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Development and Evaluation of a Contextualized Interactive Package for Teaching Quantum Physics in Tertiary Institutions in Niger State

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Abstract

The persistent challenges encountered by students in comprehending the abstract and counterintuitive concepts of quantum physics have been largely attributed to conventional instructional approaches that often lack contextual relevance, learner-centered engagement, and interactive learning experiences. This study developed and evaluated an Indigenous Contextualized Interactive Physics Instructional Package (IPIP) designed to enhance the teaching and learning of quantum physics in tertiary institutions within Niger State, Nigeria. The study adopted a two-phase research framework that integrated Design-Based Research (DBR), guided by the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) instructional design model, with a quasi-experimental pre-test–post-test non-equivalent control group design. A total of 120 students participated in the study, comprising 60 students in the experimental group and 60 students in the control group. Data were collected using the Quantum Physics Achievement Test (QPAT) and the Quantum Physics Interest Inventory Questionnaire (QPIIQ). The instruments underwent rigorous validation by specialists in Physics Education, Educational Technology, and Measurement and Evaluation, while their reliability was established through pilot testing using the Kuder–Richardson Formula 20 (KR-20) and Cronbach's Alpha reliability coefficients. Descriptive statistics were employed to answer the research questions, whereas Analysis of Covariance (ANCOVA) was used to test the hypotheses at the 0.05 level of significance. The findings revealed that the developed instructional package was both contextually appropriate and instructionally adequate for quantum physics instruction. Furthermore, students exposed to the IPIP demonstrated significantly higher academic achievement ($F(1,117) = 60.47$, $p < 0.05$) and interest levels ($F(1,117) = 49.49$, $p < 0.05$) compared with their counterparts taught using conventional instructional methods. The study concludes that the integration of indigenous contextualization and interactive instructional technologies substantially improves students' conceptual understanding, academic performance, and engagement in quantum physics. Consequently, the adoption of culturally responsive and technology-enhanced instructional strategies is recommended to improve the quality and effectiveness of physics education in tertiary institutions.

Keywords

Interactive Instructional Package,
Quantum Physics,
Student Achievement,
Student Interest,
Indigenous Contextualization

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1. Introduction

Quantum physics is widely regarded as one of the most challenging areas of physics due to its abstract, counterintuitive, and mathematically demanding nature. At the tertiary level, students often experience low achievement, weak conceptual understanding, and declining interest in concepts such as wave–particle duality, energy quantisation, and the photoelectric effect. These challenges are largely attributed to the abstract nature of quantum physics and the prevalence of misconceptions arising from inadequate representations of concepts and difficulties in connecting mathematical formalism with physical meaning (Ubben & Bitzenbauer, 2023; Borish & Lewandowski, 2024). Conventional lecture-based instruction further limits student engagement and promotes superficial learning (UNESCO, 2023).

To improve learning outcomes, technology-driven instructional approaches have been increasingly advocated. Interactive instructional packages, including simulations, animations, multimedia resources, and feedback systems, facilitate the visualization of abstract phenomena and support learner-centred instruction.

Recent evidence indicates that interactive learning environments, virtual laboratories, augmented reality (AR), and virtual reality (VR) technologies significantly enhance students' conceptual understanding and academic achievement in science and physics education, particularly when addressing abstract concepts (Koç & Kanadlı, 2025; Wang *et al.*, 2025; González *et al.*, 2024). Furthermore, technology-enhanced and immersive learning environments have been associated with increased student engagement, motivation, and active participation in learning processes (Jiang *et al.*, 2025; Mursalin *et al.*, 2025).

However, the effectiveness of instructional technologies depends on their contextual relevance. Contextualised learning connects academic content with learners' everyday experiences and cultural backgrounds, thereby making abstract concepts more meaningful. This view is supported by multimedia learning theory, which emphasises the integration of visual and contextual representations for effective learning (Mayer, 2021; Mayer & Fiorella, 2024). Studies have shown that context-based science education enhances students' motivation and conceptual understanding, particularly in developing contexts (Ntembe & Akinyemi, 2023; Bano *et al.*, 2024; UNESCO, 2024).

Despite advances in educational technology, limited attention has been given to integrating indigenous contextualisation with interactive technologies in quantum physics instruction. In Nigeria and similar developing contexts, science teaching has been widely reported to still rely on decontextualised, teacher-centred approaches that limit meaningful engagement and conceptual understanding (Adedoyin & Okebukola, 2023; UNESCO, 2024).

Recent studies and systematic reviews continue to emphasise the importance of culturally responsive, context-sensitive, and technology-enhanced instructional approaches for improving science learning outcomes in higher education (Bano *et al.*, 2024; Ntembe & Akinyemi, 2023; Koç & Kanadlı, 2025). Therefore, this study developed and validated an indigenous contextualised interactive instructional package and evaluated its effects on students' achievement and interest in quantum physics in tertiary institutions in Niger State, Nigeria.

1.1 Statement of the Problem

Students in tertiary institutions continue to experience persistent difficulties in learning quantum physics due to its abstract and non-intuitive nature, resulting in weak conceptual understanding and low achievement (Stump *et al.*, 2023; Borish & Lewandowski, 2024). These challenges are worsened by lecture-based instructional approaches that limit active engagement and conceptual reasoning in physics learning (Streveler et al., 2023; Borish & Lewandowski, 2024).

In Nigeria and similar African contexts, physics education is still largely constrained by persistent reliance on teacher-centred instructional methods and limited implementation of learner-centred and contextually responsive pedagogies, which continue to hinder students' meaningful understanding of abstract scientific concepts (Adedoyin & Okebukola, 2023; Ogunniyi, 2023; UNESCO, 2024).

Therefore, there is a need to develop and validate a contextualised interactive instructional package that integrates simulations, multimedia, and indigenous examples to enhance students' achievement and interest in quantum physics.

1.2 Aim and Objectives of the Study

The aim of this study is to develop and evaluate a contextualized interactive package for teaching quantum physics in tertiary institutions in Niger State.

The specific objectives are to:

1. Identify relevant indigenous contextual examples for teaching selected quantum physics concepts;

2. Develop and validate an interactive physics instructional package incorporating simulations, multimedia, and indigenous contexts;

3. Compare the achievement scores of students taught using the interactive package with those taught using the conventional method;

4. Compare the interest scores of students taught using the interactive package with those taught using the conventional method.

1.3 Research Questions

The study was guided by the following research questions:

1. What indigenous contextual examples are suitable for teaching selected quantum physics concepts to tertiary students in Niger State?
2. What is the structural adequacy of the developed Interactive Physics Instructional Package (IPIP) using simulations, multimedia, and indigenous contexts?
3. What are the mean achievement scores of students taught using IPIP compared with those taught using the conventional method?
4. What are the mean interest scores of students taught using IPIP compared with those taught using the conventional method?

1.4 Research Hypotheses

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

1. There is no significant difference in achievement scores between students taught quantum physics using the Interactive Physics Instructional Package (IPIP) and those taught using the conventional method.
2. There is no significant difference in interest scores between students taught quantum physics using the IPIP and those taught using the conventional method.

2 Literature Review

Quantum physics is widely recognized as one of the most challenging areas of physics due to its abstract and counterintuitive concepts, such as wave–particle duality and quantum measurement, which often result in misconceptions and poor conceptual understanding among students (Stump *et al.*, 2023; Borish & Lewandowski, 2024). These difficulties are further exacerbated by traditional lecture-based teaching methods that provide limited opportunities for active engagement and conceptual reasoning (Freeman *et al.*, 2024; Prince *et al.*, 2024).

Research has shown that interactive instructional technologies, including simulations, virtual laboratories, and immersive learning environments, enhance conceptual understanding by promoting active and inquiry-based learning (Radianti *et al.*, 2023). Consistent with multimedia learning theory, integrating visual and verbal representations facilitates meaningful learning and improves retention when cognitive load is effectively managed (Mayer & Fiorella, 2024; Bano *et al.*, 2024; Jiang *et al.*, 2025).

Furthermore, contextualised and culturally responsive instruction improves students' engagement and understanding by connecting scientific concepts to familiar socio-cultural experiences, particularly within African educational settings (Adedoyin & Okebukola, 2023; Ntembe & Akinyemi, 2023; UNESCO, 2024). Supported by Self-Determination Theory, studies indicate that interactive and contextualised learning environments enhance students' motivation and interest through greater autonomy, competence, and relatedness (Jiang *et al.*, 2025; Mursalin *et al.*, 2025).

Despite these documented benefits, the integration of interactive technologies with indigenous contextualisation in physics instruction remains limited in Nigerian educational settings (Ogegbo & Ramnarain, 2024; Akintoye *et al.*, 2024; Badmus *et al.*, 2026). This gap provides the rationale for developing the Indigenous Contextualized Interactive Physics Instructional Package (IPIP).

3 Methodology

3.1 Research Design

This study employed a two-phase design comprising Design-Based Research (DBR) and a quasi-experimental pre-test – post-test non-equivalent control group design. The DBR phase guided the systematic design, implementation, evaluation, and refinement of the Interactive Physics Instructional Package (IPIP) in authentic educational settings, making it suitable for developing context-sensitive instructional innovations (McKenney & Reeves, 2019; Reeves, 2006). This phase addressed Research Questions 1 and 2. The quasi-experimental phase was used to determine the effectiveness of the IPIP on students' achievement and interest in quantum physics using intact classes. The pre-test – post-test non-equivalent control group design enabled comparison between experimental and control groups while accounting for initial group differences (Creswell & Creswell, 2018; Shadish *et al.*, 2002). This phase addressed Research Questions 3 and 4 and the corresponding hypotheses.

3.2 Development of the Interactive Physics Instructional Package

The IPIP was developed using the ADDIE instructional design model comprising Analysis, Design, Development, Implementation, and Evaluation. During the analysis phase, difficult quantum physics concepts, learners' characteristics, and indigenous contextual examples were identified through literature review and expert consultation. The design phase involved the specification of learning objectives, content organization, and integration of contextual examples into instructional activities. The development phase focused on producing simulations, animations, multimedia resources, and interactive exercises. The package was subsequently pilot-tested and implemented in classroom settings, while the evaluation phase involved expert validation and user feedback to assess content quality, usability, interactivity, and relevance. The integration of ADDIE within the DBR framework ensured systematic development and iterative refinement of the instructional package.

3.3 Population and Sample

The population comprised all physics students enrolled in introductory quantum physics courses in tertiary institutions in Niger State, Nigeria. Three institutions were purposively selected based on curriculum similarity, availability of physics programmes, and willingness to participate. A total of 120 students participated in the study, with 60 students assigned to the experimental group and 60 students to the control group. Intact classes were used to preserve the natural classroom environment, consistent with quasi-experimental research practice.

3.4 Instruments

Three instruments were utilized for data collection: the Quantum Physics Achievement Test (QPAT), a multiple-choice test designed to assess students' conceptual understanding of selected quantum physics concepts; the Quantum Physics Interest Inventory Questionnaire (QPIIQ), a Likert-scale instrument measuring students' interest and motivation toward quantum physics; and the Interactive Physics Instructional Package (IPIP), which served as the treatment instrument and incorporated simulations, multimedia resources, and indigenous contextual examples.

3.5 Validity and Reliability

The instruments and instructional package were subjected to face and content validation by experts in Physics Education and Educational Technology. Indigenous contextual examples (RQ1) were validated through expert ratings, while the instructional adequacy of the IPIP (RQ2) was assessed using structured validation checklists. Reliability was established through pilot testing in a comparable institution outside the study area. The reliability coefficient of the QPAT was determined using the Kuder–Richardson Formula 20 (KR-20), while Cronbach's Alpha was used to estimate the reliability of the QPIIQ.

3.6 Procedure for Data Collection

The study was conducted in two phases. The first phase involved the identification and validation of indigenous contextual examples, development of the IPIP using the ADDIE model, and expert validation of its instructional adequacy. The second phase involved the experimental implementation. Both groups were administered the QPAT and QPIIQ as pretests. The experimental group was then taught using the IPIP, while the control group received instruction through the conventional teaching method over a six-week period. At the end of the intervention, the QPAT and QPIIQ were re-administered as post-tests.

3.7 Data Analysis

Data analysis was guided by the research questions and hypotheses. Mean and standard deviation were used to analyse respondents' ratings of indigenous contextual examples (RQ_1), instructional adequacy of the IPIP (RQ_2), and students' achievement and interest scores (RQ_3 and RQ_4). The hypotheses were tested using Analysis of Covariance (ANCOVA**)** at the 0.05 level of significance. ANCOVA was employed to control for pre-test differences and determine the effect of the treatment. Assumptions of normality, homogeneity of variance, and linearity were tested before conducting the analysis.

4 Results and Discussion

4.1 Validation of Indigenous Contextual Examples and IPIP (RQ1 & RQ2)

Table 1: Summary of Validation Results

Variable	Cluster Mean	SD	Decision
Indigenous contextual examples	3.34	0.72	Accepted
Instructional adequacy of IPIP	3.38	0.69	Adequate

The indigenous contextual examples and the Interactive Physics Instructional Package (IPIP) were positively evaluated by respondents, with mean ratings above the criterion value of 2.50. The findings indicate that the package was contextually relevant and instructionally adequate. This supports the use of culturally responsive and multimedia-based instructional approaches in science education (Mayer, 2021; Ogegbo & Ramnarain, 2022; UNESCO, 2023).

4.2 Effect of IPIP on Students' Achievement (RQ3)

Table 2: Achievement Scores and ANCOVA Result

Group	Pretest Mean	Posttest Mean	Mean Gain
Experimental	42.18	72.46	30.28
Control	41.73	58.21	16.48

ANCOVA Source	F	Sig.
Group	60.47	.000

Students exposed to the IPIP achieved higher posttest scores and learning gains than those taught using the conventional method. ANCOVA revealed a significant treatment effect, $F(1,117) = 60.47$, $p < .05$, indicating that the IPIP significantly improved achievement. This finding agrees with studies highlighting the effectiveness of simulation-based and technology-enhanced instruction in science learning (Wieman *et al.*, 2008; Freeman et al., 2014; Addo *et al.*, 2023).

4.3 Effect of IPIP on Students' Interest (RQ4)

Table 3: Interest Scores and ANCOVA Result

Group	Pre-test Mean	Post-test Mean	Mean Gain
Experimental	2.41	3.54	1.13
Control	2.39	2.88	0.49

ANCOVA Source	F	Sig.
Group	49.49	.000

Students taught using the IPIP demonstrated greater improvement in interest than those in the control group. The ANCOVA result showed a significant treatment effect, $F(1,117) = 49.49$, $p < .05$, indicating that the package significantly enhanced students' interest in quantum physics. This finding supports evidence that contextualized and technology-integrated instruction promotes motivation and engagement in science learning (Deci & Ryan, 2000; Holmes *et al.*, 2022; UNESCO, 2023).

The results demonstrate that the IPIP was validated as instructionally adequate and significantly improved students' achievement and interest in quantum physics. The study therefore provides evidence for integrating indigenous contextual examples with interactive instructional technologies in tertiary physics education.

5 Conclusion and Recommendations

5.1 Conclusion

This study developed and evaluated an Indigenous Contextualized Interactive Physics Instructional Package (IPIP) for teaching quantum physics in tertiary institutions in Niger State, Nigeria. The findings revealed that the package was both contextually relevant and instructionally adequate for classroom use. Students exposed to the IPIP demonstrated significantly higher academic achievement and greater interest in quantum physics than those taught through conventional instructional methods. The study therefore concludes that the integration of indigenous contextualization with interactive instructional technologies enhances students' conceptual understanding and engagement in quantum physics, providing an effective approach for improving physics teaching and learning in tertiary institutions.

5.2 Recommendations

Based on the findings, the study recommends the adoption of Indigenous Contextualized Interactive Physics Instructional Packages in tertiary institutions to facilitate the teaching of abstract quantum physics concepts and improve students' achievement and interest. Physics curricula should be enriched with context-sensitive and interactive instructional materials to promote meaningful learning and engagement.

Regular professional development programmes should also be organized to equip lecturers with the competencies required for the design and effective utilization of contextualized interactive instructional tools. Furthermore, educational institutions and relevant government agencies should provide adequate technological infrastructure, including multimedia and simulation resources, to support the implementation of such instructional innovations. Future studies should explore the application of contextualized interactive instructional packages in other challenging areas of physics, including electromagnetism and thermodynamics.

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