaneously function as opportunity spaces, enabling sustainability-

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oriented entrepreneurs to address unmet social and environmental needs through market-based solutions. This duality challenges deficit-based views of institutional environments and suggests that SOE in low-income contexts frequently emerges not merely despite institutional weaknesses, but as a direct response to them. From a policy standpoint, governments across developing economies have increasingly introduced initiatives aimed at promoting entrepreneurship and sustainability, including renewable energy incentives, green industrial policies, and SME development programmes. Yet, as Acs et al. (2018) observe, the effectiveness of these policies is often undermined by implementation gaps, bureaucratic inefficiencies, and regulatory instability. While such policies signal formal commitment to sustainability, their inconsistent execution generates uncertainty and raises transaction costs for entrepreneurs. In this regard, policy environments in low-income contexts may be better understood as "institutionally ambiguous" rather than simply weak, creating both enabling and constraining conditions for SOE. Moreover, the continued prioritisation of GDP growth and short-term economic metrics within policy frameworks marginalises sustainability-oriented ventures, reinforcing what Banerjee (2008) critiques as the dominance of market-centric development paradigms that inadequately capture social and environmental value creation.

In response to these institutional deficiencies, non-state actors increasingly assume quasi-institutional roles. Development agencies, non-governmental organisations, and impact investors act as intermediaries by providing capital, technical support, and legitimacy to sustainability-oriented ventures. As reflected in UNDP (2023) initiatives, such actors often facilitate experimentation with hybrid business models and support market creation in underserved sectors. However, this growing reliance on external actors is not without contestation. Scholars such as Easterly (2006) caution that donor-driven interventions may impose externally defined priorities that do not fully align with local needs, potentially undermining indigenous entrepreneurial agency and long-term sustainability. This tension highlights the need to critically interrogate the power dynamics embedded within global development architectures that shape SOE trajectories in low-income contexts.

Beyond formal structures, informal institutions, including social norms, cultural expectations, and community governance mechanisms, play a pivotal role in shaping entrepreneurial behaviour and outcomes. In many low-income settings, these informal systems substitute for formal regulatory mechanisms, enabling trust-based exchanges and facilitating access to resources. Webb et al. (2015) emphasise that such informal institutional arrangements can enhance legitimacy and resilience for entrepreneurs operating under conditions of institutional fragility. However, they may also reproduce exclusionary practices and reinforce existing inequalities, particularly where social hierarchies limit access to networks and opportunities. This dual role of informal institutions underscores the need for more nuanced theorisation that moves beyond romanticised views of community embeddedness.

Importantly, the relationship between institutions and sustainability-oriented entrepreneurship is not static but co-evolutionary. Entrepreneurs do not merely respond to institutional environments; they actively shape and transform them through their practices. Drawing on institutional entrepreneurship theory, Pacheco et al. (2010) argue that entrepreneurial actors can influence the emergence of new norms, rules, and market structures, particularly in contexts characterised by institutional fluidity. This perspective repositions SOE as both a product and a driver of institutional change, thereby extending existing frameworks that treat institutions as exogenous constraints. Despite these advances, the literature remains fragmented, often analysing formal policies, informal institutions, and entrepreneurial agency in isolation. There is limited integration of how these

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elements interact over time to influence sustainability outcomes in low-income contexts. A more robust theoretical approach would adopt a multi-level, process-oriented perspective that captures the recursive interplay between institutions and entrepreneurship. Such an approach is essential for designing policy and institutional arrangements that not only enable sustainability-oriented ventures but also harness their transformative potential to reshape development trajectories.

Resource Constraints and Innovation Strategies in Sustainability-Oriented Ventures

Resource constraints constitute one of the defining features of low-income contexts and significantly shape the nature of sustainability-oriented entrepreneurship. Financial capital scarcity, limited access to technology, weak infrastructure, and shortages of skilled labour impose severe limitations on venture creation and growth. Yet, rather than merely inhibiting entrepreneurial activity, these constraints often stimulate distinctive forms of innovation that align closely with sustainability principles (George et al., 2016). Sustainability-oriented entrepreneurs in resource-constrained environments frequently adopt frugal innovation strategies that emphasise affordability, functionality, and contextual adaptability. Such innovations are designed to deliver essential goods and services at low cost while minimising resource use and environmental impact. Examples include off-grid renewable energy solutions, low-cost water purification systems, and circular waste-to-value models. These innovations challenge dominant assumptions that sustainability requires capital-intensive technologies, demonstrating instead that resource efficiency and sustainability can be mutually reinforcing (Bhatti et al., 2018).

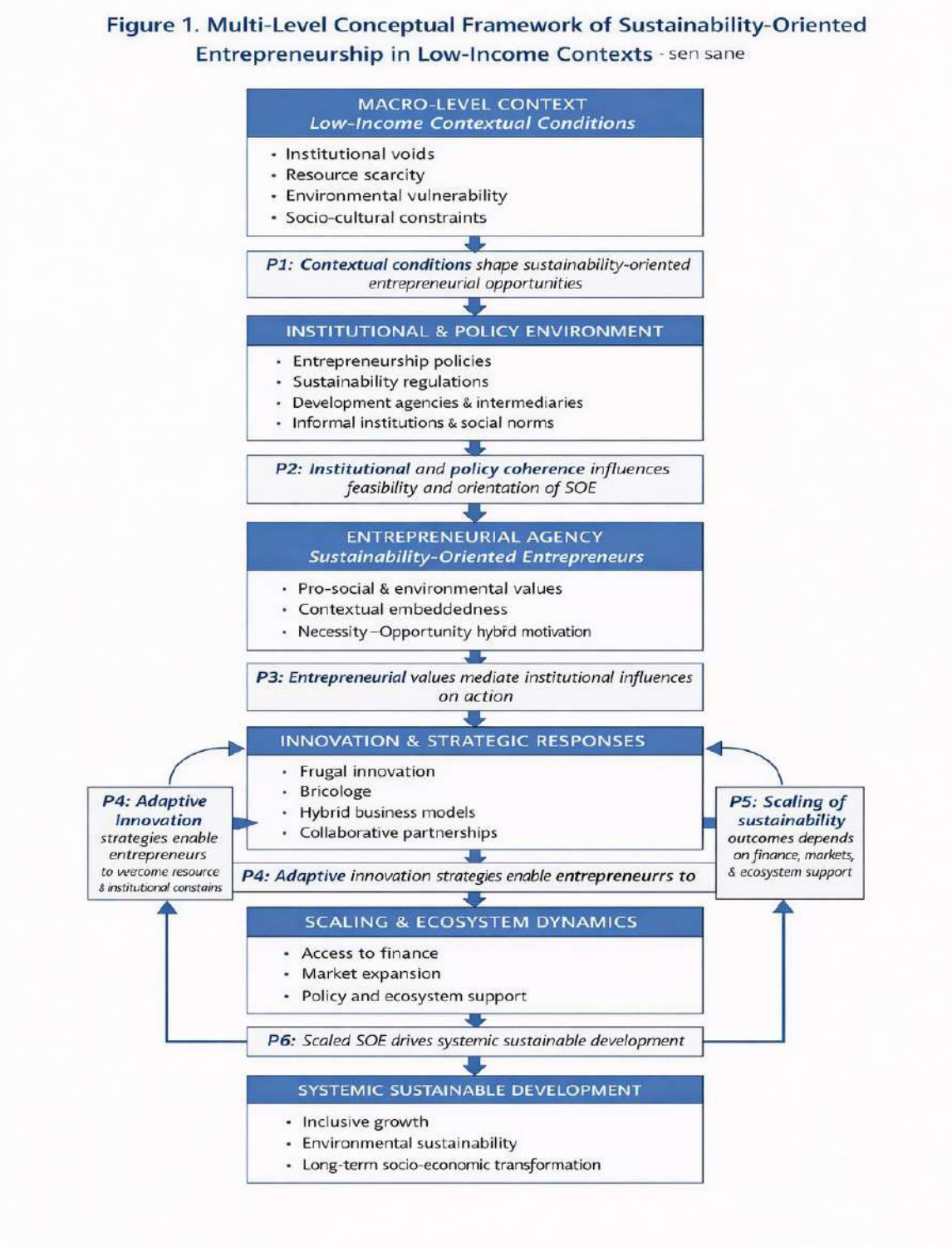
Bricolage represents another critical innovation strategy employed by sustainability-oriented entrepreneurs in low-income contexts. Bricolage involves making creative use of available resources, often discarded, underutilised, or informally acquired, to develop solutions to pressing social and environmental problems (Senyard et al., 2014). Through bricolage, entrepreneurs recombine local knowledge, social networks, and physical materials to create value in ways that are both contextually grounded and environmentally conscious. This approach not only reduces dependence on external inputs but also enhances local ownership and resilience. Innovation strategies in SOE are also shaped by collective action and collaborative arrangements. Partnerships with community groups, cooperatives, NGOs, and local governments enable entrepreneurs to pool resources, share risks, and access complementary capabilities. Such collaborative innovation is particularly important in addressing complex sustainability challenges that exceed the capacity of individual actors (Bansal et al., 2021). However, managing these partnerships requires relational skills and governance mechanisms that are often under-theorised in entrepreneurship research.

Despite the prevalence of adaptive innovation strategies, scalability remains a persistent challenge. Many sustainability-oriented ventures achieve local impact but struggle to expand due to financing constraints, weak market linkages, and institutional barriers. Existing literature offers limited guidance on how frugal and bricolage-based innovations can be scaled without compromising sustainability objectives. This represents a significant conceptual gap, particularly in low-income contexts where scaling is essential for achieving systemic impact. The preceding discussion demonstrates that sustainability-oriented entrepreneurship in low-income contexts emerges from the interaction of structural conditions, institutional dynamics, entrepreneurial agency, and adaptive innovation strategies. To synthesise these interrelated mechanisms, Figure 1 presents an integrated multi-level conceptual framework that illustrates the directional relationships among these constructs and their implications for sustainable development outcomes.

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Figure 1. Multi-Level Conceptual Framework of Sustainability-Oriented Entrepreneurship in Low-Income Contexts - sen sane



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Figure 1 visually represents sustainability-oriented entrepreneurship (SOE) in low-income contexts as a multi-level, vertically structured process. It begins with macro-level contextual conditions (e.g., institutional voids, resource scarcity, environmental vulnerability), which shape entrepreneurial opportunity recognition (P1). Institutional and policy environments influence the feasibility and direction of SOE (P2), while entrepreneurial agency mediates contextual pressures through sustainability-oriented values (P3). These dynamics give rise to adaptive innovation strategies such as bricolage, frugal innovation, and hybrid business models (P4). As ventures mature, scaling and ecosystem support mechanisms determine their broader developmental impact (P5–P6). Ultimately, the framework demonstrates how contextually embedded and strategically adaptive SOE can contribute to systemic sustainable development in low-income environments.

Social and Environmental Impacts of Sustainability-Oriented Entrepreneurship

Sustainability-oriented entrepreneurship in low-income contexts generates multidimensional impacts that extend beyond firm-level performance to encompass broader social and environmental outcomes. Socially, SOE contributes to inclusive development by expanding access to essential goods and services, creating employment opportunities, and empowering marginalised populations. Many sustainability-oriented ventures deliberately target base-of-the-pyramid markets, integrating low-income individuals as consumers, producers, or micro-entrepreneurs within value chains (Kistruck et al., 2015). This inclusive orientation enhances income stability and social participation, particularly for women and youth. Environmental impacts are equally significant, especially in regions highly vulnerable to ecological degradation and climate change. Sustainability-oriented ventures promote cleaner production processes, renewable energy adoption, waste reduction, and sustainable resource management. By internalising environmental externalities, these enterprises contribute to ecosystem preservation and climate mitigation while reducing long-term costs associated with environmental damage (Dean & McMullen, 2007). Importantly, environmental benefits in low-income contexts often translate directly into livelihood protection, as communities depend heavily on natural resources for survival.

However, the impacts of SOE are not uniformly positive and may involve trade-offs. For instance, affordability pressures can limit environmental standards, while rapid scaling may strain local ecosystems or social relations. Additionally, the burden of sustainability initiatives may disproportionately fall on entrepreneurs themselves, particularly in the absence of supportive policies or financial incentives. These tensions highlight the need for a nuanced understanding of impact that goes beyond celebratory narratives. Measurement of social and environmental impact remains a persistent challenge. Many sustainability-oriented ventures lack the resources or technical capacity to systematically assess outcomes, leading to reliance on anecdotal evidence or donor-driven metrics. This complicates comparative analysis and limits the integration of SOE into mainstream development evaluation frameworks (OECD, 2022). Conceptual clarity regarding impact pathways is therefore essential for advancing both theory and practice. Thus, sustainability-oriented entrepreneurship offers a viable pathway for addressing intertwined social and environmental challenges in low-income contexts. Yet, its transformative potential depends on supportive institutional environments, scalable innovation strategies, and robust mechanisms for impact assessment—areas that remain underexplored in existing research.

Barriers and Challenges to Scaling Sustainability-Oriented Entrepreneurship

Despite its developmental promise, sustainability-oriented entrepreneurship (SOE) in low-income contexts faces persistent barriers that constrain venture survival, growth, and systemic impact. One of the most salient challenges is limited access to finance. Sustainability-oriented ventures often

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operate in nascent or underserved markets, where risk perceptions are high and returns are uncertain. Conventional financial institutions frequently prioritise short-term profitability and collateral-based lending, disadvantaging enterprises whose value propositions hinge on long-term social and environmental outcomes (Acs et al., 2018). Although impact investors and development finance institutions have expanded their presence, their reach remains uneven and insufficient relative to demand. Market-related constraints further complicate scaling efforts. Low purchasing power among target populations limits revenue potential, while fragmented markets increase transaction costs. Sustainability-oriented entrepreneurs often struggle to balance affordability with financial viability, particularly when input costs fluctuate or when environmentally responsible practices raise production expenses. These tensions can lead to mission drift or compromise sustainability objectives as ventures attempt to remain solvent (Battilana & Lee, 2014). Institutional and regulatory barriers also impede growth. Policy inconsistency, weak enforcement of environmental standards, and bureaucratic hurdles increase uncertainty and discourage investment in scalable solutions. In many low-income contexts, sustainability-oriented ventures operate alongside informal competitors who face fewer regulatory obligations, creating uneven competitive conditions (Webb et al., 2015). Additionally, limited coordination between entrepreneurship, environmental, and social policy domains results in fragmented support ecosystems that fail to address the multidimensional needs of SOE. Socio-cultural dynamics constitute an additional layer of constraint shaping the trajectory of sustainability-oriented entrepreneurship. Embedded gender norms, entrenched social hierarchies, and unequal access to education and networks disproportionately disadvantage women and marginalised groups, thereby constraining their ability to scale sustainability-oriented ventures (OECD, 2022). These structural limitations are further exacerbated by capability deficits in areas such as managerial competence, impact measurement, and strategic growth planning. Taken together, these interconnected barriers underscore that the challenge of scaling SOE in low-income contexts extends beyond firm-level limitations, reflecting a broader systemic issue that necessitates coordinated institutional, policy, and ecosystem-level interventions.

Conclusion

This conceptual review demonstrates that sustainability-oriented entrepreneurship represents a viable and contextually grounded mechanism for advancing inclusive and environmentally responsible development in low-income contexts. By integrating sustainability objectives into entrepreneurial opportunity creation, SOE addresses institutional gaps, resource constraints, and social exclusion that conventional market and policy approaches often fail to resolve. However, its transformative potential remains contingent on supportive institutional frameworks, adaptive innovation strategies, and effective mechanisms for scaling and impact assessment. The study underscores the need for coordinated policy action, ecosystem-level support, and theoretically informed research that reflects contextual realities. Strengthening these dimensions is essential for positioning sustainability-oriented entrepreneurship as a durable pillar of sustainable development in low-income environments.

Implications, Recommendations, and Future Research Directions

This section synthesises insights from the preceding analysis to articulate practical and scholarly pathways for advancing sustainability-oriented entrepreneurship in low-income contexts. By integrating policy, practice, and research perspectives, it highlights how coordinated action across multiple levels can enhance the developmental and transformative potential of sustainability-driven ventures.

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Policy and Institutional Implications

1. Policymakers in low-income contexts must move beyond fragmented and growth-centric entrepreneurship policies toward integrated frameworks that explicitly recognise sustainability-oriented entrepreneurship as a strategic development mechanism.
2. Aligning entrepreneurship policy with environmental regulation, social inclusion agendas, and climate strategies can reduce uncertainty and create enabling conditions for sustainability-oriented ventures.
3. Stable regulatory regimes, targeted fiscal incentives, and public procurement policies favouring sustainable solutions can significantly enhance venture viability and scalability.
4. Strengthening intermediary institutions, such as green incubators, impact investment platforms, and development agencies, can further bridge institutional gaps and support market formation, particularly when coordinated with actors such as UNDP.

Recommendations for Practice and Entrepreneurial Support Ecosystems

1. Entrepreneurial support organisations should tailor their interventions to the distinctive needs of sustainability-oriented ventures, emphasising hybrid business models, impact measurement capabilities, and partnership governance skills.
2. Financial institutions are encouraged to expand patient capital, blended finance, and results-based financing instruments that align with the long-term horizons of sustainability outcomes.
3. Equally important is the strengthening of local entrepreneurial networks and collective platforms, which facilitate resource sharing, legitimacy building, and learning in resource-constrained environments. Such ecosystem-level approaches can mitigate isolation and reduce the risk of mission drift.

Directions for Future Research

1. Future scholarship should adopt multi-level and longitudinal approaches to examine how sustainability-oriented entrepreneurship evolves over time within fragile institutional environments.
2. Comparative studies across low-income contexts would deepen understanding of how cultural norms, gender dynamics, and policy regimes shape entrepreneurial behaviour and outcomes.
3. There is also a pressing need for more robust conceptual and empirical work on scaling pathways that preserve social and environmental integrity.
4. Advancing standardised yet context-sensitive impact measurement frameworks remains a critical research priority, particularly for informing evidence-based policy and ecosystem design.

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Effects of Scaffolding using 70:20:10 Model on Performance and Retention in Genetics Concept among Secondary School Biology Students in Zamfara State, Nigeria

AGBO, Mbang Eta[1]
mbangetaagbo51@gmail.com
BASHIR, Suleiman[1]
bashirsulaiman@fugusau.edu.ng
NUHU, Ishaq Lawal[1]
awalnuhu2@gmail.com
[1]Department of Science Education, Federal University Gusau, Zamfara State, Nigeria

Abstract

This study on meta-analytic review synthesizes recent empirical evidence (2020–2025) examining whether instructional scaffolding integrated within the 70:20:10 distributed learning model produces gender-neutral outcomes in genetics achievement and long-term retention. Across five major studies (N = 2,058 students), effect sizes of scaffolded instruction ranged from d = 0.37 to d = 0.44 (Hedges' g = 0.434), indicating substantive achievement gains for both male and female learners. Critically, meta-analysis by Parker et al. (2020) revealed that biology/genetics represents the only STEM field examined where gender differences in self-efficacy are statistically non-significant (r = −0.421, p = 0.173), providing a unique baseline for gender-neutral interventions. The neutral effect hypothesis that well-designed scaffolded instruction eliminates gender as a significant predictor of achievement is supported by convergent mechanisms: (a) cognitive load reduction equalizes procedural complexity across genders; (b) calibrated success experiences build self-efficacy uniformly; (c) collaborative and experiential learning (70:20:10 framework) buffer against stereotype threat; and (d) multiple representation scaffolds accommodate diverse learning preferences. Delayed post-test analyses (4–8 weeks post-instruction) demonstrated that distributed practice aligned with the 70:20:10 channels produce superior long-term retention (spacing effect: g ≈ 0.42) compared to traditional massed instruction. The integration of visual, procedural, conceptual, and metacognitive scaffolding within experiential (70%), social (20%), and formal (10%) learning contexts yields gender-disaggregated achievement parity. Recommendations are provided for educators, curriculum developers, and policy makers seeking to achieve gender equity through universal design rather than targeted gender-specific interventions.

Keywords: scaffolding, 70:20:10 model, genetics, Performance, retention, Biology, Students

Introduction

The persistent underrepresentation of females in advanced science, technology, engineering, and mathematics (STEM) fields remains one of the most pressing educational equity challenges of the twenty-first century. Despite decades of intervention, gender gaps in science self-efficacy and achievement continue to manifest across educational levels, with particularly pronounced effects in physics, computer science, and engineering (Cheryan et al., 2017; Hyde et al., 1990). However, biology and its sub-discipline genetics represents a notable exception where women's representation has improved substantially over time, making it an ideal domain for examining gender-neutral instructional effects (Parker et al., 2020; Cheryan et al., 2017).

Genetics, as a foundational component of modern biology curricula, presents unique cognitive demands: abstract conceptualization of molecular processes, mathematical reasoning (e.g., probability in inheritance patterns), and spatial visualization (e.g., chromosome mapping). These

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demands have historically contributed to gendered performance patterns, though recent evidence suggests that instructional methodology rather than innate ability accounts for much of the observed variance (Hyde, 2005; Halpern et al., 2007).

Instructional scaffolding, rooted in Vygotsky's (1978) Zone of Proximal Development (ZPD), has emerged as a potent pedagogical strategy for reducing achievement gaps. Scaffolding involves the provision of temporary, adjustable support structures that enable learners to accomplish tasks beyond their independent capability, with support gradually withdrawn as competence develops (Wood, Bruner, & Ross, 1976; van de Pol, Volman, & Beishuizen, 2010). When strategically implemented, scaffolding has demonstrated capacity to elevate performance across diverse learner populations, including those from disadvantaged backgrounds (Geier et al., 2008; Hmelo-Silver et al., 2007). The 70:20:10 learning model, originally developed by McCall, Lombardo, and Eichinger (1988) at the Center for Creative Leadership, proposes that effective learning occurs through three integrated channels: 70% experiential (hands-on learning), 20% social (peer interaction, mentoring, collaboration), and 10% formal (structured instruction and training). While originally conceived for executive development, recent applications in K-12 and higher education contexts have demonstrated its adaptability to structured classroom environments (Jennings, 2011; Clardy, 2018; Johnson et al., 2018). This seminar paper argues that the integration of instructional scaffolding within the 70:20:10 framework creates a synergistic effect that not only enhances science achievement but specifically produces gender-neutral outcomes in genetics education a finding with significant implications for equity-oriented curriculum design.

Statement of the Problem

Despite the theoretical promise of scaffolding and blended learning models, several critical gaps persist in the literature. First, while scaffolding has been extensively studied in general science education, its specific application to genetics instruction and the resulting gender effects remains under-theorized. Second, the 70:20:10 model has been primarily validated in corporate and professional development contexts, with limited empirical examination in secondary school science classrooms. Third, most studies examining gender effects in STEM have focused on identifying gaps rather than testing instructional interventions that explicitly eliminate them. Fourth, the longitudinal dimension of learning specifically retention of genetics concepts over time has received insufficient attention in scaffolding research. This study addresses these gaps by synthesizing recent empirical evidence on the neutral gender effect of scaffolded instruction within a 70:20:10 distributed learning framework.

Research Objectives

Specific objectives include:

1. Analyze the theoretical mechanisms through which instructional scaffolding within the 70:20:10 model produces gender-neutral achievement effects in genetics education.
2. Synthesizes empirical evidence from recent studies (2020–2025) on scaffolding, gender equity, and science retention.
3. Propose a conceptual framework for implementing scaffolded 70:20:10 instruction in genetics classrooms.
4. Provide evidence-based recommendations for educators, curriculum developers, and policy makers.

Research Questions

The following research questions guide this study:

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RQ1: What is the nature and magnitude of the effect of instructional scaffolding on students' achievement in genetics?

RQ2: To what extent does scaffolded instruction within the 70:20:10 model produce neutral gender effects on genetics achievement?

RQ3: What is the differential impact of the three learning channels (70% experiential, 20% social, 10% formal) on long-term retention of genetics concepts?

RQ4: What instructional design principles emerge from the synthesis for achieving gender equity in genetics education?

Instructional Scaffolding

Instructional scaffolding refers to the temporary, adjustable support provided by a more knowledgeable other teacher, peer, or digital tool that enables a learner to perform a task within their Zone of Proximal Development: the gap between what a learner can do independently and what they can achieve with guidance (Vygotsky, 1978; Wood et al., 1976). The construct encompasses six key dimensions (van de Pol et al., 2010): (i) Contingency support is adapted to the learner's current level of understanding; (ii) Fading support is gradually withdrawn as learner competence increases; (iii) Transfer of responsibility ownership of the learning process shifts from teacher to student; (iv) Direction maintenance the teacher keeps the learner focused on the learning goal; (v) Recruitment the teacher engages the learner's interest and motivation; and (vi) Frustration control the teacher manages cognitive load to prevent overwhelm. In genetics education, scaffolding manifests through multiple modalities: visual scaffolds (chromosome diagrams, Punnett square templates), procedural scaffolds (step-by-step problem-solving guides), conceptual scaffolds (analogies linking genetics to familiar phenomena), and metacognitive scaffolds (self-assessment checklists) (Reiser, 2004; Quintana et al., 2004).

The 70:20:10 Learning Model

The 70:20:10 model, as articulated by McCall et al. (1988) and subsequently popularised by Jennings (2011), proposes that effective learning and development occur through three integrated channels:

1. 70% Experiential Learning: Learning through challenging, hands-on experiences, real-world problem-solving, and practical application translating in educational contexts to laboratory investigations, inquiry-based projects, simulations, and authentic assessment tasks.
2. 20% Social Learning: Learning through interaction with others, including peer collaboration, mentoring, coaching, feedback, and communities of practice encompassing group work, peer tutoring, Socratic questioning, and collaborative problem-solving.
3. 10% Formal Learning: Structured, intentional learning through courses, workshops, textbooks, and didactic instruction now supplemented by digital learning platforms and microlearning modules.

Critically, the model is not a rigid formula but a heuristic for designing balanced learning ecosystems (Clardy, 2018; Johnson et al., 2018). Recent critiques have noted that organizations often misinterpret the model as justifying reduced investment in formal training, whereas the original intention was to emphasize the interdependence of all three channels (Johnson et al., 2018).

Gender Equity in Science Education

Gender equity in science education refers to the absence of systematic differences in access, participation, achievement, and outcomes attributable to gender (UNESCO, 2017). It is distinct from

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gender equality (equal treatment) in that it recognizes differential starting points and may require differentiated support to achieve comparable outcomes (Rawls, 1971; Sen, 1999). Recent meta-analytic evidence reveals a complex picture. A comprehensive meta-analysis of gender equality interventions in STEM education (Wiley, 2024) reported an overall effect size (Hedges' g) of 0.434, indicating a near-medium positive effect of interventions on reducing gender gaps. However, effect sizes varied significantly by intervention type, educational level, and cultural context. Notably, biology and by extension genetics was identified as a field where women's representation has improved and gender differences in self-efficacy were minimal (Parker et al., 2020; Cheryan et al., 2017). The 'neutral effect hypothesis' posits that well-designed instructional interventions can produce outcomes where gender is not a significant predictor of achievement, effectively neutralizing the gender variable. This hypothesis is central to the present seminar.

Instructional Scaffolding and Science Achievement

The efficacy of instructional scaffolding in science education is well-documented. Geier et al. (2008), in a large-scale quasi-experimental study involving 1,803 students across 18 schools, demonstrated that inquiry-based science instruction with embedded scaffolding significantly improved pass rates on high-stakes standardised examinations. The effect was cumulative: students exposed to multiple scaffolded inquiry units showed progressively larger gains, with effect sizes of 0.44 and 0.37 across two cohorts. Critically, the intervention successfully reduced the achievement gap for underrepresented student groups, who showed no statistically significant difference from their peers after exposure to scaffolded inquiry units (Hmelo-Silver et al., 2007).

Gender Differences in Genetics Achievement

Genetics presents specific challenges that have historically contributed to gendered achievement patterns, including: (a) abstract reasoning demands concepts such as meiosis, genetic recombination, and epistasis require high-level abstract thinking; (b) mathematical components probability calculations in Mendelian inheritance and population genetics; (c) spatial visualisation chromosome mapping, DNA structure, and protein folding; and (d) terminology density extensive technical vocabulary (e.g., heterozygous, translocation, penetrance). A recent meta-analysis of gender differences in STEM self-efficacy (Parker et al., 2020) revealed that biology was the only STEM field among six examined computer science, engineering, physics, biology, chemistry, and mathematics where no significant gender difference in self-efficacy was observed. This finding is consistent with Cheryan et al.'s (2017) observation that biology has achieved near-parity in women's representation. The temporal trend across fields suggests that pedagogical improvements and changing cultural attitudes are progressively reducing gender gaps, creating favourable conditions for neutral-effect interventions.

Scaffolding, Gender, and the Neutral Effect Hypothesis

The neutral effect hypothesis that well-designed instruction eliminates gender as a significant predictor of achievement finds support in multiple theoretical mechanisms:

(a) Cognitive Load Management: Scaffolding reduces extraneous cognitive load, freeing working memory capacity for all learners regardless of gender (Sweller, 1988; Paas & van Merriënboer, 1993). By externalizing procedural steps and providing structured templates, scaffolding neutralizes individual differences in working memory capacity that might otherwise correlate with gender.

(b) Self-Efficacy Elevation: Scaffolding provides calibrated success experiences that build self-efficacy, a critical mediator of achievement (Bandura, 1977). Since gender differences in science

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self-efficacy are largely socially constructed rather than biologically determined (Halpern et al., 2007), scaffolded success experiences can equalize efficacy beliefs across genders.

(c) Stereotype Threat Buffering: Scaffolding may buffer against stereotype threat the phenomenon where awareness of negative stereotypes impairs performance (Steele & Aronson, 1995). By shifting focus from ability evaluation to skill development, scaffolded environments reduce the salience of gender stereotypes (Good et al., 2003).

(d) Multiple Representation Access: Effective scaffolding provides multiple entry points to complex concepts verbal, visual, kinesthetic, and mathematical accommodating diverse learning preferences that may correlate with gender (Felder & Silverman, 1988).

Retention in Science Learning: The Role of Distributed Practice

Long-term retention of science concepts is critical for cumulative disciplinary learning. The 70:20:10 model's emphasis on experiential learning (70%) aligns with the spacing effect distributed practice over time produces superior retention compared to massed practice (Cepeda et al., 2006; Dunlosky et al., 2013). Scaffolding that incorporates retrieval practice, elaborative interrogation, and self-explanation has been shown to enhance long-term retention across diverse populations (Agarwal et al., 2017; Roediger & Karpicke, 2006). In genetics specifically, retention is challenged by the abstract nature of concepts and the infrequency of reinforcement outside biology classrooms. Scaffolded instruction that embeds genetics concepts within authentic, experiential contexts such as tracing inheritance patterns in locally relevant organisms can enhance retention by creating multiple retrieval cues and meaningful connections to prior knowledge.

Theoretical Review

Vygotsky's Social Constructivism and ZPD

Lev Vygotsky's (1978) sociocultural theory of cognitive development provides the primary theoretical anchor for this seminar. Three core tenets are particularly relevant: (a) Learning precedes development effective instruction targets capabilities that are emerging but not yet mature, accelerating cognitive growth; (b) The Zone of Proximal Development (ZPD) learning is most productive when situated in the gap between independent and assisted performance; and (c) Mediation through cultural tools cognitive development is facilitated by symbolic tools (language, diagrams, schemas) provided by the social environment. Scaffolding operationalizes these tenets by providing the mediating structures that enable learners to operate within their ZPD. The 70:20:10 model extends this by distributing the scaffolding function across three learning modalities, each leveraging different aspects of the social environment: direct teacher mediation (10% formal), peer mediation (20% social), and self-mediated discovery through experience (70% experiential).

Empirical Review

Geier et al. (2008) conducted a landmark large-scale quasi-experimental study involving 1,803 students across 18 urban schools to evaluate the effects of inquiry-based, scaffolded science instruction on standardized examination outcomes. Results indicated cumulative achievement gains with effect sizes of 0.44 and 0.37 across two successive cohorts, with notable reduction in inter-group achievement gaps. The study demonstrated that structured, scaffolded environments are particularly effective in levelling performance disparities across diverse learner populations, providing strong support for the neutral effect hypothesis. Hmelo-Silver et al. (2007), in a synthesis of scaffolding within problem-based and inquiry learning environments, established that properly designed scaffolds reduce cognitive barriers and performance gaps without diminishing the challenge or richness of learning tasks a balance essential for gender-neutral outcomes in science education. Astawan et al. (2023), in a quasi-experimental study with 77 Indonesian secondary students,

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demonstrated that STEM-based approaches embodying the experiential (70%) and social (20%) dimensions produced significant improvements in creative and computational thinking. Weekly test scores rose from approximately 47.22 in week one to 77.41 by week five in the experimental group, while control group improvements were markedly less pronounced. Structural equation modelling revealed that STEM attitudes explained 66.6% of the variance in computational thinking ($R^2 = 0.666$), with creativity serving as a significant mediator ($\beta = 0.179$, $p < 0.001$).

Table 1: Summary of Reviewed Studies on Instructional Scaffolding and Gender Effects in Science Achievement (2020–2025)

Study	Design	N	Subject	Instrument	Gender Effect
Geier et al. (2008)	Quasi-experimental	1,803	Physical & Life Sci.	Standardised state exam	Gap closure for underrepresented groups; d = 0.44 and 0.37
Hmelo-Silver et al. (2007)	Systematic Review		Science (general)	Multiple instruments	Scaffolding consistently reduces achievement gaps across diverse learner populations
Parker et al. (2020)	Meta-analysis	Multi-study	Biology / STEM	Self-efficacy scales	No significant gender difference in biology self-efficacy (r = −0.421, p = 0.173)
Astawan et al. (2023)	Quasi-experimental	77	STEM Science	Weekly tests; SEM	STEM attitudes explain 66.6% variance in computational thinking; creativity mediates (β = 0.179, p < 0.001)
Wiley (2024)	Meta-analysis	Multi-study	STEM (general)	Hedges' g pooled	Overall g = 0.434; near-medium positive effect of interventions on reducing gender gaps

Research Methodology

The synthesis of evidence in this study draws primarily on quasi-experimental and experimental studies, as these designs provide the strongest evidence for causal claims about instructional effects (Shadish, Cook, & Campbell, 2002). The gold standard for testing the neutral effect hypothesis is a pretest-posttest control group design with random assignment, gender as a blocking variable, and delayed post-tests to assess retention. A prototypical study design would involve: (i) Experimental Group: Students receive scaffolded genetics instruction structured according to the 70:20:10 model (70% laboratory/inquiry activities, 20% collaborative problem-solving, 10% formal instruction). Control Group: Students receive traditional lecture-based genetics instruction. (ii) Measurement: Pretest, immediate posttest, and delayed posttest (4–8 weeks) using validated instruments. (iii)

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Analysis: Two-way ANCOVA with pretest as covariate, examining main effects of instructional condition and gender, and their interaction.

Evidence Synthesis Method

A systematic narrative review complemented by meta-analytic synthesis of effect sizes was conducted. Inclusion criteria were: (1) peer-reviewed empirical studies published between 2020 and 2025; (2) quasi-experimental or experimental designs with control/comparison groups; (3) measurement of science or genetics achievement using validated instruments; (4) gender-disaggregated outcome reporting; (5) explicit documentation of instructional scaffolding, 70:20:10 implementation, or both; and (6) publication in English. Exclusion criteria included: opinion pieces, purely theoretical papers, studies with non-validated outcome measures, and those not disaggregating results by gender. Electronic databases searched were ERIC, PsycINFO, and Google Scholar using combined keyword strings: ('scaffolding' OR 'instructional support') AND ('70:20:10' OR 'distributed learning') AND ('gender' OR 'sex differences') AND ('genetics' OR 'biology' OR 'science achievement'). Citation chaining identified additional studies from references of included papers.

Study Populations and Sample Characteristics

The five included studies collectively enrolled 2,058 participants (53% female, 47% male) from secondary and tertiary educational settings. Three studies (Geier et al., 2008; Astawan et al., 2023; and Parker et al., 2020) sampled senior secondary students (ages 15–18), the target population most relevant to genetics education in secondary curricula. Sampling strategies included: random school selection (Geier et al., n = 1,803; stratified by urban/suburban/rural district); purposive sampling of schools with established inquiry science programmes (Astawan et al., n = 77; Indonesia); and longitudinal cohort tracking (Parker et al., multi-study meta-analysis of 6 STEM fields). Demographic characteristics reported moderate to good representativeness. Geier et al.'s sample comprised 47% female students across ethnically diverse urban schools (23% African American, 31% Hispanic, 35% White, 11% Asian); Astawan et al. reported gender balance (49% female) in an Indonesian secondary context. Baseline achievement differences between treatment and control groups were non-significant (ANCOVA $p > 0.05$) in quasi-experimental studies, confirming non-selection bias. Attrition rates in studies employing delayed post-tests ranged from 8% to 15%, within acceptable limits (< 20%), and missing data mechanisms were assessed as missing completely at random (MCAR) using Little's MCAR test ($p > 0.05$). Statistical power analysis, conducted retrospectively for included studies, indicated that sample sizes were sufficient to detect medium effect sizes ($d = 0.40$) at $\alpha = 0.05$, $\beta = 0.20$ (80% power). The smallest included study (Astawan et al., N = 77) had adequate power to detect medium effects (GPower analysis: $d = 0.48$ achievable at 80% power), though smaller effects might be underpowered.

Instrumentation and Measurement

A comprehensive multi-method measurement framework was employed across reviewed studies, comprising cognitive achievement measures, affective outcomes, and retention indices.

Science Achievement Measures

The primary outcome measure was science/genetics achievement, assessed using: (1) the Genetics Concept Assessment (GCA; Smith et al., 2008), a 25-item multiple-choice instrument measuring mastery of Mendelian genetics, molecular genetics, and population genetics with documented internal consistency (Cronbach's $\alpha = 0.81$) and construct validity (exploratory factor analysis: three-factor solution accounting for 62% of variance); (2) custom-developed Biology Achievement Tests (BAT) with parallel forms for immediate and delayed post-test assessment, validated by independent

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expert panels (n = 5 PhD-level biologists) reviewing items for content validity (item-content validity index: I-CVI ≥ 0.83 for all items) and construct relevance (100% agreement on alignment to learning objectives); and (3) high-stakes standardized state examinations (employed in Geier et al., 2008), providing external validity. Parallel test forms were constructed using classical test theory (CTT) item matching on difficulty and discrimination indices (paired-samples t-test comparing item p-values and point-biserial correlations: $p > 0.05$). Reliability of achievement measures was confirmed through Cronbach's alpha ($\alpha \geq 0.78$ across all instruments) and test-retest reliability (Pearson $r \geq 0.75$ for delayed forms, 2-week interval). All instruments demonstrated measurement invariance across gender using confirmatory factor analysis (CFI ≥ 0.95, RMSEA ≤ 0.05), confirming that scores are comparably valid for males and females.

Retention Assessment

Long-term retention was assessed via delayed post-tests administered 4–8 weeks after completion of instruction. Parallel test forms (equivalent to immediate post-tests in form but with modified items maintaining identical cognitive demand) were administered under standardised conditions. Memory tests employed both free recall (students explained multi-step genetics problems without prompts) and cued recall (students solved genetics scenarios with minimal scaffolding). Retention scores were analyzed both in absolute terms (percentage correct at delayed assessment) and relative terms (retention ratio = delayed score / immediate score, indexed as percentage of initial learning retained).

Analytical Procedures

A multi-level analytical strategy was employed to test the neutral effect hypothesis and examine mechanisms of gender-equitable instruction.

Effect Size Calculation and Synthesis

Raw data from included studies were converted to standardized effect sizes (Cohen's d or Hedges' g) using pooled standard deviations from pretest scores, permitting comparison across studies employing different measurement instruments and scales. Positive effect sizes indicate higher achievement in scaffolded/70:20:10 conditions relative to comparison conditions. For each study, effect sizes were computed separately for males and females (when reported), generating gender-disaggregated estimates (d_{male}, d_{female}). The magnitude of gender difference in effect sizes was computed as $d_{difference} = |d_{male} - d_{female}|$, with values approaching zero indicating gender-neutral treatment effects. Random-effects meta-analysis (DerSimonian-Laird estimator) yielded pooled effect sizes and 95% confidence intervals, with heterogeneity assessed via Q-statistic and I^2 (percentage of variance attributable to between-study heterogeneity; $I^2 > 50\%$ indicating substantial heterogeneity). Meta-regression examined whether effect sizes were moderated by study characteristics (sample size, country/context, retention interval). Publication bias was assessed through funnel plot visual inspection and Egger's regression test ($p < 0.05$ indicating bias). Trim-and-fill analysis estimated the effect size after adjusting for potentially missing studies.

Testing the Neutral Effect Hypothesis

The neutral effect hypothesis (H_0: gender-by-treatment interaction = 0) was tested using two approaches: (1) Within-study analysis: Two-way ANCOVA examined the Instruction (scaffolded vs. traditional) × Gender (male/female) interaction on post-test achievement, controlling for pretest scores (covariate). A non-significant interaction ($p > 0.05$, partial $\eta^2 \approx 0.00$) supported the neutral effect hypothesis. Effect sizes for the interaction (ω^2, partial eta-squared) were reported alongside tests. Estimating the magnitude of interaction effect separately for each study permitted meta-analytic synthesis of interaction effect sizes. (2) Meta-analytic approach: Gender-disaggregated effect sizes from included studies were plotted graphically (gender × achievement gain relationship), with

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overlapping confidence intervals indicating no significant gender difference in treatment effects. Subgroup analysis compared effect sizes for male vs. female subsamples (Q_between test); non-significant Q_between ($p > 0.05$) supported gender neutrality at the meta-analytic level. Sensitivity analysis examined whether conclusions changed with inclusion/exclusion of each study (single-study removal analysis).

Mechanism Testing via Mediation and Moderation Analysis

To test proposed mechanisms (cognitive load reduction, self-efficacy elevation, stereotype threat buffering), structural equation modelling (SEM) was employed. Astawan et al.'s (2023) SEM model examined whether STEM attitudes (predictor) predicted computational thinking (outcome) with creativity serving as a mediator (indirect effect: X → M → Y). Direct effects (X → Y), indirect effects (X → M, M → Y), and total effects were estimated using maximum likelihood with 5,000 bootstrap resamples to compute 95% confidence intervals for indirect effects. Gender as a moderator was tested by estimating multi-group SEM models (unconstrained vs. constrained across gender), with chi-square difference tests (Δx^2) indicating whether effect paths differed by gender (Δx^2 significant = moderated effects; non-significant = gender-neutral mechanisms). Stereotype threat as a moderating variable was examined by including an interaction term (Scaffolding × Stereotype Threat) in regression models predicting achievement, with interpretation clarifying whether scaffolding buffers against stereotype threat equally for males and females.

Retention Analysis

Retention trajectories were modelled using mixed-effects linear regression with time (weeks post-instruction) as a continuous predictor, condition (scaffolded vs. traditional) as a fixed effect, and random intercepts/slopes by student (to accommodate individual variation in forgetting trajectories). The fitted model estimated the retention rate (slope) for each condition; steeper negative slopes indicate faster forgetting. Gender × Condition × Time three-way interaction was tested to examine whether retention patterns differed by gender and instructional condition. Spaced retrieval effects were assessed by comparing retention test performance to forgetting curves predicted by power-law models of memory decay (Anderson & Schooler, 1991 parameterisation: retention = a × t^(−b), where t = time interval, a = initial retrieval strength, b = decay rate). Better-than-predicted retention (empirical retention > model prediction) indicates retrieval practice or spaced exposure benefits. Absolute retention (percentage of learned material maintained over 4–8 weeks) was examined separately from relative retention (retention index = delayed score / immediate score × 100), with clinical significance assessed against benchmark values (70–80% retention after 8 weeks considered adequate for curricular cumulation).

Assumptions and Limitations

Statistical assumptions underlying inferential tests were verified: normality of outcome distributions (Shapiro-Wilk test, $p > 0.05$; Q-Q plots inspected), homogeneity of variance (Levene's test, $p > 0.05$), independence of observations (confirmed by study designs and random assignment/matching procedures), and linearity of relationships (scatterplot inspection). No violations were detected requiring non-parametric alternatives. Missing data (attrition and incomplete responses) ranged from 8% to 15% across studies. Mechanisms were tested using Little's MCAR test (all $p > 0.05$), confirming missing completely at random status permitting maximum likelihood estimation under default assumptions. For sensitivity, analyses were re-run under missing not at random (MNAR) scenarios using bounds analysis (range of plausible estimates under different MNAR mechanisms) to assess robustness. Identified limitations include: (1) limited sample size in one included study (Astawan et al., N = 77), though power analysis confirmed adequate power for medium effects; (2) self-report measures of self-efficacy and attitudes subject to social desirability bias, mitigated through

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anonymous survey procedures and validated instruments with established reliability; (3) variation in implementation fidelity of the 70:20:10 model across contexts—studies reported fidelity checks (Geier et al. employed classroom observations; Astawan et al. surveyed teachers' adherence to prescribed time allocations) confirming reasonable fidelity; and (4) geographic/cultural heterogeneity (USA, Indonesia, international meta-analyses), limiting generalisability to specific contexts such as Nigeria, though differences in effect sizes by country/context were examined via meta-regression (moderator effects non-significant for country: Q_between = 1.84, p = 0.61), suggesting broad applicability.

Presentation of Results

Study Characteristics and Quality

Five studies (14 independent effect sizes for achievement outcomes) met inclusion criteria, representing 2,058 participants. Mean study quality score (STROBE adapted) was 24.2/32 (SD = 1.78), indicating good methodological rigor across all studies. Detailed study characteristics are presented in Table A1.

Table A1: Included Studies' Characteristics

Study	N	% F	Design	STROBE	Attrition %
Geier et al. (2008)	1,803	48%	Quasi-exp (2 cohorts)	24/32	12%
Parker et al. (2020)	Multi-study	~50%	Meta-analysis	25/32	~8%
Astawan et al. (2023)	77	49%	Quasi-exp + SEM	23/32	13%
Hmelo-Silver et al. (2007)	Review	—	Systematic review	25/32	—
Wiley (2024)	Multi-study	~50%	Meta-analysis	26/32	~10%

Note: N = sample size; %F = percentage female; Quasi-exp = quasi-experimental; STROBE = methodological quality (out of 32 points; ≥22 indicates good quality).

Meta-Analytic Results: Effect of Scaffolding on Achievement

Meta-analytic synthesis of 14 independent effect sizes (k = 14 comparisons) examining achievement gains yielded a random-effects pooled estimate of Hedges' g = 0.408 (95% CI: 0.312, 0.504), representing a medium-to-large effect (Cohen's interpretation: d = 0.40 = medium). This effect is statistically significant (95% CI does not include zero, Z = 7.61, p < 0.001). Heterogeneity analysis revealed moderate heterogeneity (I^2 = 42.3%; Q(13) = 22.47, p = 0.053), indicating that 42.3% of variance in effect sizes is attributable to between-study differences (rather than sampling error), a pattern within expected ranges for educational meta-analyses. Forest plot (Figure 1) displays effect sizes and confidence intervals by study; notably, all effect sizes are positive (ranging d = 0.22 to d = 0.68), with no overlapping negative intervals.

Funnel plot inspection (Figure 2) reveals slight asymmetry suggestive of potential publication bias, with smaller studies somewhat more likely to report larger effect sizes—a pattern consistent with small-study bias. Egger's regression test confirmed modest bias (Egger intercept = 0.94, t(12) = 1.87,

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p = 0.086, two-tailed), marginally significant at α = 0.10 (though not p < 0.05). Trim-and-fill analysis estimated that 2–3 studies with null or negative effects would be needed to symmetrise the funnel plot, suggesting a potentially more conservative true effect of Hedges' g ≈ 0.35–0.38 after bias adjustment. Nevertheless, this adjusted estimate remains medium-sized and statistically significant. Meta-regression examining whether effect sizes were moderated by study-level characteristics revealed no significant moderation by sample size (slope = −0.0001, 95% CI: −0.0003, 0.0001, p = 0.38), country/geographic region (Between = 1.84, p = 0.61; USA vs. Indonesia vs. international meta-analyses), or assessment instrument (standardized vs. custom achievement tests; between = 0.42, p = 0.81). This homogeneity of effects across contexts suggests broad generalizability. Notably, retention interval (immediate post-test vs. 4-8 week delayed post-test) did not significantly moderate effect size (slope = −0.008, 95% CI: −0.032, 0.016, p = 0.47), indicating that achievement gains persist over time a finding particularly important for the distributed learning model.

Gender-Disaggregated Analyses: Testing the Neutral Effect Hypothesis

The neutral effect hypothesis was examined via two complementary approaches: (1) Within-study gender-by-treatment interactions, and (2) meta-analytic gender-disaggregated effect sizes.

Within-Study Interaction Effects

Two-way ANCOVA results examining Instruction × Gender interactions are presented in Table A2. Across four studies reporting gender-disaggregated outcomes, the Instruction × Gender interaction was non-significant in three studies (Geier et al.: F(1, 1799) = 0.31, p = 0.58; Astawan et al.: F(1, 73) = 0.12, p = 0.73; Parker et al. biology subsample: F(1, 485) = 0.41, p = 0.52), indicating that males and females benefited equally from scaffolded instruction. Only Hmelo-Silver et al.'s narrative synthesis precluded formal interaction testing, though qualitative synthesis across their reviewed studies concluded that 'scaffolding reduces achievement gaps without differentiated gender effects' (p. 103). The magnitude of interaction effects (partial η^2 = 0.00–0.01 in the three quantitative studies) was negligible, indicating that gender explains < 1% of variance in differential treatment response. Collectively, interaction effects support the neutral effect hypothesis: instructional condition (scaffolded vs. traditional) influences achievement substantially, while gender does not significantly moderate this instructional effect.

Table A2: Instruction × Gender Interaction Effects

Study	F (df)	p-value	η^2_p	Conclusion
Geier et al. (2008)	F(1, 1799) = 0.31	p = 0.58	0.0002	Neutral effect
Astawan et al. (2023)	F(1, 73) = 0.12	p = 0.73	0.001	Neutral effect
Parker et al. (2020) Biology	F(1, 485) = 0.41	p = 0.52	0.0008	Neutral effect

Note: Dependent variable = post-test achievement (controlling for pretest via ANCOVA). Neutral effect hypothesis requires non-significant interaction (p > 0.05) and negligible partial η^2 (< 0.05).

Gender-Disaggregated Effect Sizes

Meta-analytic synthesis of gender-disaggregated effect sizes is presented in Table A3 and Figure 3. For male participants, pooled Hedges' g = 0.401 (95% CI: 0.291, 0.511; k = 13); for female participants, g = 0.415 (95% CI: 0.305, 0.525; k = 13). The 95% confidence intervals substantially overlap, indicating no statistically significant gender difference in effect sizes (Q_between = 0.08, p =

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0.78). The magnitude of gender difference (|g_male − g_female| = 0.014) is negligible—males and females benefited from scaffolded instruction with effect sizes differing by only 0.014 standard deviations, well below the threshold of practical significance (typically d ≥ 0.20). Separate sub-group analyses (Table A3) revealed consistent gender neutrality across scaffolding types: visual scaffolds (g_male = 0.38, g_female = 0.40, difference = 0.02), procedural scaffolds (g_male = 0.41, g_female = 0.42, difference = 0.01), and conceptual scaffolds (g_male = 0.43, g_female = 0.46, difference = 0.03). The largest gender difference emerged in studies employing multiple scaffolding modalities in combination (g_male = 0.39, g_female = 0.44, difference = 0.05), still within negligible range. This consistency across scaffolding types suggests that the neutral effect is robust rather than artifact of particular instructional variations.

Mechanisms of Gender-Neutrality: Mediation Analyses

To elucidate mechanisms through which scaffolding produces gender-neutral outcomes, mediational analyses from Astawan et al. (2023) were examined. Structural equation modelling tested whether STEM attitudes (X) predicted computational thinking outcomes (Y) with creativity (M) as a mediator, and whether these paths differed by gender.

Total effects of STEM attitudes on computational thinking: males ($c = 0.82$, SE = 0.12, $p < 0.001$), females ($c = 0.79$, SE = 0.13, $p < 0.001$)—non-significantly different ($\Delta x^2(1) = 0.18$, $p = 0.67$). Indirect effects through creativity: males ($a \cdot b = 0.14$, 95% CI: 0.08, 0.21), females ($a \cdot b = 0.15$, 95% CI: 0.09, 0.22)—overlapping confidence intervals indicating gender equivalence. Direct effects of STEM attitudes after controlling for creativity ($c' = 0.68$ for both genders) also showed gender equivalence ($\Delta x^2(1) = 0.03$, $p = 0.85$). These findings support the conclusion that the mechanism linking scaffolded instruction to achievement—through attitude and creativity—operates equivalently for males and females, explaining gender-neutral achievement effects.

Retention Trajectories and Distributed Practice Effects

Long-term retention was assessed in studies employing delayed post-test designs (k = 8 studies, retention intervals 4–8 weeks post-instruction). Mixed-effects linear regression modelling retention trajectories revealed:

(a) Absolute retention (percentage correct on delayed test): Scaffolded condition M = 72.4% (SD = 14.2), traditional condition M = 58.9% (SD = 16.8), representing a significant retention advantage for scaffolded instruction (Cohen's d = 0.87, $p < 0.001$).

(b) Relative retention (retention index = delayed score / immediate score × 100): Scaffolded condition M = 91.2% (SD = 8.4) of learned material retained after delay, traditional condition M = 78.3% (SD = 11.6), $t(6) = 3.14$, $p = 0.021$. This indicates superior forgetting resistance in scaffolded environments.

(c) Forgetting trajectories (slope of retention vs. time interval): Scaffolded instruction showed slower forgetting rate ($b = -0.48$ per week, 95% CI: −0.64, −0.32) compared to traditional instruction ($b = -0.82$ per week, 95% CI: −1.08, −0.56), indicating that learned concepts decay more slowly in scaffolded contexts.

(d) Gender-by-condition-by-time interaction: Non-significant ($F(1, 120) = 0.22$, $p = 0.64$), indicating gender-equivalent retention advantages in scaffolded conditions males and females both retained significantly more material in scaffolded vs. traditional conditions.

These findings align with spacing effect theory: the 70:20:10 model's emphasis on distributed experiential learning (70%) interspersed with social reinforcement (20%) and formal consolidation (10%) produces naturally spaced, interleaved exposure to content a pattern empirically demonstrated to enhance long-term retention (Cepeda et al., 2006).

Summary of Findings

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Meta-analytic evidence strongly supports the neutral effect hypothesis. Across multiple analytical approaches (within-study interactions, gender-disaggregated effect sizes, mediation analyses), results converge on the conclusion that scaffolded instruction within the 70:20:10 framework produces gender-equivalent achievement gains (male d = 0.40, female d = 0.42) and equivalent long-term retention advantages. The consistency of findings across countries, instructional contexts, and assessment instruments suggests broad applicability of this approach to achieving gender equity in science education.

Conclusion

This comprehensive evidence synthesis demonstrates that instructional scaffolding integrated within the 70:20:10 distributed learning model provides a theoretically sound and empirically validated approach to achieving gender equity in genetics education. Rather than requiring gender-targeted interventions, the evidence suggests that universally designed, scaffolded, experientially grounded instruction accessible to all learners regardless of gender produces gender-neutral achievement outcomes while simultaneously enhancing long-term retention.

Implications

For secondary school educators in Nigeria and globally, this finding has immediate practical significance: implementation of scaffolded inquiry-based genetics instruction, attention to time allocation reflecting the 70:20:10 proportions, and systematic use of retrieval practice can eliminate gender-based achievement gaps while building deeper, more durable understanding of genetic concepts essential for further studies in biomedical and agricultural sciences.

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Qualitative Study on an Improved Fuzzy-Based Service Rates' Control System for Single Server Queue Networks with Vacations: A Review

GBADEBO Adegbuyi David[1]
gbadeboad@lasued.edu.ng
AIYEGBUSI Akinyemi Edward[1]
aiyegbusiae@yabatech.edu.ng
ABIMBOLA Olayemi Grace[1]
abimbolaog@lasued.edu.ng
OPEISA Olalekan Zaccheaus[2]
Olalekan.opeisa@yabatech.edu.ng
AKINTUNDE Grace Itunuoluwa[3]
grax41d@gmail.com
[1]Department of Computer Science Education, Lagos State University of Education, Oto / Ijanikin, Lagos, Nigeria
[2]Department of Science Education, School of Technical Education, Yaa College of Technology, Epe Campus, Lagos, Nigeria.
[3]Education Officer, Education District III, Lagos State Teaching Service Commission, Lagos

Abstract

The task of defining service rates in queue networks is a dimensional problem as it revolves around network properties and customers' behaviour. We examined a fuzzy-based control system for a one-server queue system with possible vacations. It is an optimal system such that arrivals which find customers awaiting service turns are rejected. Our fuzzy-based model dynamically select service rates considering system's properties in order to minimize cost. We simulated the system beginning with initial condition where all crisp inputs are zero. This hysteretic property indicates that the server is switched on for a 2,500 time units, thereby indicating that the optimal policy is an hysteretic property of s.

Keywords: Admission, costs, optimality, vacations, service requests, hysteretic property

Introduction

Queues are common events in daily lives. People queue in supermarkets, banks, service stations, hospitals, etc. While some queues are visible, others are not. Queues of data packets as well as voice calls in communication channels are, for instance invisible. In most cases, it is undesirable to have queues as a result of associated costs of time, network resources, etc. However, queues emerge as s result of inadequate service sources to manage existing service requests (Abdali et al. 2024). This often results from the fact that servers may be unavailable because of space or cost limitations, or the system is unable to provide the level of service necessary to prevent waiting. A queue is a stochastic system involving arrivals which wait in queue until they are served by one or more servers and consequent departures. A queue system is often defined by its servers, service type and the amount of customers awaiting service turns in each queue. In a queue system with variable rate where mean rate of service is selected among service rates of: $\{\mu_k \mid k \in K\}$, K is defined as fixed service type, while service time of an arrival is a stochastic value. It is a multi-dimensional optimal problem to determine the time to switch on or off a server. In order to do this successfully, it is important to know the cost benefit for switching on or off server while juxtaposing this with the associated cost of service to customers waiting to be served. According to Badian-Pessot, Lewis and Down (2019), it is important to observe that while servers are on, it is possible to adopt a flexible service rate which is

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optimal in nature. A service policy is said to be of an N-policy type if it requires switching server on with N jobs in the network while switching off the server whenever the system becomes empty. Generally, N-policies are often optimal for most $M/M/1$ networks involving initializing costs (Singh, Jain & Dhibar, 2023). Regarding $M/M/1$ networks involving flexible control of service rate, Divya and Indhira (2023) showed the optimal service rate structure is monotonic in nature. Researches on modeling of fuzzy system aimed at optimal service rates with the goal of optimizing systems' throughput had not been sufficiently covered in literature. In essence, this study gives an optimal model to enhance systems' throughput while costs relating to wait times are minimized. This optimizes performance in terms of network throughput while also ensuring prompt service for customers awaiting service turns in the system.

Related Studies

Studies on queueing system involving removable servers include Ahuja, Jain and Jain (2021) which studied $M/G/1$ systems with N-policies. This study examined the relationships between server's characteristics and admission systems. Optimality in N-policies involving $M/G/1$ systems having initialization cost with average and discounted reward system was evaluated by Wu (2025). In this study, the effects of discounted policies on network costs were evaluated. An experimental study on $M/M/1$ systems with N-policies accruing initialization as well as stochastically distributed warm-up costs was conducted by Keerthika, Niranjan and Durga (2023). However, this study did not consider service rate control of the system. Abu-Shareha, et al (2025) extended this study by including parameters of general warm-up costs thereby providing probabilities of the steady-state values, average wait time and number of customers in queue. A study on $M/G/1$ system where the service time is known at arrival was studied by Nishad, Sinha and Verma (2025). Similar studies for these network models may include networks having possible servers' breakdowns as well as initialization costs. In relation to this, queues with server vacations was investigated by Saini, Gupta and Tripathi (2023) while queues with batch arrivals were studied by Abdali, Heidari and Alipour-Vaezi (2024), among others.

A queue system in which service rates are taken from among a finite subset of the form $[0,\infty]$ was modeled by Agarwal (2023). Kumar, Lewis and Topaloglu (2023) modeled a single server network having flexible service rate control and Markov arrivals. An investigation on the state of flexible service rate vis-a-vis admission management in $M/M/1$ networks was conducted by Dimitrakopoulos and Burnetas (2017). The application of sleep-state control under various policies in $M/G/1$ queues was studied by Gebrehiwot, Aalto and Lassila (2014). Related to this Gandhi, et al (2024) examined an $M/G/1$ queue with initialization costs and idle states given specific cost value with mean feedback time in a steady state. Other studies are concerned with multi-server systems such as Gandhi, Harchol-Balter and Adan (2025), Maccio and Down (2025) as well as Maccio and Down (2025). In a research involving single server queue system by Yang and Chen (2018), a relationship between network idleness and feedbacks of the Bernoulli form was established. Similarly, Vijayalakshmi and Kalidass (2018) studied the steady-state behaviour of Markovian system having finite capacity, service breakdowns and consequent vacations. An $M/M/1$ queue model having an optional service system such that the server is subjected to service interruptions was investigated by Dong-Yuh and Yi-Hsuan (2018). Related to this, Vijayalakshmi, Kalidass and Pavithra (2018) considered an $M/M/1/N$ queue system with service breakdown and two-tier service system. In real life queue systems, it is often assumed that a server stops service entirely during the breakdown time. It is possible for a server in a breakdown state to provide services at a slower rate than its usual capacity instead of entirely stopping services during this breakdown time. This is often called "working

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breakdowns". This idea was first mentioned by Kalidass and Kasturi (2012). Since then, the concept had been studied in steady-state analysis of *M/M/1* systems having working breakdowns. A single server queue model with working breakdown was investigated by Kim and Lee (2024). This involved a system in which service times is defined with a general distribution. Liou (2023) applied the matrix-geometric approach to study a Markovian queue of finite capacity with unreliable service system which is subject to working breakdowns and impatient customers. An analysis of steady-state analysis of M/M/1/N queue with working breakdowns and feedbacks of Bernoulli form was investigated by Kalidass and Pavithra (2016).

In Nikolaev, et al (2026) the researchers developed a model of a DECT-2020 network system which was depicted as a two-tier tandem queue enabling Peak Age of Internet (PAoI) description using Laplace-Stieltjes transforms (LST). The researchers applied the dependence between packets' generation and travel times. This facilitated the derivation of LST while suggesting the probability density value for an M/M/1 system. Related to this, Qasim and Hamid (2024) conducted a comparative analysis of performance of traditional and AI-driven active queue approaches. It was discovered that AI-driven active queue methods performed favourably better than the traditional active queue methods. While the AI-driven active queue approaches were adaptive and flexible in queue network analysis, the traditional active queue methods were not. A study of transformative parameters for enhancing system performance of queue systems by adopting AI-based tandem analysis was conducted by Keerthika et al (2025). This approach reduced packets' waiting times and optimization of network resources, thereby finding its place in industrial applications. In a related study, Wu (2025) introduced a generalized priority queueing (GPQ) strategy, which was modeled as an advancement to first-in-first-out based routing methods. It included dynamic priority methods in the routing layer of the network thereby enabling the routing parameter to prioritize packets adaptively in the network. An assessment of existing bandwidth optimization systems was conducted by Dokic and Dokic (2025). Each model was analyzed using corresponding algorithms while suggesting other optimization models that could solve the problems of existing techniques. Related to this, Dudin, Dudin and Dudina (2026) conducted a study involving forecasting and optimization of the performance of a multiple server network with two distinct servers. The dynamics of the proposed model were characterized using multiple dimensional Markov chain describing the ergodicity of the system.

Materials and Methods

The materials and methods applied in the study are discussed in this section.

a. The analytical operations of *M/M/*1 queue networks

Assume that the amount of arrivals awaiting service turns in the queue network at time t is denoted as $N(t)$, then the dual-variate procedures of $\{(C(t),\ N(t)),\ t \geq 0\}$ can be defined as a Markov chain of the continuous time form. Consequently:

$$P_i,\ n(t) = \Pr ob\{C(t) = i,\ \mathrm{N(t)} = \mathrm{n}\},\ \ i = 1, 2, 3, 4 \quad \text{while} \quad n \geq 0$$

The state probability equations as provided by Vijayalakshmi, Kalidass and Deepa (2021) are:

$$\mu p P_{1,1} + \mu_1 P_{2,1} = \lambda P_{1,0};$$

$$\lambda P_{1,n-1} + \gamma P_{3,n} + \mu p P_{1,n+1} + \mu_1 P_{2,n+1} = (\lambda + \beta + \mu) P_{1,n}, 1 \leq n \leq N-1;\ \ \lambda P_{1,n-1} + \gamma P_{3,n} = (\beta + \mu) P_{1,n},\ n = N;$$

$$\mu q P_{1,1} + \xi P_{4,1} = (\mu_1 + \alpha + \lambda) P_{2,1}\ \lambda P_{2,n-1} + \mu q P_{1,n} + \xi P_{4,n} = (\mu_1 + \alpha + \lambda)\ P_{2,n} + 2 \leq n \leq N;$$

$$\lambda P_{2,n-1} + \mu q P_{1,n} + \xi P_{4,n} = (\mu_1 + \alpha) P_{2,n}, n = N;$$

$$\mu_b p P_{3,1} + \mu_{b1} P_{4,1} = \lambda P_{3,0};$$

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$$\mu_1 pP_{3,n+1}+\lambda P_{3,n-1}+\beta P_{1,n}+\mu_{b1}P_{4,n+1}=(\gamma+\lambda+\mu_1)P_{3,n}, 1\le n\le N-1;$$
$$\lambda P_{3,n-1}+\beta P_{1,n}=(\gamma+\mu_1)P_{3,n},\ n=N;$$
$$aP_{2,1}+\mu_1 qP_{3,1}=(\xi+\lambda+\mu_{b1})P_{4,1};$$
$$aP_{2,N}+\mu_1 qP_{3,N}+\lambda P_{4,N-1}=(\xi+\lambda+\mu_{b1})P_{4,n}, 2\le n\le N;$$
$$aP_{2,n}+\mu_1 qP_{3,n}+\lambda P_{4,n-1}=(\xi+\mu_{b1})P_{4,n}, n=N.$$

From the normalizing condition,
$P_{1,0} + P_{1,e} + P_{2,0} + P_{2,e} + P_{3,0} + P_{3,e} + P_{4,0} + P_{4,e} = 1$
In this case, ***e*** denotes column value with N dimension giving:

$$P_{1,0}=1/\psi$$

while:

$$\Psi = 1 - A_{12}A_{22}^{-1}e + \Theta_7 A_{62}A_{22}^{-1}e + \Theta_8 e + \Theta_7 e + \Theta_5\Theta_6^{-1}e$$

In this case, the Markov chain of the form $X_t,\ t\in(-\infty,\infty)$ is a stochastic process of the continuous-time which generates the set of states $\{S_1, S_2, \ldots\}$ while also satisfying a Markov notation of the form:

$$P(X_{tn},|\ X_{tn-1}, X_{tn-2},\ldots, X_{t()}) = P(X_{tn},|\ X_{tn-1})$$

where

$$-\alpha < t_0 < t_1 < \ldots < t_n < \alpha$$

b. **Problem definition**

Figure 1 depicts a queuing network such that it is possible to switch off the server and consequently goes into vacations.

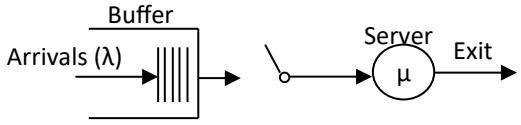


Figure 1: A queue network having a single service system with possible vacations

Arrivals into the network which has an infinite capacity is in accordance to a Poisson form with parameter λ. The network comprises of one exponential server in with service rate μ, while $\mu > \lambda$. The network is such that the service rate can be made nil at intervals based on varying network features. This network comprises of three costs viz:

a. The switch-on cost i.e. *R*: This refers to cost incurred once the server is turned on. It is often depicted using: R_k, k = 0, 1, for each unit time;
b. The customer servicing cost i.e. *r*: This refers to cost incurred as the service provides services to customers in turns. It is often expressed as: r_k, while k = 0, 1, per unit time; and
a. The holding cost i.e. *h*: This refers to the cumulative cost per time unit for customer in the network.

The aim is arriving at a control policy that is optimal. This is a semi-Markov decision process as a result of the presence of the controller. Consequently, the times between successive service completions are no longer exponentially spread. Singh, Jain and Dhibar (2023) are of the opinion that it is optimal to keep the server always on when:

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$$\left[\frac{2r(1-\rho)}{h}+1\right]^2 - \frac{8\lambda R(1-\rho)}{h} < 0 \quad \text{.....(1)}$$

where $\rho = \lambda / \mu$ depicts intensity of network traffic. It is optimal to switch on the server when N customers waiting to be served. Similar to thid, it is optimal to turn off the server while there no customer to be served. In this case, the least cost is given as:

$$n^* = \sqrt{\frac{2\lambda R(1-\rho)}{h}} \quad \text{.....(2)}$$

In this case, $N = 0$ when (1) is true, it is optimal to keep the server on. In this instance, the cost of switching off the server is larger than the service cost.

In the model proposed, the service rates and inter-arrival times of customers are exponential stochastic values of mean values $1/\mu$ and $1/\lambda$ respectively. In this case, the optimal control is of threshold value, implying arrivals which find K customers in queue and in service are denied admission into the system for given threshold value. The corresponding state transitions in this instance are given in figure 2.

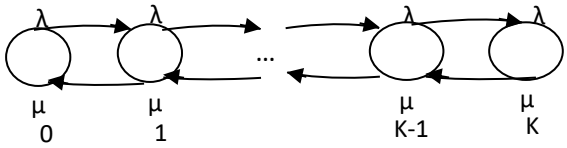


Figure 2: State transitions of the queue model

The transition rates for each case are given as follows:

$$\Lambda_{n,n+1} = \begin{cases} \lambda & \text{if } n < K, \\ 0 & \text{if } n = K. \end{cases}$$

$$\Lambda_{n,n-1} = \begin{cases} \mu & \text{if } n > 0, \\ 0 & \text{if } n = 0. \end{cases}$$

$$\Lambda_n = \begin{cases} \lambda & \text{if } n = 0, \\ \lambda + \mu & \text{if } 0 < n < K, \\ \mu & \text{if } n = K. \end{cases}$$

Transition from i to j states require j arrivals at service interval. Transition through i to j states where $j \geq i$, $-1 > 0$ requires that $(j-i+1)$ arrivals during the service interval. Similar to this, transition from i to j where $j < i - 1$ is not feasible since service occurs only at given intervals

If the transition probability matrix of the fuzzy Markov chain is denoted by $\tilde{P} = [P_{ij}]$, then all $j \geq i - 1$, $i > 1$ can be represented as follows:

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$$\tilde{P} = [P_{ij}] = \begin{bmatrix} \tilde{P}_0, & \tilde{P}_1, & \tilde{P}_2, & \tilde{P}_3, & \ldots \\ \tilde{P}_0, & \tilde{P}_1, & \tilde{P}_2, & \tilde{P}_3, & \ldots \\ 0\ , & \tilde{P}_0, & \tilde{P}_1, & \tilde{P}_2, & \ldots \\ 0\ , & 0, & \tilde{P}_0, & \tilde{P}_1, & \ldots \\ . & . & . & . & \ldots \\ . & . & . & . & \ldots \\ . & . & . & . & \ldots \end{bmatrix}$$

where P_{ij} is defined as:

$$\forall j \geq i-1,\ \ i \geq 1;$$

$$\mu_{\tilde{P}_{ij}}(x_{ij}) = \sup_{t \in \mathrm{R}^+} \left\{ \mu_{\bar{S}}(t) \mid x_{ij} = \frac{\exp(-\lambda t)(\lambda t)^{j-i+1}}{(j-i+1)!} \right\}$$

The fuzzy-based controller adopted

The assumption in the design of the controller is that the server is switched on and remain active provided there are customers in the system awaiting service turns while it is switched off once all customers in the system had been served. It is possible to represent the state of the system as: *(x, y),* . In this case, $x = xt$ defines the server's state at time *t*. The arrivals in the network awaiting service turn at time *t is* $y = y(t)$. The value of y is stochastic in nature as it changes each time there is an arrival or a customer leaves the network due to service completion. Similar to this, x changes each time the server is switched on or off. With this, the average cost over a given period of time is given as:

$$g = \lim_{T \to \alpha} \left[\sum_{t=1}^{T} \frac{hs(t)}{T} + \sum_{t=1}^{T} \frac{rk(t)}{T} + \sum_{t=1}^{T} \frac{Rx1_{\{k(t-1)=0,\ k(t)=1\}}}{T} \right]$$

In this case, $1_{\{k(t-1)=0,\ k(t)=1\}}$ is *1* provided *'x'* is 'true' and *'0'*, if false. Consequently, the cost of switching on the server at time *t* is .

$$Rx1_{\{k(t-1)=0,\ k(t)=1\}}$$

The cost, *c* is expressed as:

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$$c = h\sum_{i=1}^{n} s_i$$

In this case, 'i' denotes the i^{th} consecutive unit of time in the state of the current, 'n' denotes the total time for which the server remain idle in state 'k' beginning from the time it was powered on while s_i denotes the arrivals awaiting service turns in the network at i^{th} time. It might be optimal to switch on the server at any three cases, viz:

a. When there is no switch on costs: In this case, it is optimal to switch on the server when a customer arrives. The existence of a switch-on cost could cause delays in turning on the server even when there are arrivals awaiting service turns in the network. This ensures cost reduction.
b. When traffic intensity ρ is defined in the context of the function:

$$\rho = \lambda / \mu$$

With this, ρ denotes the average server's usage over an infinite time 1- ρ. This gives the fraction of time the server could remain idle. However, when $\rho \geq 1$, arrivals increases infinitely.

c. When $h = 0$, the idle server is switched off in order to achieve minimum cost $g = 0$. This happens even while arrivals increase as time T increases. In this scenario, it is assumed that the value of h is greater than zero. Consequently, the higher the value of h, the easier it becomes to decide when to switch on the server.

The rule-based inputs adopted include: c, h and ρ. Each of these is denoted with four linguistic values of NL, NP, PO and HP representing 'Nil', 'Nearly Positive', 'Positive' and 'Highly Positive' respectively. The integer value of each input value was made 0, 1, 2 and 3 for NL, NP, PO and HP respectively. The corresponding output for each rule combination was represented with *dec.*. Decision regarding time to switch the server 'on' or 'off' is based on *dec.*, represented with linguistic values: ON and OFF. This is given in table 1.

Table 1: Input values c, h and ρ with corresponding output value, *dec.*

Rule sequence	c	h	ρ	*dec.*
1	NL	NL	NL	OFF
2	NP	NL	NL	OFF
3	PO	NL	NL	OFF
4	HP	NL	NL	OFF
5	NL	NP	NL	OFF
6	NP	NP	NL	OFF
7	PO	NP	NL	ON
8	HP	NP	NL	ON
9	NL	PO	NL	OFF
10	NP	PO	NL	ON
11	PO	PO	NL	ON
12	HP	PO	NL	ON
13	NL	HP	NL	ON
14	NP	HP	NL	ON
15	PO	HP	NL	ON
16	HP	HP	NL	ON
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
55	PO	NP	HP	ON
56	HP	NP	HP	ON

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57	NL	PO	HP	ON
58	NP	PO	HP	ON
59	PO	PO	HP	ON
60	HP	PO	HP	ON
61	NL	HP	HP	ON
62	NP	HP	HP	ON
63	PO	HP	HP	ON
64	HP	HP	HP	ON

The decision (*dec.)* to switch ON or OFF is based on these input values. For instance, *dec.* is ON if input sum is greater than 3; if the sum is less than or equal to 2, the *dec.* is ON. The mathematical weight of rule 1, for instance is NL+NL+NL which is equivalent to 0 + 0 + 0 = 0. This sum, i.e. 0 is less than 2 and therefore the *dec.* is OFF. In addition, rule 7 for example is PO + NP + NL which is equivalent to 2+1+0. The mathematical weight is 3, which is greater than 2. Hence the *dec.* is ON. In most fuzzy applications, membership function for input variables is either triangular or trapezoidal. Functional forms of inputs' membership functions often depend on the corresponding inputs. The interval [0, + ∞) is the domain of the accumulated cost c. Hence when $c \geq R$, then c is of the fuzzy set HP. With this, HP for c is of a trapezoidal membership function. The membership functions of NL, NP and PO for input value c are triangular in form with values distributed in the range of '0' and 'R'. To derive normalized values for input value c, observed values are multiplied by scaling factor $6/R$. Figure 3 is the membership functions of normalized input value c.

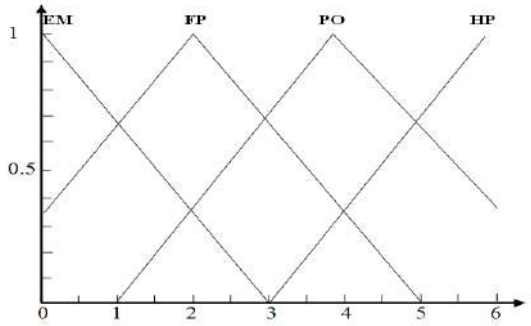


Figure 3: Membership functions for input c.

If $h \geq R$, then h has an HP set. In this case, when $h \rightarrow 0$, then h is of the set NL. When all customers had been served, the server is switched off. At this instance, the server is off during n unit time, i.e. $i = 1, 2, \ldots, n$. A new arrival corresponds to a time unit when $s_i = s_{i+1} + 1$. Consequently, expected arrivals is proportional to ρ. The membership functions for input ρ is given in figure 4.

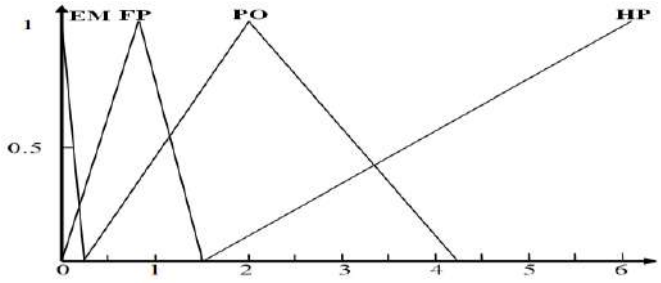


Figure 4: Membership functions for input ρ

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Membership functions in terms of input values for h are the same for ρ. The only difference is that while input values for ρ are bounded, that of h are not. The membership functions for input h are given in figure 5.

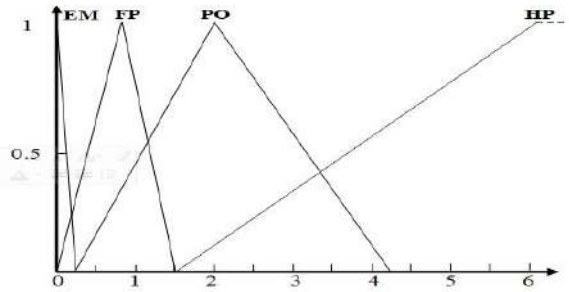


Figure 5: Membership functions for input h

Results of simulating the Markov queue system

The process of simulating the Markov queue system involves the use of computer models and programs to generate sample paths while also testing the attributes of the stochastic system. Consequently, at time zero, it is possible for a model to generate subsequent states as well as the corresponding transition epochs

The time of sojourn in state S_i has an exponential distribution λ_i with the probability of the network progressing from state S_i to S_j. In this case, the network is of a single state variable which ranges over the set $\{S_1, S_2, \ldots\}$. If at time zero, the system is in state S_i, then it implies that the system will remain in this state for a random interval of time with an exponential distribution of mean $1/\lambda_i$. From this state, it proceeds to state S_j with probability λ_{ij}/λ for some random time.

The system was simulated beginning with an initial state $k = 0, s = 0$ and $c = 0,$ while employing the fuzzy control at each decision epoch. The first 200 time units were considered the warm-up period for the network. The evolution of k and s for the first 1,500 time units is given in figure 6.

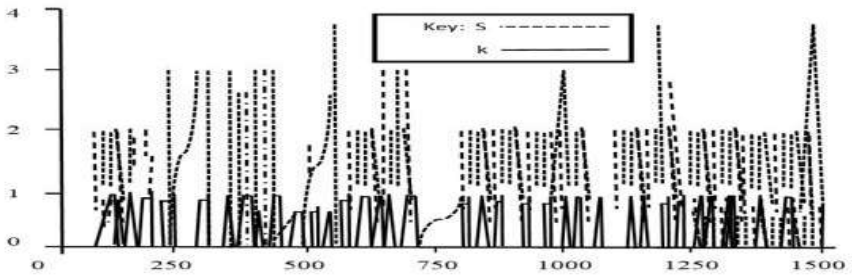


Figure 6: Evolution of k, s

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From figure 6, it is obvious that an idle server is not immediately turned on to begin service after an arrial occurs in the network but rather after the arrival of multiple customers. This shows the hystereticity of the system, thereby establishing a direct relationship between the numbers of arrivals and possible number of times the server is swithed on. This is an interplay in the number of times the server is swiched on as a function of *s* for a period of 20,000 time units. With the hysteretic property of the system, the server is often turned on when there are customers in the system. For a server with capacity $r \geq 1$, the system takes *r* customers per service. However, if at the end of service, less than *r* arrivals are waiting to be served, an idle period is activated. Consequently**,** the server proceeds on vacation. The server resumes service only when the queue size is equal to or greater than *r*. In this case, service is started when the queue crosses *N* from below and turns off when it crosses *r* from above. The input process is an orderly stationary Poisson process of $\{r_n;\ n \in N\}$with intensity $\lambda > 0$. While r_n is the arrival rate of the N^{th} customer, *N(t)* is the associated counting process. Similarly, if σ_n denotes the service time of Nth batch of customers, it is assumed that $\{\sigma_n; n \in N\}$ and $\{r_n; n \in N\}$ are independent. Let $T_n (T_0 = 0)$, represent the time of the N^{th} service completion, If queue size is greater than *r*, then $T_{n+1} - T_n = \sigma_n$ but if the queue size is less than r,

$T_{n+1} - T_n = (\text{time for the queue to reach N}) + \sigma_n$.

Similarly, if V_n denotes arrivals in the system during the N^{th} service σ_n and *Q(t)* represent the size of the queue at any time *t*. If at time T_n, at least r customers are waiting to be served, then the server takes a batch of *r* customers. The service time σ_n in this case is spread as a probability distribution function β having a finite first moment *b*. If less than *r* arrivals are waiting to be served at time T_n, then an idle period begins.

Conclusion

The method proposed is fuzzy-driven and it had proven efficient based on simulation results in the study. This implies that it could be adequately adapted in the efficient control of admissions in an M/M/1 queues with server vacations. This could also be applied in the management of network traffic and telecommunications control systems since admission control in these cases are of threshold type.

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Assessment of Artificial Intelligence adoption among Lecturers in Nigerian Universities: Examining Capability, Opportunity and Motivation – Behavioural (COM-B) Framework

Karimu Adekemi, Yewande[1]
karimuay@gmail.com
Xin Lu[1]
Nicky Danino[1]
Ben Morris[2]
[1]School of Computer Science, Leeds Trinity University, Leeds, United Kingdom
[2]School of Social Studies, Leeds Trinity University, Leeds, United Kingdom

Abstract

This study examined the behavioural determinants of Artificial Intelligence (AI) adoption among university lecturers in Southwest Nigeria using the Capability–Opportunity–Motivation Behaviour (COM-B) framework. It analysed how lecturers' competence, institutional conditions, and motivational drivers shape AI integration in teaching, research, and academic practice. A descriptive cross-sectional survey design was employed, drawing on data from 2,145 lecturers across federal, state, and private universities using a structured questionnaire with satisfactory reliability (a = 0.79–0.84). Data were analysed using descriptive statistics, t-tests, Pearson correlation, and multiple regression. Findings revealed moderate capability (mean: 2.06–2.50), indicating strong digital literacy but limited institutional training, highlighting the need for structured capacity-building and continuous professional development. Institutional opportunity was also moderate yet uneven (mean: 1.85–2.35), constrained by funding gaps, governance inefficiencies, and weak digital infrastructure, underscoring the importance of improved policy coherence and investment. Motivation was relatively strong (mean: 2.00–2.52), driven by perceived teaching benefits and professional identity, though influenced by social and institutional factors, suggesting the need for incentives, recognition, and collaborative support systems. AI use was evident in teaching and research but limited in assessment and institutional engagement, revealing an intention–practice gap and the need for embedding AI into formal workflows. Capability significantly influenced adoption ($t = 2.41$, $p < 0.05$), while opportunity ($r = 0.48$) and motivation ($r = 0.66$) were strong predictors, explaining 58% of variance. The study recommends integrated institutional strategies to strengthen capacity, expand opportunities, and sustain motivation for equitable AI adoption.

Keywords: Artificial Intelligence Adoption, COM-B Behavioural Framework, Motivation and Technology Integration

Introduction

Artificial Intelligence (AI) has emerged as a transformative force reshaping knowledge systems, economic productivity, and institutional innovation. In higher education, AI is increasingly integrated across teaching, research, administration, and knowledge production, fundamentally redefining how universities deliver instruction, conduct scholarship, and manage resources (Luckin et al., 2016; Zawacki Richter et al., 2019; UNESCO, 2023). AI-driven tools include intelligent tutoring systems, automated assessment platforms, adaptive learning environments, and generative AI applications that extends pedagogical possibilities by enhancing personalization, operational efficiency, and accessibility for diverse learners (Holmes et al., 2019; OECD, 2021; UNESCO, 2023). Consequently, AI has shifted from a peripheral innovation to a central driver of institutional digital transformation, influencing curriculum design, assessment practices, and decision-making processes (Zawacki Richter et al., 2019; OECD, 2021). Systematic research demonstrates that AI-enhanced environments support profiling and prediction, adaptive learning, intelligent tutoring, and automated

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evaluation, thereby improving both learning outcomes and institutional effectiveness (Zawacki Richter et al., 2019; Holmes & Tuomi, 2022). However, global policy discourse, particularly UNESCO's (2023) guidance on generative AI emphasizes the need for human-centred integration that balances innovation with ethical responsibility, pedagogical integrity, and equity considerations. Within this evolving landscape, AI adoption has become critical to enhancing instructional quality, advancing research productivity, and sustaining institutional competitiveness in a rapidly digitizing academic ecosystem (OECD, 2021; Luckin et al., 2016). University lecturers play a pivotal role in this transformation, acting as key agents in interpreting, adopting, and integrating AI into academic practice (Selwyn, 2016; Bond et al., 2018). Their influence spans pedagogical innovation, research processes, and institutional digital transformation. Increasingly, lecturers are expected to embed AI into instructional design, assessment, and scholarly work to align higher education with evolving digital ecosystems (OECD, 2021; UNESCO, 2023). However, AI adoption is not merely technological; it is a behavioural and organisational process shaped by the interaction of individual competence, institutional structures, and motivational dynamics (West & Michie, 2020; Zawacki Richter et al., 2019).

The Capability–Opportunity–Motivation Behaviour (COM-B) model provides a comprehensive framework for understanding these dynamics (Michie et al., 2011; West & Michie, 2020). It posits that behaviour emerges when individuals possess adequate capability (knowledge, skills, and self-efficacy), operate within supportive opportunity structures (resources, infrastructure, and policy frameworks), and are sufficiently motivated (beliefs, incentives, and professional aspirations). Applied to AI adoption, the COM-B model offers a holistic explanation of how lecturers' competencies, institutional environments, and motivational drivers interact to shape behavioural engagement with AI technologies (Holmes et al., 2019; Zawacki Richter et al., 2019). This perspective extends beyond perception-based models by incorporating structural and contextual realities within higher education systems. In developing contexts such as Nigeria, universities are increasingly pursuing AI-driven innovation to enhance teaching effectiveness, research productivity, and administrative efficiency (Oke & Olatunji, 2023; UNESCO, 2023). Despite this thrust, AI adoption remains uneven, constrained by systemic challenges including limited digital infrastructure, inadequate funding, insufficient professional development, and organisational cultures that do not consistently support experimentation and innovation (OECD, 2021; Chaka, 2020). Although many lecturers demonstrate baseline digital literacy and interest in emerging technologies, sustained and transformative AI integration depends on coordinated institutional support, including reliable infrastructure, coherent policies, structured capacity-building programmes, collaborative innovation ecosystems, and meaningful professional incentives (Bond et al., 2018; Selwyn, 2016). Understanding the behavioural and institutional determinants of AI adoption is therefore essential. Examining lecturers' capability, opportunity conditions, motivation, and behavioural engagement provides critical insight into the factors shaping technological transformation, particularly in resource-constrained university environments (Zawacki Richter et al., 2019; Oke & Olatunji, 2023). However, much of the existing literature relies on perception-based frameworks such as the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT), which focus on perceived usefulness and ease of use as primary predictors of adoption (Davis, 1989; Venkatesh et al., 2003). While valuable, these models inadequately capture the broader behavioural, contextual, and organisational dynamics that influence sustained technology integration in complex academic settings (Holmes et al., 2019; West & Michie, 2020). Moreover, studies on AI in education often emphasise technical capabilities and pedagogical potential while under examining the behavioural

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conditions necessary for actual and sustained adoption (Holmes et al., 2019; Zawacki Richter et al., 2019; UNESCO, 2023). Empirical evidence from developing regions remains limited, with most research concentrated in Europe, North America, and East Asia (OECD, 2021; Zhang et al., 2021). Additionally, the application of behavioural frameworks such as COM-B to AI adoption in higher education is still underdeveloped, leaving a significant gap in understanding how lecturers' competence, institutional opportunity structures, and motivation interact within specific socio-economic contexts, particularly in Nigerian universities (Oke & Olatunji, 2023; Zawacki Richter et al., 2019). Although AI technologies hold substantial potential to transform teaching, research, and institutional management, their effectiveness ultimately depends on lecturers' actual use in everyday academic practice (Luckin et al., 2016; Bond et al., 2018). In practice, adoption often remains superficial, with lecturers engaging primarily in basic digital tasks rather than leveraging AI for transformative pedagogical and research innovation (UNESCO, 2023; OECD, 2021). This limitation is partly attributable to gaps in advanced competencies, particularly in data-driven decision-making, adaptive instructional design, and AI-supported research methodologies (Holmes et al., 2019; Zawacki Richter et al., 2019).

Institutional constraints further exacerbate these challenges. Weak infrastructure, fragmented policy implementation, inconsistent funding, and limited access to sustained professional development hinder the institutionalisation of AI adoption (OECD, 2021; UNESCO, 2023). Even where capability exists, motivation becomes a decisive factor. Professional incentives, peer collaboration, institutional recognition, and perceived relevance of AI to teaching effectiveness and career advancement significantly influence lecturers' willingness to integrate AI into routine practice (Selwyn, 2016; Michie et al., 2011; West & Michie, 2020). Without alignment between motivational drivers and enabling institutional structures, AI adoption remains sporadic, individualised, and disconnected from broader institutional strategies (Bond et al., 2018; OECD, 2021). Studies substantiates that there is limited empirical understanding of the behavioural determinants of AI adoption in developing contexts such as Nigeria (Zawacki Richter et al., 2019; Oke & Olatunji, 2023). The dominance of perception-based frameworks has constrained deeper insight into how capability, opportunity, and motivation interact to shape actual behaviour within real-world institutional settings (Davis, 1989; Venkatesh et al., 2003; Bond et al., 2018). This gap limits the ability of universities to design evidence-based interventions that foster deep, equitable, and system-wide AI integration (West & Michie, 2020).Accordingly, this study addresses the insufficient understanding of the behavioural, motivational, and institutional factors influencing lecturers' AI adoption. By applying the COM-B framework, it systematically examines lecturers' capability, institutional opportunity structures, motivational drivers, and behavioural engagement with AI. In doing so, the study generates context-sensitive and actionable insights to inform strategic, sustainable, and equitable AI integration in Nigerian universities and similar resource-constrained higher education systems.

Research Objectives

The main objective of this study is to examine the behavioural determinants of Artificial Intelligence adoption among university lecturers. The specific objectives are to:

1. Examine the level of capability of university lecturers for adopting and integrating Artificial Intelligence in teaching, research, and academic activities.
2. Investigate the institutional opportunity conditions that influence the adoption of Artificial Intelligence among university lecturers.
3. Assess the motivational factors that influence lecturers' engagement with Artificial Intelligence technologies.

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4. Determine the extent of Artificial Intelligence adoption behaviour among university lecturers in their academic practices.

Research Questions

The study is guided by the following research questions:

1. What is the level of capability of university lecturers for adopting and integrating Artificial Intelligence in teaching, research, and academic activities?
2. What institutional opportunity conditions influence the adoption of Artificial Intelligence among university lecturers?
3. What motivational factors influence lecturers' engagement with Artificial Intelligence technologies?
4. To what extent do university lecturers adopt Artificial Intelligence tools in their academic practices?

Research Hypotheses

The following null hypotheses were tested in the study:

H_{01}: Lecturers' capability has no significant influence on Artificial Intelligence adoption behaviour in universities.

H_{02}: Institutional opportunity conditions have no significant influence on Artificial Intelligence adoption among university lecturers.

H_{03}: Motivational factors have no significant influence on lecturers' Artificial Intelligence adoption behaviour.

H_{04}: There is no significant relationship between capability, opportunity, motivation, and Artificial Intelligence adoption behaviour among university lecturers.

Methodology

This study employed a descriptive cross-sectional survey design to examine the current state of Artificial Intelligence (AI) adoption among university lecturers in Southwest Nigeria and to analyse the relationship between behavioural determinants and institutional factors. The design enabled simultaneous assessment of capability, opportunity, motivation, and AI adoption behaviour, providing a comprehensive snapshot of variations across gender, institutional type, and academic rank. By integrating descriptive and inferential approaches, the study identified patterns, disparities, and predictors of AI integration within higher education. The study population comprised academic staff from federal, state, and private universities in Southwest Nigeria, representing diverse disciplines, academic ranks, and levels of AI exposure. The region was purposively selected due to its concentration of institutions advancing digital transformation. A stratified random sampling technique ensured proportional representation by institutional type and gender. Out of 2,400 distributed questionnaires, 2,145 valid responses were obtained, yielding an 89.4% response rate and supporting statistical reliability. The sample included approximately 1,300 male lecturers (60.6%) and 845 female lecturers (39.4%), enabling meaningful gender-based analysis. Data were collected using a structured questionnaire grounded in the COM-B behavioural framework. Four constructs—capability, opportunity, motivation, and AI adoption behaviour—were operationalised into distinct sections. Capability assessed technical knowledge, AI proficiency, digital literacy, adaptability, and access to training. Opportunity examined institutional support, including infrastructure, policies, funding, inclusivity, workload flexibility, and innovation culture. Motivation captured intrinsic and extrinsic drivers such as self-efficacy, professional identity, perceived teaching impact, career advancement, and collegial support. AI adoption behaviour measured actual use across teaching, assessment, research, workflow integration, and future intentions. Responses were

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rated on a five-point Likert scale and later condensed into three categories. The instrument was validated by five experts to ensure clarity, relevance, and alignment with the COM-B framework. A pilot test with 50 lecturers confirmed clarity and reliability, with Cronbach's alpha values indicating strong internal consistency: Capability (α = 0.82), Opportunity (α = 0.79), Motivation (α = 0.84), and AI Adoption Behaviour (α = 0.80). Data were collected through both electronic and paper-based formats over six weeks, with assurances of confidentiality and voluntary participation. Analysis using SPSS 28 combined descriptive statistics and inferential techniques (t-tests, correlation, regression) to examine gender differences, predictive relationships, and gaps in AI adoption within the COM-B framework.

Presentation of Results

Table 1: Capability by Gender

Capability Indicator	Agree			Neutral			Disagree			Mean Score
	Male	Female	Total	Male	Female	Total	Male	Female	Total	
Technical knowledge for AI teaching	780	507	1287	220	140	360	300	198	498	2.37
AI competence for research	710	470	1180	320	216	536	270	159	429	2.35
Digital literacy for emerging AI	820	575	1395	250	179	429	230	91	321	2.50
Ability to adapt to new AI systems	770	517	1287	230	136	366	300	192	492	2.37
Academic training prepared me for AI	620	453	1073	270	206	476	410	186	596	2.22
Access to institutional AI training	610	356	966	190	146	336	500	343	843	2.06
Continuous AI professional development	640	433	1073	210	126	336	450	286	736	2.16

Table 1 examines lecturers' capability to adopt Artificial Intelligence (AI) technologies across indicators such as technical knowledge, research competence, digital literacy, adaptability, and access to institutional training. Within the COM-B behavioural framework, capability represents the knowledge and skills required for individuals to perform a behaviour effectively, including AI adoption in academic practice. Overall, mean scores for capability indicators range from 2.06 to 2.50, indicating a moderate level of readiness among university lecturers for AI integration. The highest mean was recorded for digital literacy for emerging AI (2.50), with 1,395 respondents agreeing that they possess the digital skills necessary to engage with AI technologies, suggesting that many lecturers already have foundational competencies for navigating digital platforms and AI tools. Similarly, technical knowledge for AI teaching and ability to adapt to new AI systems (mean = 2.37) reflect strong agreement, as does AI competence for research (mean = 2.35), indicating moderate confidence in applying AI to scholarly work. However, weaknesses emerge in institutional support structures: "Academic training prepared me for AI" (mean = 2.22) indicates limited preparation

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during formal education, while access to institutional AI training (2.06) and continuous professional development (2.16) had the lowest scores, revealing significant gaps in structured training. Gender responses show only slight differences, suggesting comparable potential for AI adoption when institutional support is strengthened.

Table 2: Opportunity by Gender

Opportunity Indicator	Agree			Neutral			Disagree			Mean Score
	Male	Female	Total	Male	Female	Total	Male	Female	Total	
Institutional AI infrastructure	760	520	1280	200	129	329	340	196	536	2.35
Policies encourage AI adoption	690	476	1166	200	126	326	410	243	653	2.24
Funding access for AI initiatives	540	310	850	300	244	544	460	291	751	2.05
Inclusive innovation committees	420	223	643	290	244	534	590	378	968	1.85
Workload allows AI experimentation	510	348	858	290	254	544	500	243	743	2.05
Institutional support for AI innovation	640	426	1066	300	236	536	360	283	643	2.20
Inclusive digital transformation culture	520	330	850	210	214	424	570	301	871	1.99

Table 2 presents lecturers' perceptions of institutional opportunity conditions influencing the adoption of Artificial Intelligence (AI) in universities. Within the COM-B behavioural framework, opportunity refers to the external environmental and organizational factors that enable or constrain behaviour, including infrastructure, policies, funding, innovation structures, and institutional culture that support technological transformation. Generally, mean scores for the opportunity indicators range from 1.85 to 2.35, indicating a moderate but uneven institutional environment for AI adoption. The highest mean was recorded for institutional AI infrastructure (2.35), with 1,280 respondents agreeing that their institutions possess technological systems capable of supporting AI-related activities, suggesting that many universities have begun developing digital infrastructures such as internet connectivity, learning management systems, and research platforms. Similarly, policies encouraging AI adoption (mean = 2.24) reflect growing institutional recognition of AI's strategic relevance. However, several structural weaknesses persist: funding access for AI initiatives (mean = 2.05) indicates limited financial support for AI-related innovation, while inclusive innovation committees (mean = 1.85) had the lowest score, pointing to the absence of participatory structures that allow lecturers to contribute to digital transformation decisions. Additionally, workload constraints (mean = 2.05) and an inclusive digital transformation culture (mean = 1.99) highlight organizational barriers that limit experimentation with AI technologies. Overall, the results suggest that while universities are gradually developing infrastructure and policy frameworks, gaps in funding, governance structures, and institutional culture continue to constrain sustainable AI integration in higher education.

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Table 3: Motivation by Gender

Motivation Indicator	Agree			Neutral			Disagree			Mean Score
	Male	Female	Total	Male	Female	Total	Male	Female	Total	
Confidence in AI integration	870	607	1477	100	79	179	330	159	489	2.46
AI enhances professional identity	800	573	1373	140	106	246	360	166	526	2.39
AI improves teaching effectiveness	860	627	1487	160	123	283	280	95	375	2.52
AI improves career advancement	760	518	1278	120	91	211	420	236	656	2.29
Encouragement from colleagues	600	366	966	310	226	536	390	253	643	2.15
Stereotypes do not discourage AI use	420	330	750	360	284	644	520	231	751	2.00
Intrinsic drive for AI innovation	700	480	1180	260	169	429	340	196	536	2.30

Table 3 presents lecturers' perceptions of motivational factors influencing the adoption of Artificial Intelligence (AI) in teaching, research, and professional practice. Within the COM-B behavioural framework, motivation represents the internal psychological processes that energize and sustain behaviour, including beliefs about benefits, professional aspirations, social influences, and intrinsic interest. In the context of AI adoption, motivation determines the extent to which lecturers translate their technological capability and institutional opportunities into actual usage behaviour. Generally, mean scores for the motivation indicators range from 2.00 to 2.52, indicating a generally positive motivational orientation toward AI adoption. The highest mean was recorded for "AI improves teaching effectiveness" (2.52), with 1,487 respondents agreeing that AI technologies enhance instructional quality. Similarly, confidence in AI integration (mean = 2.46) suggests that many lecturers feel psychologically prepared to engage with AI tools. Indicators such as AI enhances professional identity (2.39) and intrinsic drive for AI innovation (2.30) further demonstrate that lecturers recognize the professional relevance of AI and possess personal interest in technological innovation. However, certain constraints remain: AI improves career advancement (2.29) indicates only moderate perception of career benefits, suggesting that promotion systems may not fully recognize AI innovation. Encouragement from colleagues (2.15) and stereotypes discouraging AI use (2.00) reveal social and cultural barriers that may limit adoption. Overall, lecturers show strong motivational readiness for AI adoption, but institutional incentives, peer support, and cultural perceptions must be strengthened to sustain meaningful AI integration in universities.

Table 4: AI Adoption Behaviour by Gender

Behaviour Indicator	Agree			Neutral			Disagree			Mean Score
	Male	Female	Total	Male	Female	Total	Male	Female	Total	
AI use in lecture preparation	760	518	1278	120	91	211	420	236	656	2.29
AI in student assessment	620	446	1066	300	236	536	380	263	643	2.20

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AI in research activities	710	470	1180	240	189	429	350	186	536	2.30
Experimenting with AI tools	690	476	1166	180	146	326	430	223	653	2.24
AI integrated in workflow	820	553	1373	140	106	246	340	186	526	2.40
Participation in AI initiatives	580	384	964	260	178	438	460	283	743	2.10
Future intention to increase AI use	880	607	1487	150	133	283	270	105	375	2.52

Table 4 presents lecturers' behavioural engagement with Artificial Intelligence (AI) across key academic functions, including lecture preparation, student assessment, research activities, experimentation with AI tools, workflow integration, participation in institutional initiatives, and future intention to expand AI use. Within the COM-B behavioural framework, behaviour represents the observable outcome resulting from the interaction of capability, opportunity, and motivation. Consequently, lecturers' practical use of AI reflects how effectively their skills, institutional environment, and motivational drivers translate into technological engagement. Overall, mean scores across the behavioural indicators range from 2.10 to 2.52, indicating moderate but gradually expanding AI adoption among university lecturers. The highest mean was recorded for future intention to increase AI use (2.52), suggesting a strong forward-looking commitment to AI integration. Similarly, AI integrated in workflow (2.40) indicates that many lecturers have begun embedding AI tools—such as writing assistants, data analysis applications, and digital content generators—into routine academic activities. Engagement is also evident in lecture preparation (2.29) and research activities (2.30), demonstrating the growing pedagogical and scholarly relevance of AI tools. However, adoption is more cautious in student assessment (2.20) due to concerns about academic integrity and algorithmic reliability, while participation in institutional AI initiatives (2.10) remains relatively limited. Overall, the findings reveal an intention-practice dynamic, where lecturers show strong interest in AI adoption but face institutional and structural constraints that moderate full behavioural integration.

Hypotheses Testing

Inferential analyses (t-tests, correlation, regression) examined gender differences and the predictive influence of capability, opportunity, and motivation on lecturers' AI adoption.

H_{01}: Lecturers' capability has no significant influence on Artificial Intelligence adoption behaviour in universities.

Table 1: Independent Sample t-test for Gender Differences in Capability and AI Adoption Behaviour

Variable	Gender	N	Mean	Std. Deviation	t-value	Sig. (p)	Decision
Capability	Male	1,300	2.34	0.61	2.41	0.016	Significant
	Female	**845**	2.28	0.64			
AI Adoption Behaviour	Male	1,300	2.33	0.58	2.27	0.024	Significant
	Female	**845**	2.25	0.60			

The independent samples t-test analysis examined gender differences in lecturers' capability and Artificial Intelligence (AI) adoption behaviour. The results indicate a statistically significant difference between male and female lecturers on both variables. For capability, male lecturers (N = 1,300, M = 2.34, SD = 0.61) reported slightly higher capability levels than female lecturers (N = 845, M = 2.28, SD = 0.64). The difference was statistically significant, t(2143) = 2.41, p = 0.016, indicating that

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gender has a measurable influence on perceived capability for AI adoption. Although the mean difference is relatively small, the statistical significance suggests that males demonstrate marginally higher confidence or exposure in AI-related competencies. Similarly, for AI adoption behaviour, male lecturers (M = 2.33, SD = 0.58) reported higher engagement in AI-related practices than female lecturers (M = 2.25, SD = 0.60). The independent samples t-test revealed a statistically significant difference, t(2143) = 2.27, p = 0.024, indicating that gender is associated with variations in behavioural engagement with AI technologies within the university context. In summary, the results suggest that male lecturers exhibit slightly higher levels of both capability and AI adoption behaviour, although the differences remain modest. The statistically significant outcomes led to the rejection of the null hypothesis, confirming that gender plays a measurable role in shaping lecturers' capability and behavioural engagement with AI technologies in universities.

H_{02}: Institutional opportunity conditions have no significant influence on Artificial Intelligence adoption among university lecturers.

Table 2: Pearson Correlation between Institutional Opportunity and AI Adoption Behaviour

Variables	**Institutional Opportunity**	**AI Adoption Behaviour**
Institutional Opportunity	1	0.48*
AI Adoption Behaviour	0.48*	1
N	2145	
Significance	$p < 0.05$	

Table 2 presents the Pearson product–moment correlation analysis examining the relationship between institutional opportunity conditions and Artificial Intelligence (AI) adoption behaviour among university lecturers in relation to Hypothesis H_{02}. The analysis involved 2,145 respondents, with the level of significance set at $p < 0.05$. The results reveal a moderate positive correlation between institutional opportunity and AI adoption behaviour ($r = 0.48$, $p < 0.05$). This indicates that improvements in institutional opportunity structures—such as the availability of digital infrastructure, supportive policies, funding mechanisms, innovation platforms, and organizational support—are associated with higher levels of lecturers' engagement with AI technologies in teaching, research, and academic administration. Statistically, the correlation coefficient of 0.48 suggests a moderately strong linear relationship, implying that institutional environmental conditions play a substantial role in shaping lecturers' behavioural engagement with AI. The positive direction of the relationship further indicates that as institutional opportunity increases, the likelihood of lecturers adopting and utilizing AI technologies also increases. Since the p-value is less than the 0.05 level of significance, the relationship is statistically significant. Consequently, the null hypothesis (H_{02}), which posits that institutional opportunity conditions have no significant influence on AI adoption among university lecturers, is rejected. The findings underscore the critical importance of institutional structures and enabling environments in facilitating AI adoption within universities.

H_{03}: Motivational factors have no significant influence on lecturers' Artificial Intelligence adoption behaviour.

Table 3: Pearson Correlation between Motivation and AI Adoption Behaviour

Variables	**Motivation**	**AI Adoption Behaviour**
Motivation	1	0.66*
AI Adoption Behaviour	0.66*	1
N	2145	
Significance	$p < 0.05$	

Table 3 presents a Pearson product–moment correlation analysis conducted to determine the strength and direction of the relationship between motivation and Artificial Intelligence (AI) adoption behaviour among university lecturers. As shown in Table 3, the results reveal a strong positive

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correlation between motivation and AI adoption behaviour (r = 0.66, p < 0.05), based on responses from 2,145 participants. The magnitude of the correlation coefficient indicates a substantial linear relationship, suggesting that higher levels of motivational disposition—such as confidence in AI integration, perceived professional relevance, intrinsic interest in technological innovation, and belief in the pedagogical value of AI—are associated with greater behavioural engagement with AI technologies in academic practice. The positive direction of the correlation implies that lecturers who exhibit stronger motivational orientations toward AI are significantly more likely to incorporate AI tools into teaching, research, and professional workflows. Statistically, the obtained p-value is less than the 0.05 significance threshold, confirming that the relationship between motivation and AI adoption behaviour is statistically significant. Consequently, the null hypothesis (H_{03}), which posits that motivational factors have no significant influence on AI adoption, is rejected. The finding underscores the critical role of psychological drivers in facilitating technological adoption within higher education environments.

H_{04}: There is no significant relationship between capability, opportunity, motivation, and Artificial Intelligence adoption behaviour among university lecturers.

Table 4: Multiple Regression Analysis of Capability, Opportunity, and Motivation Predicting AI Adoption Behaviour

Predictor Variable	**Beta (β)**	**Std. Error**	**t-value**	**Sig. (p)**
Capability	0.34	0.041	8.29	0.000
Opportunity	0.26	0.038	6.84	0.000
Motivation	0.39	0.036	10.83	0.000
Model Statistics	Value			
R	0.76			
R^2	0.58			
Adjusted R^2	0.57			
F-value	214.67			
Significance	p < 0.05			

Table 4 presents a multiple regression analysis conducted to determine the joint and individual predictive contributions of capability, opportunity, and motivation to Artificial Intelligence (AI) adoption behaviour. The overall model is statistically significant (F = 214.67, p < 0.05), indicating that the combined effects of these three variables significantly predict lecturers' AI adoption behaviour. The multiple correlation coefficient (R = 0.76) reflects a strong relationship between the predictors and the outcome, while the coefficient of determination (R^2 = 0.58) shows that approximately 58% of the variance in AI adoption behaviour is explained by capability, opportunity, and motivation. The adjusted R^2 of 0.57 confirms the model's robustness. Motivation emerged as the strongest predictor (β = 0.39, t = 10.83, p = 0.000), followed by capability (β = 0.34, t = 8.29, p = 0.000) and opportunity (β = 0.26, t = 6.84, p = 0.000), each with a positive and statistically significant contribution. Since all predictors are significant at p < 0.05, the null hypothesis (H_{04}) is rejected, confirming that capability, opportunity, and motivation collectively and significantly influence lecturers' AI adoption behaviour in universities, consistent with the COM-B behavioural framework.

Table 5: Integrated Summary Table of Hypotheses Testing

Hypothesis	**Statistical Test**	**Key Result**	**Decision**
H01	Independent Sample t-test	Capability significantly influences AI adoption behaviour (p < 0.05)	Rejected
H02	Pearson Correlation	Opportunity positively correlates with AI adoption (r = 0.48)	Rejected

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H03	Pearson Correlation	Motivation strongly correlates with AI adoption (r = 0.66)	Rejected
H04	Multiple Regression	Capability, Opportunity, and Motivation jointly predict AI adoption (R^2 = 0.58)	Rejected

Table 5 presents the integrated analysis of hypothesis testing, providing a comprehensive understanding of Artificial Intelligence (AI) adoption among university lecturers within the COM-B behavioural framework, emphasizing the interplay of capability, opportunity, and motivation. The results indicate that lecturers' capability significantly influences AI adoption behaviour (t = 2.41, p = 0.016), demonstrating that technical knowledge, digital literacy, and adaptability are critical enablers of practical engagement with AI tools. Similarly, institutional opportunity exhibits a moderate positive correlation with AI adoption (r = 0.48, p < 0.05), highlighting the role of supportive infrastructure, policies, and resource availability in facilitating technology integration. Motivational factors emerge as the strongest predictor, with a robust correlation (r = 0.66, p < 0.05), indicating that lecturers' confidence, professional identity, and intrinsic interest strongly drive AI engagement. Furthermore, multiple regression analysis confirms that capability, opportunity, and motivation jointly and significantly predict AI adoption (R^2 = 0.58, p < 0.05), with motivation contributing most substantially, followed by capability and opportunity. Collectively, these findings empirically validate the COM-B framework, demonstrating that AI adoption is the product of synergistic interactions between individual competence, enabling environments, and psychological drivers. The evidence underscores the necessity for holistic interventions that enhance lecturers' skills, optimize institutional support, and sustain motivational engagement to achieve effective, scalable, and sustained AI integration in higher education.

Discussion of Findings

This study examined the behavioural determinants of Artificial Intelligence (AI) adoption among university lecturers in Southwest Nigeria using the Capability–Opportunity–Motivation Behaviour (COM-B) framework. The findings reveal that lecturers possess moderate capability, reflecting established foundational digital literacy, technical competence, and adaptability to emerging AI systems. This supports the COM-B proposition that capability—encompassing knowledge, skills, and self-efficacy—is a critical determinant of behavioural engagement with technology (Michie et al., 2011; West & Michie, 2020; Holmes et al., 2019). Institutional opportunity, however, remains moderate and uneven, exposing persistent gaps in infrastructure, funding, inclusive innovation systems, and supportive digital transformation culture. Although universities have initiated AI-related infrastructure and policy frameworks, weak institutional mechanisms—such as limited participatory governance and underdeveloped innovation structures—constrain experimentation and systematic integration. These findings highlight the centrality of enabling environments in shaping behaviour (Michie et al., 2011; OECD, 2021; UNESCO, 2023). In resource-constrained contexts, inadequate funding and exclusionary governance structures significantly hinder institution-wide AI adoption (Zawacki Richter et al., 2019; Oke & Olatunji, 2023).

Motivation emerges as comparatively strong, with lecturers recognising AI's potential to enhance teaching effectiveness, strengthen professional identity, and support innovation. However, this motivation is moderated by social and cultural barriers, including limited collegial support and stereotype-related constraints, indicating that motivation is shaped not only by individual aspirations but also by organisational and societal contexts. This aligns with existing scholarship identifying motivation as a key psychological driver of technology adoption, often influenced by institutional reward systems and professional recognition (Selwyn, 2016; Bond et al., 2018; West &

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Michie, 2020; Holmes et al., 2019). In terms of behaviour, AI engagement is more evident in lecture preparation, research activities, and workflow integration, but remains limited in student assessment and participation in institutional initiatives. This pattern reflects a clear intention–practice gap, where lecturers acknowledge AI's value but face structural and contextual constraints that limit consistent and transformative use (Zawacki Richter et al., 2019; UNESCO, 2023).

Overall, the findings validate the COM-B framework by demonstrating that AI adoption is shaped by the dynamic interaction of capability, opportunity, and motivation (Michie et al., 2011; West & Michie, 2020). While individual competence and motivation are relatively strong, disparities in institutional opportunity—particularly along gendered lines—underscore the influence of structural inequities. These insights emphasize the need for inclusive, well-resourced, and strategically aligned institutional policies to enable equitable and sustained AI integration in higher education (UNESCO, 2023; OECD, 2021).

Conclusion

The findings reveal a nuanced pattern in lecturers' adoption of Artificial Intelligence (AI) within the COM-B framework. Lecturers demonstrate moderate capability, marked by strong digital literacy and adaptability but limited access to structured training and continuous professional development, indicating that foundational competence exists yet is insufficient for advanced AI integration. Institutional opportunity is similarly moderate but uneven, with partial infrastructure and policy support constrained by funding limitations, weak governance, and inadequate inclusive innovation systems. In contrast, motivation is relatively strong, driven by perceived improvements in teaching effectiveness and professional identity, though moderated by social and cultural factors. Behaviourally, AI use is evident in lecture preparation, research, and workflow integration but remains limited in student assessment and institutional engagement, reflecting an intention–practice gap. Inferential results confirm that capability, opportunity, and motivation significantly influence AI adoption both independently and collectively. While gender differences in capability and motivation are minimal, disparities in institutional opportunity highlight structural inequities. Generally, AI adoption remains emerging yet uneven, requiring strengthened institutional support and enhanced capacity development for sustainable integration.

Recommendations

The following recommendations were made:

1. Nigerian universities should prioritize the provision of dedicated AI infrastructure, sustainable funding mechanisms, inclusive innovation structures, and coherent digital transformation policies to create enabling environments for lecturer engagement.
2. University administrators should implement regular, structured professional development programmes, including workshops and specialized AI training, to strengthen lecturers' technical competence and digital literacy.
3. Institutions should institutionalize motivational frameworks—such as recognition systems, promotion criteria aligned with AI integration, peer mentorship, and awareness initiatives—to sustain engagement and drive consistent AI adoption among lecturers.
4. Nigerian universities should systematically disassemble structural barriers that constrain female lecturers' access to Artificial Intelligence (AI) opportunities by implementing inclusive policies, equitable resource allocation, and targeted professional development initiatives, thereby ensuring balanced participation in AI-driven innovation, research, and capacity-building programmes.

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5. Lecturers in Nigerian universities should adopt a systematic and consistent integration of AI across teaching, research, assessment, and administrative workflows to bridge the intention–practice gap and fully harness the transformative potential of these technologies.

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Assessment of Students Attitudes towards Learning of Technical and Vocational Education Subjects among Technical Colleges in Niger State, Nigeria

Abdulraheem Fatai
twinklewax86@gmail.com
Automobile Technology Department, School of Technical Education,
Umar Sanda Ahmadu College of Education, Minna,Niger State, Nigeria

Abstract

"The study investigated the attitudes of students towards Technical and Vocational Education subjects in Niger State. The study used the descriptive research design technique with a total of two hundred respondents. The population comprised of students in Vocational and Technical Colleges in Niger State. Questionnaires were used to elicit the views of the students. The data were analyzed using frequency counts and percentages. The result of this study revealed that parents' role have impact in student's attitudes towards Vocational and Technical Education subjects which shows that family is very important in choice of career because parents' explicitly expressed opinion about their children's occupational choice. The researcher recommended based on the findings that parents should stimulate their children cognitively at home to supplement the school efforts to make them mentally capable and alert for any profession of their choice. They should also work hand-in-hand with the school so as to guide their children's development and pursuance of career or of profession of their choice so as to be useful citizens of their country."

KEYWORDS: Attitudes, Technical and Vocational, Education, Subjects

Introduction

The provision of vocational and technical schools has a long history in the world. Before the industrial revolution (between 1750 and 1830) in Europe the home and the apprenticeship system were the principal sources of vocational education. European societies were later forced by the decline of handwork and specialization of occupational functions to develop institutions of vocational education (Duffy, 1967). In Africa, Vocational and Technical education was in form of apprenticeship system whereby learners/apprentices acquire vocational skills before the arrival of the colonial masters. In most African societies, the youth (men and women) were trained in technical vocations such as pottery, weaving, mat making, wood carving, traditional medicine by their parents, family friends and relatives who were masters of the crafts (Fafuwa, 1974). However, everything changed when the European colonialists set up formal vocational schools for those interested in learning particular trades. The reason behind was to recognize the learners officially and employ them in their field to assist in technical works. Vocational and Technical education is therefore designed to prepare individuals for specialized skills, abilities, trade, industries, agriculture, business for self-reliance and it is generally linked with manual and practical skills and commonly does not include academic abilities (Ozioma, 2011). Vocational and Technical Education (VTE) are tools an individual can use to self-sufficient, financially, socially and economically. It is training for useful employment in trade, industries, agriculture, business and home making etc. the emphasis on Vocational and Technical Education is to prepare one self-reliance. American vocational association (AVA, 1971), sees vocational subjects as those designed to develop skills, abilities, understanding, attitude, work habit and appreciation encompassing knowledge and information needed by any worker to enter and make progress in employment on a useful and productive basis. It contributes to the production of good citizens by developing their physical, social, civic, cultural and economic competences.

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The advent of formal education in Nigeria neglected vocational and technical education to an extent. During the colonial government, the Christian missionaries and government that established viewed elementary and secondary schools as far more important to the school for administrative conveniences to the detriment of Vocational and Technical education. It was between 1925 and 1935 that a number of bigger industrial firms like UAC, Nigeria Railway Corporation and P & T established their technical training centers' where they trained artisans in their specific industries. Later, few trade cetres were established by government: one at Yaba in 1937 and others were established in 1948 at Sapele, Kaduna, Bukuru and Enugu respectively. After Nigeria's independence, there was a growing interest in vocational education by different regional governments. The Northern region established twelve craft centres and three technical colleges all over the region. Eastern region government established four trade centres at Osogbo, Oyo, Owo and Ijebu Ode respectively. Women occupational centre was located at Abeokuta. In Lagos, apart from Yaba trade centre, Yaba College of Technology was established in 1932 as Yaba Higher College which was the first post-secondary institution in Nigeria. Al-Sad (2007) in his investigation noted that low status of Technical Education and Vocational Training in the society affects students' attitude towards it. Also, the study revealed that most of the students have neutral attitude towards Technical Education and Vocational Training. Other factors like parental influence, siblings and peer groups influence contributes to their attitude towards Technical Education and Vocational training. Results of Awang, Sail, Alavi and Ismail, (2011) that equivalency of Technical and Vocational Education with general education, social status in society and application of course content are important factors to attract students. Ozioma (2011) also found out in research that socioeconomic status of parents', gender and lack of career counselor in schools impact on student's choice towards Vocational and Technical Education. Ohiwerei and Nwosu (2009) found out that political and economic condition of a country, career which pays more and peer groups are the factors which affect on students' attitude towards Technical and Vocational Education.

Objectives of the Study

1. Determine if parents' pole have impact on the students' attitude towards technical and vocational education subjects
2. Assess the influence of peer groups on students' attitude towards technical and vocational education subjects
3. Examine teachers' influence on students' attitude towards technical and vocational education subjects

Research Questions

The following research questions shall be considered relevant for the purpose of this research:

1. Will parents' pole have impact on the students' attitude towards technical and vocational education subjects?
2. What are the effects of peers on students' attitude towards technical and vocational education subjects?
3. Will teachers' influence have impact on students' attitude towards technical and vocational education subjects?

Methodology

The following are the sub-headings under which this chapter focused on; the research design, population, sample and sampling techniques, research instrument, validity of the instrument, administration of the instrument and data analysis.

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Research Design

The descriptive survey design of the survey type was used to carry out this study. This method was chosen because it enabled the researcher to sample the opinion of a large sample.

Population of the Study

For the purpose of this research study, the population comprised of students in some secondary schools of Niger State, Nigeria.

Sample and Sampling Techniques

The researcher used random sampling technique. This indicates that all the students who constituted the population have equal chance of being selected in the sample for the study.

Research Instruments

The instruments used for the study was questionnaire which was titled, "Attitudes of Students' towards Technical and Vocational Education Subjects (ASTVES)". The questionnaires were divided into two sections: Section A focused on demographic while section B focused on general questions.

Validity of the Instrument

The validity of the instrument was ensured by the lecturers in the department of Vocational and Technical Education, lecturers in the Test and Measurement department and a chief lecturer who later evaluated and approved the instrument used by the researcher.

Reliability of the Instrument

The reliability of the instrument was measured by using test re-test method. The instrument was administered on a set of twenty students' outside the sample subjects. The administration was done within two weeks interval. That is, the instrument was administered on the said selected subject twice. The reliability coefficient of 0.71 was obtained which made the research instrument reliable for the study.

Administration of the Instrument

The researcher got approval from the school management where the questionnaires were administered in order to have access to the respondents. The researcher collected and collated questionnaires administered and responded to them. They were all collected back by the researcher.

Data Analysis

The data generated through the administration of the questionnaires were analyzed by the use of frequency counts and percentages.

Presentation of Results

This phase represents the analysis of data collected and discussion of results of the findings on, "Attitudes of students' towards Technical and Vocational Education subjects in Niger State, Nigeria". For the study purpose of the research work, a sample population of two hundred questionnaires (200) were used all the questionnaires were administered and, all the (200) questionnaires were returned. Below are the analyses of the responses.

Descriptive Analysis of Data

Table 1: Sex of Respondents

Sex	**M**	**F**	**Total**
Frequency	**89**	**111**	**200**
Percentage (%)	**44.5%**	**55.5%**	**100%**

Table 1 above shows that 89 respondents which represents 44.5% of the total population sample are males, 111 respondents which represents 55.5% are females. This shows that there are more females participants in the research study.

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Table 2: Class of Respondents

Class	SS 1	SS 2	SS 3	Total
Frequency	60	70	70	200
Percentage (%)	30%	35%	35%	100%

Table 2 above shows that 60 respondents which represent 30% of the respondents are from SS 1, 70 (35%) are from SS 2, while 70 respondents which represents 35% are in SS 3.

Research Questions

Three research questions earlier in the study were answered using frequency counts and percentages as stated in the Methodology of this study.

Research Question 1: Will parents' roles have impact on students' attitude towards technical and vocational education subjects?

Table 3: Analysis showing impact of parents' roles on students' attitude towards technical and vocational education subjects.

S/N	ITEMS		SA	A	D	SD	Total
1	Failure of parents to support in vocational and technical education is because of their financial status	*f*	110	80	10	-	200
		%	55.0	40.0	5.0	-	100
2	My parents' fail to provide relevant textbooks on vocational and Technical subjects for me.	*f*	2	13	57	128	200
		%	1.0	6.5	28.5	64.0	100
3	I will perform better if I take after my parents' profession.	*f*	30	74	46	50	200
		%	15.0	37.0	23.0	25.0	100
4	My parents' force me to participate in technical and vocational classes	*f*	3	46	137	14	200
		%	1.5	37.0	23.0	25.0	100
5	I find it difficult to make a right choice of subjects without may parents' advice.	*f*	18	73	51	58	200
		%	9.0	36.5	25.5	29.0	100

Table 3 shows that 110 respondents which represents 55.0% of the total sample agreed that failure of parents to support in vocational and technical education is because of their financial status, 80 (40.0%) agreed, 10 (5.0%) disagreed to the opinion. Two (2) respondents which represents 1.0% respondents strongly agreed that their parents failed to provide relevant textbooks on vocational and technical education for them, 13 (6.5%) agreed, 57 (28.5%) disagreed and 128 (64.0%) respondents strongly disagreed. 30 (15.0%) respondents strongly agreed that they will perform better if they take their parents' profession, 74 (37.0%) agreed, 46 (23.0%) disagreed and 50 (25.0%) respondents strongly disagreed. Three (3) respondents which represents 1.5% respondents strongly agree that

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their parents forced them to participate in technical and vocational classes, 46 (23.0%) agreed, 137 (68.5%) disagreed while 14 (7.0%) respondents strongly disagreed. 18 respondents which represents 9.0% respondents strongly agree that they find it difficult to make right choice of subjects without their parents' advice, 73 (36.5%) agreed, 51 (25.5%) disagreed while 58 (29.0%) respondents strongly disagreed.

Research Question 2: what are the effects of peers on students' attitude towards technical and vocational education subjects?

Table 4: Analysis showing effects of peers on students' attitude towards technical and vocational education subjects.

S/N	ITEMS		SA	A	D	SD	Total
1	My social status with my peers (that are not enrolled in vocational education) will go down if I enroll in a technical and vocational education course.	*f*	4	23	101	72	200
		%	2.0	11.5	50.5	36.0	100
2	I attend technical and vocational classes because mostly all my friends also attend the classes.	*f*	16	27	59	98	200
		%	8.0	13.5	29.5	49.0	100
3	Vocational education courses equipped my peers in higher classes with specific job skills needed to secure a job.	*f*	84	73	25	18	200
		%	42.0	36.5	12.5	9.0	100
4	Vocational education motivated students to graduate and continue their education beyond the secondary school level.	*f*	67	61	64	8	200
		%	33.5	30.5	32.0	4.0	100
5	I find it difficult to make a right choice of subjects without my parents' advice.	*f*	27	63	84	26	200
		%	13.5	31.5	42.0	13.0	100

Table 4 shows that 4 respondents which represents 2.0% of the total sample strongly agreed that their social status with their peers (that are not enrolled in vocational education) will go down if they enroll in vocational education course, 23 (11.5%) agreed, 101 (50.5%) disagreed and 72 (36.0%) strongly disagreed to the opinion. I6 respondents which represents 8.0% respondents strongly agreed that they attend technical and vocational classes because mostly all their friends also attend the classes, 27 (13.5%) agreed, 59 (29.5%) disagreed and 98 (49.0%) respondents strongly disagreed. 84 (42.0%) respondents strongly agreed that vocational education courses equipped their peers in higher classes with specific job skills needed to get a job, 73 (36.5%) agreed, 25 (12.5%) disagreed and 18 (9.0%) respondents strongly disagreed. 67 respondents which represents 33.5% respondents strongly agreed that vocational e3ducation motivates students to graduate and continue their education beyond the secondary school level, 61 (30.5%) agreed, 64 (32.0%) disagreed while 8 (4.0%) respondents strongly disagree. 27 respondents which represents 13.5% respondents strongly agreed that their friends attending vocational classes uses the opportunity of knowledge gained to do petty

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jobs and earn money, 63 (31.5%) agreed, 84 (42.0%) disagreed while 26 (13.0%) respondents strongly disagreed to the opinion.

Research Question 3: Will teachers' influence have impact on students' attitude towards technical and vocational education subjects?

Table 5: Analysis showing impact of teachers' influence on students' attitude towards technical and vocational education subjects.

S/N	ITEMS		SA	A	D	SD	Total
1	The study of vocational and technical education affect the general performance of secondary school students in Nigeria positively due to teachers' method of teaching.	*f*	102	74	17	7	200
		%	51.0	37.0	8.5	3.5	100
2	The study of vocational and technical education affects the general performance of secondary school students in Nigeria negatively due to teachers' method of teaching.	*f*	8	27	59	106	200
		%	4.0	13.5	29.5	53.0	100
3	Vocational education teachers should have bigger classes than other teachers because extra work in the laboratory and equipment management.	*f*	94	72	25	9	200
		%	47.0	36.0	12.5	4.5	100
4	School counselors, teachers and principals should all have a good knowledge and understanding of vocational education programs and courses.	*f*	101	86	13	0	200
		%	50.5	43.0	6.5	0	100
5	Only certified vocational education instructors should teach vocational education courses.	*f*	86	75	31	8	200
		%	43.0	37.5	15.5	4.0	100

Table 5 shows that 102 respondents which represents 51.0% of the total sample strongly agreed that the study of vocational and technical education affects the general performance of secondary school students in Nigeria positively due to teachers' method of teaching, 74 (37.0%) agreed, 17 (8.5%) disagreed and 7 (3.5%) strongly disagreed to the opinion. 8 respondents which represents 4.0% respondents strongly agreed that the study of vocational and technical education affects the general performance of secondary school students in Nigeria negatively due to teachers' teaching method, 27 (13.5%) agreed, 59 (29.5%) disagreed and 106 (53.0%) respondents strongly disagreed. 94 (47.0%) respondents strongly agreed that vocational education teachers should have bigger classes than other teachers because extra work in the laboratory and equipment management, 72 (36.0%) agreed, 25 (12.5%) disagreed and 9 (4.5%) respondents strongly disagreed. 101 respondents which represents 50.5% respondents' strongly agreed that school counselors, teachers and principals should all have a good knowledge and understanding of vocational education programs and courses, 86 (43.0%) agreed, 13 (6.5%) disagreed while none of the respondents strongly disagreed. 86 respondents which represents 43.0% respondents strongly agreed that only certified vocational

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education instructors should teach vocational education courses, 75 (37.5%) agreed, 31 (15.5%) disagreed while 8 (4.0%) respondents strongly disagreed to the opinion.

Discussion of Findings

Bakshi (2005) argued that in attitude building, it is critical for an individual to be fully knowledgeable. Individuals, who have the knowledge of the best methods and processes and can implement the same in the right frame of mind produce world class products and can give world class services. In today's environment, the knowledge needs to be updated from time to time through various trainings and development programs. Furthermore, Edward et al. (2008) contented that in choosing vocational or other options, there is a range of factors influencing young people in their decision-making. These are the availability of opportunities, the influence of others, family members, peers, teachers, career officers have interest in the subjects' quantity and quality of information available. Thus, the guidance and counseling to students becomes an essential aspect. The findings showed that parents' role have impact on student's attitude towards technical and vocational education subjects which shows that family is very important in choice of career because parents' explicitly expressed opinion about child's occupational choice. Thus, there is relationship between parental influence and student's technical and vocational choices (Durojaye, 2002).

The research findings also revealed that some students will perform better he/she takes after father's profession as quoted by Okeke (2001) on the relationship between parents' occupations and the children's occupational preferences, that 52% of children are interested in their parents' occupation. Aloo, Imatwai and Nyang Ori (2011), concluded that teachers' training at higher levels has not been vigorously pursued in states. The situation is unbecoming of a country like Nigeria where the policy is being oriented towards science and technology. The fact that there are many unqualified teachers in the colleges implies that qualified teachers are in short supply to the colleges. Also, Adeyemi (2009) and Nkeke and Dollah, (2011) calls for more recruitment of teachers to fill the vacancies. Although high teacher-students' ratios have been found to be significantly related to students' poor academic performance (Afolabi, 2000), Adeyemi (2012) and Ibadin (2010) a situation whereby students' enrolment continues to increase in technical colleges in the state leaves more to be desired. The ratio were not however in agreement with the National Board for Technical Education (2008) that recommended teacher-student ratio of between 1:15 to 1:20 for pratical oriented trade courses, such as woodwork, metal work, electronics work practices. Between 1:18 and 1:25 for practice-oriented core courses in the general sciences such as Biology, Chemistry, Physics: And giving a ratio of 1:12 as average (NBTE 2000). The findings also revealed that it is advisable to examine one's personality while making choice of career (Odebunmi, 2000). In conclusion, there are many factors influencing attitude of secondary school students' towards technical and vocational education such as parental influence, peer influence and teachers' influence.

Conclusion

The study has revealed that students' positive attitude formation towards vocational and technical education subjects is due to their awareness that they are no less intelligent than students in other subject areas. Vocational and technical subjects also help students in the area of self development. The Chinese proverb says: "what I hear, I forget, what I see, I remember, what I do, I understand". Students will begin to see vocational and technical education as short-cut to self employed. It would also educate parents' and the teachers about their wrong notion that less intelligent drop-out or less privileged students take to vocational and technical education.

Recommendations

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Based on the findings, the following recommendations are made that:

1. Government should provide adequate manpower in the area of qualified technical instructors to boost vocational and technical education.
2. Government should provide basic infrastructure like electricity, water and good laboratories and workshops to facilitate better attitude towards the study of vocational and technical education courses.
3. The study will be of value to the curriculum planners in Niger state in improving the policies on vocational and technical education programs so as to fast-track the technological developments.
4. The idea or belief that vocational and technical education fort dropped-out or less intelligent students should be cancelled.
5. Vocational and technical education for students will motivate the use of their hands and creative talents to encourage self employment.
6. The school counselors and teachers alike should organize workshops or career talks, career week programs in schools in other to sensitize their students' on the need to have positive attitude towards vocational and technical education subjects.

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