EFFECTS OF ALGODOO SIMULATION-ENHANCED PROJECT-BASED AND COLLABORATIVE STRATEGIES ON PRE-SERVICE PHYSICS TEACHERS' PROBLEM-SOLVING SKILLS IN SOUTH-WEST NIGERIA

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Abstract

The persistent difficulty students experience in understanding core concepts in physics remains a major concern in higher education, particularly in South-West Nigeria, where conventional teaching approaches often limit deep conceptual understanding. This study investigated Algodoo simulation-enhanced project-based and collaborative learning strategies as a pathway to improving pre-service physics teachers' problem-solving skills. A quasi-experimental pretest–posttest non-equivalent control group design was adopted. The population comprised 81 physics education students in South-West Nigerian universities, while a sample of 67 students was drawn from three universities, using purposive sampling technique. Two validated instruments: Classroom Observation Protocol for Undergraduate Students and Physics Problem-Solving Test were used for data collection, with reliability coefficients established using Kuder-Richardson statistical technique. The experimental groups were exposed to instruction supported by Algodoo simulations, whereas the control group received conventional lecture-based instruction over a specified period. Data were analysed using descriptive statistics and Analysis of Covariance (ANCOVA). The findings revealed that the groups exposed to Algodoo simulation-enhanced learning demonstrated significantly higher problem-solving skills in physics compared to their counterpart in the control group ($p < 0.05$). A significant effect of the treatment on learning outcome was also observed. The study concluded that simulation-enhanced teaching strategies foster improved pre-service physics teachers' problem-solving skills in physics. It is therefore recommended that Algodoo and similar simulation tools be integrated into university teaching, alongside adequate training and technological support for effective implementation.

Keywords: algodoo, simulation-enhanced project, strategy, physics

Introduction

The teaching and learning of physics in higher education remain central to scientific advancement, technological innovation, and national development. This is because this discipline fosters critical thinking, analytical reasoning, and problem-solving competencies required for addressing complex real-world challenges. Despite the current pace of technological development, students in many Nigerian universities, particularly in South-West Nigeria, continue to demonstrate persistent difficulties in mastering fundamental physics concepts. These challenges are often reflected in poor academic performance, weak conceptual understanding, and a tendency toward rote memorisation rather than meaningful learning (West African Examinations Council, 2022). Such learning deficiencies raise concerns about the effectiveness of prevailing instructional approaches in fostering deep understanding and transferable problem-solving skills.

A major contributing factor to these challenges is the continued reliance on traditional lecture-based teaching methods, which emphasise passive knowledge transmission and limit students' active problem-solving skills in the learning process (Adeoye & Jimoh, 2023). In such environments, learners are positioned as recipients of information rather than active constructors of knowledge. This pedagogical limitation is particularly problematic in physics, where many concepts are abstract and require visualisation, experimentation, and conceptual integration for effective understanding. When instruction fails to connect theoretical principles with experiential learning, students often develop fragmented knowledge structures that hinder their ability to apply concepts in problem-solving contexts (Harry, 2024). Furthermore, meaningful scientific understanding in physics extends beyond procedural competence to include interpretation, modelling, and application of quantitative relationships in dynamic contexts (Gokhan & Orhan, 2023). The inability to integrate accurate reasoning with physics concepts further exacerbates students' difficulties in solving physics problems.

In response to these limitations, there has been a growing shift toward learner-centred and technology-enhanced instructional approaches in science education. Simulation-based learning, in particular, has emerged as a promising strategy for enhancing conceptual understanding and promoting active learning. This is highly essential as simulation environments afford learners the opportunity to manipulate variables, test hypotheses, and observe outcomes in real time, thereby facilitating deeper cognitive processing and participation. Empirical evidence, for instance, indicates that simulation-based instruction improves students' conceptual understanding, academic achievement, and problem-solving skills in science (Hwang, 2020; Kimmerle, 2019). These environments also support inquiry-based learning by enabling students to explore complex phenomena which may be difficult to replicate in traditional laboratory settings. In addition, simulation tools make abstract concepts more concrete through visualisation and interactive representation, thereby enhancing comprehension and retention (Rangkuti et al., 2024). Within higher education contexts, such approaches have been shown to improve students' motivation, problem-solving skills, and overall learning outcomes (Vanderburg et al., 2021).

The effectiveness of simulation-based learning is strengthened by established learning theories. Constructivist learning theory posits that learners actively construct knowledge through interaction with their environment, emphasising the importance of experiential and inquiry-based learning. Similarly, multimedia learning theory highlights the role of integrating visual and interactive elements in facilitating meaningful learning by reducing cognitive load and enhancing information processing (Richard Mayer, 2024). These theoretical perspectives provide a strong foundation for the integration of simulation tools into instructional practice, particularly in the domain of physics which requires visualisation and dynamic representation of concepts.

One such simulation tool gaining increasing attention in physics education is Algodoo. Algodoo is an interactive, physics-based simulation software that enables users to create, visualise, and manipulate physical systems within a dynamic virtual environment. Through real-time interaction and immediate feedback, Algodoo can make learners explore fundamental concepts such as motion, force, energy, and momentum in an engaging and intuitive manner. Beyond enhancing conceptual understanding, a tool like Algodoo also supports the development of mathematical reasoning by allowing students to interpret graphical relationships, analyse quantitative data, and apply mathematical models to physical situations. This integration of simulation tools to physics learning is therefore essential for developing robust problem-solving skills in science education.

Despite the documented benefits of simulation-based learning, its integration into university teaching in Nigeria remains limited. Many higher education institutions face challenges such as inadequate technological infrastructure, limited access to digital tools, and insufficient training for educators in the use of innovative instructional technologies (Ibrahim et al., 2020). Furthermore, much of the existing research on simulation-based instruction has been conducted outside the African context, thereby limiting the applicability of its findings to Nigerian universities. Though previous studies have examined physics achievement in isolation, however, limited attention has been given to the effect of simulation tools on students' problem-solving skills. There is also a paucity of empirical studies that investigate the effect of simulation-enhanced, project-based, and collaborative instructional strategies within the context of pre-service physics teacher education.

This study addresses these gaps by investigating the effect of Algodoo simulation-enhanced project-based and collaborative learning strategies on pre-service physics teachers' problem-solving skills in South-West Nigeria. By adopting a quasi-experimental design, the study provides empirical evidence on the effectiveness of integrating interactive simulation tools into physics instruction. It further contributes to the growing body of knowledge on innovative pedagogical approaches that promote active learning, conceptual understanding, and the integration of physics in higher education. Enhancing students' problem-solving skills is not only an academic objective but also a critical requirement for national development. This is because, as Nigeria strives toward sustainable development and global competitiveness, the need for graduates who are equipped with strong analytical and problem-solving competencies becomes increasingly imperative. This integration of simulation-enhanced instructional strategies into university classrooms therefore represents a viable pathway for improving the quality and relevance of prospective science education teachers.

Literature Review

The Cognitive Theory of Multimedia Learning was developed by Richard E. Mayer to explain how individuals learn more effectively when instructional materials combine words and images rather than presenting information in a single format. This study is rooted in cognitive psychology and focuses on how learners process information presented through multimedia environments. In contemporary science education, where digital technologies and interactive simulations are increasingly used, CTML provides an important theoretical lens for understanding how learners construct knowledge through visual and verbal information presented simultaneously. The central premise of CTML is that meaningful learning occurs when learners actively engage in selecting, organising, and integrating information presented through different sensory channels (Ayua, 2019; Adeoye & Jimoh, 2023). Mayer's theory is built on three major assumptions: the dual-channel assumption, the limited-capacity assumption, and the active-processing assumption. The dual-channel assumption posits that humans possess separate channels for processing visual-pictorial information and auditory-verbal information. The limited-capacity assumption suggests that each channel can process only a limited amount of information at a given time. The active-processing assumption proposes that learners must engage cognitively with instructional material by selecting relevant information, organising it into coherent mental representations, while integrating it with prior knowledge. These assumptions collectively explain why multimedia instructional environments often enhance comprehension and retention when properly designed (Kuhlmann, Bernacki & Greene, 2023; Mayer, 2024).

In the context of physics education, many concepts are abstract and difficult for learners to visualise through traditional lecture-based instruction alone. Concepts in mechanics, such as motion, velocity, and collisions, as well as optics concepts like reflection, refraction, refractive index, and dispersion of white light involve dynamic processes that are often difficult to demonstrate effectively using static diagrams or verbal explanations. Multimedia environments that combine visual animations, numerical data, and conceptual explanations can therefore support deeper understanding. A simulation tool such as Algodoo affords learners the opportunity to manipulate these quantities/concepts, observe changes in real time, and connect precise representations with visual phenomena. According to CTML, such environments support the construction of coherent mental models of scientific processes because they allow learners to integrate verbal explanations with visual representations of physical phenomena (Mayer & Fiorella, 2021).

Research Objectives

Specifically, the objectives of the research are to:

1. Examine the effect of Algodoo simulation-enhanced Project-Based Learning strategy on pre-service physics teachers' problem-solving skills
2. Examine the effect of Algodoo simulation-enhanced Collaborative Learning strategy on pre-service physics teachers' problem-solving skills
3. Determine the influence of gender on pre-service physics teachers' problem-solving skills, when taught using Algodoo simulation tool

Research Questions

1. What is the effect of Algodoo simulation-enhanced project-based learning strategy on pre-service physics teachers' problem-solving skills?
2. What is the effect of Algodoo simulation-enhanced collaborative learning strategy on pre-service physics teachers' problem-solving skills?
3. Does gender influence pre-service physics teachers' problem-solving skills, when taught using Algodoo simulation tools?

Research Hypotheses

1. There is no significant difference between the problem-solving skills of pre-service physics teachers taught using Algodoo simulation tool and their counterpart taught using traditional lecture method
2. There is no significant influence of gender on students' problem-solving skills, when taught using Algodoo simulation-enhanced tools.

Method

This study adopted a pre-test, post-test, control group quasi-experimental research design. The population consisted of all pre-service physics education students in public universities in South-West Nigeria, while the sample size was 67. The study covered three public universities (two federal and one state) offering Physics Education programmes in Ondo and Ogun States, namely Adeyemi Federal University of Education, Ondo; Tai Solarin Federal University of Education, Ijebu-Ode; and Olabisi Onabanjo University, Ago-Iwoye. Purposive sampling was used in selecting the institutions, while random assignment was employed in allocating participants to the experimental and control groups.

Results

Research Question One: What is the effect of Algodoo simulation-enhanced Project-Based Learning strategy on pre-service physics teachers' problem-solving skills?

Table 1.0: Descriptive Statistics of Pre-test, Post-test, Mean Gain and Standard Deviation of Students' Problem-Solving Skills by Treatment Group

Variable	Group	N	Pre-Test	Post-Test	Mean Gain	Std. Dev
Problem-Solving	PjBL	18	42.94	54.11	11.17	2.42
	Control	34	42.35	43.79	1.44	2.43

The descriptive statistics (*See Table 1.0)* reveal a clear pattern of improvement among students exposed to the Algodoo simulation-enhanced instructional strategy compared to those in the control group. For instance, the PjBL group demonstrated the highest mean gain (11.17), whereas the control group showed minimal improvement (1.44).

Research Question Two: What is the effect of Algodoo simulation-enhanced Collaborative Learning strategy on pre-service physics teachers' problem-solving skills?

Table 2.0: Descriptive Statistics of Pre-test, Post-test, Mean Gain and Standard Deviation of Students' Problem-Solving Skills by Treatment Group

Variable	Group	N	Pre-Test	Post-Test	Mean Gain	Std. Dev
Problem-Solving	CL	15	43.00	55.90	12.90	3.10
	Control	34	42.35	43.79	1.44	2.43

The descriptive statistics (*See Table 2.0)* reveals a clear pattern of improvement among students exposed to the Algodoo simulation-enhanced instructional strategy compared to those in the control group. For instance, the CL group demonstrated the highest mean gain (12.90), compared to the control group which showed minimal improvement (1.44). This indicates that while both strategies were effective, the results showed that collaborative learning may have a slight advantage in enhancing problem-solving abilities.

Succinctly put, the results indicate that students exposed to Algodoo simulation-enhanced Project-Based and Collaborative Learning strategies performed better in physics problem-solving activities than those taught using the traditional lecture method. However, CL shows a slight advantage in enhancing the development of these skills than PjBL.

Research Question Three: What is the influence of gender on pre-service physics teachers' problem-solving skills when taught using Algodoo simulation tool?

Table 2.2: Descriptive Statistics of Post-test Scores of Pre-Service Physics Teachers by Gender (Treatment Group)

Descriptive Statistics

Gender		Mean	Std. Deviation	N
Post_PS	Male	55.08	3.75	25
	Female	54.50	3.07	8
	Total	54.94	3.56	33

The results indicate that male pre-service physics teachers recorded slightly higher mean scores in development of problem-solving skills, while female students performed close to their male counterparts (*See Table 2.2*). However, the differences between male and female students are minimal, suggesting that gender may have little or no substantial influence on learning outcomes when taught using the Algodoo simulation-enhanced strategy.

Research Hypothesis One: There is no significant difference between the problem-solving skills of pre-service physics teachers taught using Algodoo simulation tool and their counterpart taught using traditional lecture method

Table 3.0: ANCOVA Results Showing the Effect of Teaching Strategy on Students' Development of Problem-Solving Skills

Tests of Between-Subjects Effects

Dependent Variable:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2
Corrected Model	2109.478[a]	3	703.159	67.929	< 0.05	0.764
Intercept	426.382	1	426.382	41.191	< 0.05	0.395
Pre_PS	2.136	1	2.136	0.206	0.651	0.003
Group	2076.942	2	1038.471	100.323	< 0.05	0.761
Error	652.134	63	10.351			
Total	165496.000	67				
Corrected Total	2761.612	66				

a. R Squared = .764 (Adjusted R Squared = .753)

The analysis of covariance (ANCOVA) revealed a statistically significant effect of teaching strategy (*See Table 3.0)* on the dependent variable, problem-solving. $F(1, 63) = 100.323$, $p < 0.05$, while partial η^2 is 0.761. This indicates that students taught using Algodoo simulation-enhanced instructional strategies differed significantly from those taught using the traditional lecture method. The pairwise comparison shows that both CL and PjBL were responsible for the significance, though the group taught using CL simulation-enhanced strategy rated slightly higher than PjBL. Therefore, the null hypothesis was rejected, and the effect size (partial $\eta^2 = 0.761$) suggests a substantial influence of treatment on students' problem-solving abilities.

Research Hypothesis Two: There is no significant influence of gender on students' problem-solving skills, when taught using Algodoo simulation-enhanced tools.

Table 3.1: ANCOVA Results Showing the Influence of Gender (Male vs Female) on Pre-Service Physics Teachers' Problem-Solving Skills

Tests of Between-Subjects Effects

Dependent Variable:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2
Corrected Model	59.435[a]	2	29.718	0.704	0.498	0.022
Intercept	168.176	1	168.176	3.983	0.050	0.059
Pre_PS	31.710	1	31.710	0.751	0.389	0.012
Gender	26.899	1	26.899	0.637	0.428	0.010
Error	2702.177	64	42.222			
Total	165496.000	67				
Corrected Total	2761.612	66				

a. R Squared = .022 (Adjusted R Squared = -.009)

The analysis of covariance (ANCOVA) revealed no statistically significant influence of gender (*See Table 3.1)* on pre-service physics teachers' problem-solving skills. $F(1, 64) = 0.637$, $p > 0.05$. This indicates that male and female students did not differ significantly in their learning outcomes when exposed to the Algodoo simulation-enhanced instructional strategy. Therefore, the null hypothesis was not rejected, and the effect size (partial $\eta^2 = 0.012$) suggests that gender had a minimal influence on the dependent variable.

Discussion

The findings of this study indicate that Algodoo simulation-enhanced instructional strategies improved pre-service physics teachers' problem-solving skills compared to the traditional lecture method. This improvement may be attributed to the interactive, visual, and exploratory nature of simulation-based learning, which enhances conceptual understanding and development of problem-solving skills.

The observed effect size suggests that integrating technology with learner-centred instructional approaches such as project-based and collaborative learning fosters deeper learning and meaningful knowledge construction. This aligns with constructivist and multimedia learning theories, which emphasise active participation and dual coding of information.

Furthermore, the non-significant influence of gender suggests that Algodoo-based instruction provides an inclusive learning environment that supports both male and female learners equally. This indicates that learning outcomes are more dependent on instructional design than on the demographic variable of gender.

Succinctly put, these findings support the effectiveness of simulation-enhanced instructional strategies in improving physics education and contribute to the achievement of Sustainable Development Goal 4 (Quality Education) by promoting innovative and inclusive teaching approaches.

Recommendations

1. Physics educators should integrate simulation tools such as Algodoo into instructional practices to enhance students' active participation and conceptual understanding.
2. Teacher education programmes should include training on simulation-enhanced project-based, and collaborative learning strategies to prepare pre-service physics (science) teachers for modern classroom challenges.
3. Curriculum developers should revise physics curricula to incorporate simulation-based and activity-oriented instructional approaches.
4. Regular workshops and professional development programmes should be organised to equip lecturers with competencies in the use of educational simulation softwares such as Algodoo.
5. Higher education institutions should ensure equitable access to instructional resources across federal and state universities to minimise the disparities in learning outcomes.

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