Published by The College of Science & Information Technology (COSIT), TASUED, Vol. 19, No. 1, pp. 89-98.

COSIT, TASUED
Journal of Science and Information Technology (JOSIT)

Evaluating the Effectiveness of Adaptive Simulations on Science Education Outcomes in Secondary Schools: A Case Study of Secondary Schools in Ogun State, Nigeria

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Abstract

This study examines the impact of adaptive simulations on student learning outcomes, engagement, and satisfaction in secondary schools in Ijebu, Ogun State, Nigeria. Utilizing a mixed-method research design grounded in the positivist paradigm, the study employed a quasi-experimental, pre-test-post-test approach and survey instruments to evaluate differences between traditional and simulation-based teaching in Chemistry and Physics. The results revealed that students taught using simulations achieved significantly higher pass rates—71% in Chemistry compared to 63% with traditional methods resulting in 8% increase in pass rates, and 71% in Physics compared to 51% resulting in 22% increase in pass rate—demonstrating substantial improvements in conceptual understanding and academic performance. Additionally, strong positive correlations were found between simulation adoption and both teacher perceptions ($r = 0.763$) and student engagement and motivation ($r = 0.779$), highlighting the importance of educator support and learner-centered environments. The study emphasizes the effectiveness of simulations, particularly in abstract STEM subjects, and underscores their potential to address educational challenges in Nigeria such as overcrowded classrooms and limited resources. Findings provide practical implications for policymakers and educators, advocating for the integration of adaptive simulations into national curricula to enhance equity, quality, and innovation in science education across diverse learning contexts.

Keywords: Adaptive, Simulation, Traditional Learning Method, Performance, Secondary School

INTRODUCTION

Background to Study

In the Nigerian educational context, adaptive simulations—interactive learning environments that customize content and feedback according to individual learner performance—are emerging as innovative tools with significant potential to improve teaching and learning (Gligorea et al., 2023). As technology rapidly transforms various sectors, including education (Haleem et al., 2022), adaptive simulations present a promising solution to persistent challenges faced by Nigerian schools, such as overcrowded classrooms, scarce instructional resources, and diverse learner abilities. Through personalized learning experiences, these simulations can foster more effective and inclusive education across Nigeria's varied learning settings.

Adaptive simulations, rooted in major learning theories, offer personalized, interactive learning experiences that enhance understanding of complex scientific concepts like those in Chemistry and Physics. Banda & Nzabahimana (2023) and Campos et al. (2020) highlight the effectiveness of simulations in improving conceptual understanding, engagement, and academic performance. However, their implementation in Nigerian secondary schools remains limited due to challenges like inadequate infrastructure, teacher training gaps, and resistance to change (Ayanwale et al., 2022).

Cite as:

Ogunbanwo, A. S.; Owoade, A. A.; Uwalaka, G. C. (2025). Evaluating the Effectiveness of Adaptive Simulations on Science Education Outcomes in Secondary Schools: A Case Study of Secondary Schools in Ogun State, Nigeria. *Journal of Science and Information Technology (JOSIT)*, Vol. 19, No. 1, pp. 89-98.

©JOSIT Vol. 19, No. 1, June 2025.

Despite their potential, the lack of local empirical evidence hinders informed decision-making (Chernikova et al., 2020).

This research aims to investigate how adaptive simulations affect student learning outcomes, engagement, and satisfaction, and how well they align with existing curricula. It seeks to provide practical insights for policymakers and educators on integrating simulations to enhance inclusive and effective education.

Research Objectives

The research focuses on three main areas:

1. comparing learning outcomes between students taught with simulations and those using traditional methods;
2. examining teacher and administrator perceptions;
3. and assessing the impact on student engagement and achievement.

The study addresses the gap in localized empirical evidence on adaptive simulations and aims to provide actionable insights for policymakers and educators.

Research Questions/ Hypotheses

To address the research objectives, the following research questions are posed using secondary schools in Ijebu, Ogun State, Nigeria, as a case study:

1. What are the differences in learning outcomes between students exposed to adaptive simulations and those in traditional classrooms?
2. What are the perceptions and experiences of teachers, and educational administrators regarding the integration of adaptive simulations in educational system?
3. What is the impact of adaptive simulations on student engagement, motivation, and learning outcomes?

Research Hypotheses

To provide a structured framework for the study, the following hypotheses are formulated:

Hypothesis One (H_{o1}): There is no significant difference in learning outcomes between students exposed to adaptive simulations and those in traditional classrooms in secondary schools in Ijebu, Ogun State Nigeria.

Hypothesis Two (H_{o2}): The perceptions and experiences of teachers, and educational administrators have no significant influence on adaptive simulations integration and effectiveness in Ijebu, Ogun State Nigeria.

Hypothesis Three (H_{o3}): The adaptive simulations have no significant impact on student engagement, motivation, and satisfaction in secondary schools in Ijebu, Ogun State.

RELATED WORKS

Recent research highlights the effectiveness of adaptive learning technologies across different educational settings. Studies like Aleksandrovich et al. (2024) and Sibley et al. (2024) show significant academic benefits, including improved engagement and knowledge retention through AI support, gamification, and tailored instruction, particularly for students with limited prior knowledge. However, these studies are mostly focused on tertiary education and often exclude reinforcement learning-based models. Other investigations, such as Ayanwale et al. (2024) and Bayaga & Alexander (2023), emphasize contextual readiness and demographic influences on learners' perceptions of adaptive learning technologies.

Computer-based simulations have shown significant benefits in enhancing science education across Africa (Oyeniran et al., 2021; Sifuna et al., 2016). A comparative study by Adesoji et al. (2021) further showed that, while hands-on activities slightly outperformed simulations in chemistry performance, simulations excelled in improving students' science process skill. While Fabeku & Enyeasi (2024) boosted chemistry scores and retention by combining simulations with video media.

These findings are backed by studies such as Anoir & Khaldi (2023), which advocate simulations for enhancing critical thinking and collaboration, and are rooted in constructivist learning theories that emphasize inquiry-based and experiential learning.

Despite these successes, notable gaps persist—especially in the Nigerian educational context. Limited research exists on the long-term impacts of digital tools and adaptive simulations, particularly regarding sustained learning outcomes and post-implementation effectiveness (Adedoyin & Soykan, 2020; Ifijeh & Yusuf, 2020). Infrastructure readiness remains a key barrier, as many Nigerian schools continue to face challenges such as unreliable electricity, poor internet access, and lack of digital equipment (Nickerson, 2020; Phulpoto *et al.*, 2024; Okonkwo & Daramola, 2022). Addressing these issues is crucial to developing sustainable and context-specific strategies for adaptive simulations in Nigerian secondary education.

METHODOLOGY

This section discusses how this study was conducted and the research instruments adopted. This study explores the effectiveness of adaptive simulations in enhancing science education among secondary school students in Ogun State, using research onion model (Saunders et al. 2015). It follows a positivist philosophy and a deductive approach, employing a quasi-experimental, pre-test-post-test design alongside surveys for data collection. The mixed method strategy focuses on structured questionnaires and academic performance evaluations to assess the impact of adaptive simulations on learning outcomes in Chemistry and Physics.

A cross-sectional time horizon was adopted, targeting 166 participants—including 120 senior secondary students (SS2), 42 teachers, 1 principal and 3 administrators from both private and public schools in Ogun state. Sixty students each were selected from private and public school through convenience sampling. The selected students were divided into control and experimental groups.

The experimental group was taught using Computer-Assisted Instruction (CAI) and PhET simulations, providing a technology-enhanced learning environment that emphasized interactivity, visualization, and immediate feedback. CAI allowed students to learn at their own pace while engaging with structured content tailored to their needs. The inclusion of PhET simulations—interactive, research-based tools developed by the University of Colorado—enabled learners to manipulate variables and observe real-time changes, which is particularly valuable in science subjects where abstract concepts can be challenging to grasp. While the control group received traditional, teacher-centered instruction, including lectures, chalkboard explanations, textbook readings, and Q&A sessions, without multimedia or interactive tools. A standardized lesson plan aligned with the Secondary School Curriculum ensured consistency in topics, objectives, and timing across sessions. This rigorous approach enabled a fair comparison between conventional teaching and the computer-assisted, simulation-based instruction provided to the experimental group.

Schools were selected based on type, location, and willingness to participate, with efforts made to ensure academic comparability between groups. Data were collected through pre- and post-tests and a 10-item Likert-scale questionnaire, focusing on academic performance and students' perceptions of CAI. Instrument validity was confirmed through expert reviews, and reliability was supported by Cronbach's alpha values above 0.7.

The five-week intervention combined simulations, interactive lessons, and assessments to actively engage students and deepen their understanding of scientific concepts. Computer-based simulations offered visual, interactive representations to connect theory with real-world applications. Interactive lessons fostered participation through exploration, discussions, and guided inquiry. Regular assessments evaluated learning, reinforced concepts, and provided feedback. This multimodal approach, grounded in constructivist learning theory, aimed to boost cognitive engagement, retention, and performance, especially in STEM subjects. The five-week duration allowed time for skill development, iterative learning, and effective measurement of student progress.

Descriptive statistics were used to analyse responses, while inferential analyses included independent samples t-tests to compare mean differences between groups, and Pearson's correlation to examine relationships between continuous variables. This specifies the use of the independent t-test, which is appropriate for comparing means between two independent groups, such as control and experimental groups in educational research, and Pearson's correlation, commonly applied to measure the strength and direction of linear relationships between variables in educational assessments. Ethical considerations such as informed consent, confidentiality, and voluntary participation were strictly observed.

RESULTS AND DISCUSSION

This section presents the results of the statistical analysis of the data received from the administration of the research instrument. A Cronbach's Alpha reliability test, performed on the collected data, showed a dependability of 89.4%, which exceeds the 70% threshold. This indicates that all 23 questions are trustworthy, sufficient for the study's purpose, and strongly related to each other.

Demographic Result

Table 1 indicates the demography for both students in public and private school, all participants were SS2 students.

Table 1. Student Information.

	Private Schools		Public Schools	
	Freq.	**%**	**Freq.**	**%**
Age				
11 – 15	52	87	40	67
16 – 18	8	13	20	33
Gender				
Male	28	47	34	57
Female	32	53	26	43
Class				
SS2	60	100	60	100
Total	60	100.0	60	100.0

Source: Field Work 2024.

For the public schools, forty (40), 67% students were between the age of 11 and 15 while twenty (20), 33% were between the ages of 16 and 18. Male students' participants were thirty-four (34), 57% and female students were twenty-six (26), 43%. Thus, this shows that the majority of the students' participants from the public schools were male between the ages of 11 and 15.

For the private schools, the table 1 also shows that fifty-two (52), 87% of the students' participants were between the age of 11 and 15 while eight (8), 13% were between the ages of 16 and 18. Male students were 47% while female students' participants were 53%. The results show that the majority of the students' participants were female and the age of the participants were between 11 and 15.

Table 2: Principals and Teachers Information.

	Frequency	%
Years of experience		
0-5	22	47.8
6-10	15	32.6
11-15	4	8.7
16-20	1	2.2
21+	4	8.7
Role		
Principal	1	2.2
Teacher	42	91.3
School Administrator	3	6.5
Total	46	100.0

Source: Field Work 2024.

Table 2 reveals that twenty 22 (47.8%) of the teachers have work experience between 0–5 years, 15 (32.6%) of the teachers have between 6–10 years' work experience, 4 (8.7%) of the teachers have between 11–15 years' work experience, 1 (2.2%) of the teachers have between 16–20 years' work experience while 4 (8.7%) of the teachers have 21+ years' work experience. Also, the school principal account for 2.2% of the respondents, 91.3% of the respondents are teachers, while 6.5% of the respondents are school administrators.

Comparison between Control group (traditional method) and Experimental group (simulation method)

This section present results of student performance in Chemistry and Physics using the two instructional methods: the traditional method (control group) and the simulation-based method (experimental group).

In Chemistry, the control group recorded a total fail rate of 330 (37%) and a pass rate of 570 (63%) (Table 3), while Table 4 shows that the experimental group had a lower fail rate of 264 (29%) and a higher pass rate of 636 (71%). This represents an 8% improvement in pass rate with the use of simulations, indicating that adaptive simulations had a moderate positive impact on students' comprehension and retention of Chemistry concepts. The finding is similar to Alake & Olojo (2020) findings which was conducted in Ekiti Sate in Nigeria.

Table 3. Chemistry Control Group.

Chemistry Assessment: Traditional method				
Ques	**Fail**		**Pass**	
	Freq.	**%**	**Freq.**	**%**
1	6	10%	54	90%
2	4	7%	56	93%
3	36	60%	24	40%
4	32	53%	28	47%
5	10	17%	50	83%
6	10	17%	50	83%
7	2	3%	58	97%
8	2	3%	58	97%
9	60	100%	0	0%
10	52	87%	8	13%
11	34	57%	26	43%
12	2	3%	58	97%
13	4	7%	56	93%

14	54	90%	6	10%
15	22	37%	38	63%
Total	330	37%	570	63%

Table 4. Chemistry Experimental Group.

Chemistry Assessment: Simulation				
Ques	**Fail**		**Pass**	
	Freq.	**%**	**Freq.**	**%**
1	36	60%	24	40%
2	0	0%	60	100%
3	22	37%	38	63%
4	10	17%	50	83%
5	14	23%	46	77%
6	10	17%	50	83%
7	4	7%	56	93%
8	12	20%	48	80%
9	56	93%	4	7%
10	34	57%	26	43%
11	14	23%	46	77%
12	0	0%	60	100%
13	4	7%	56	93%
14	20	33%	40	67%
15	28	47%	32	53%
Total	264	29%	636	71%

In Physics, the difference between the control and experimental groups was even more pronounced. The control group recorded a fail rate of 448 (50%) and a pass rate of 456 (51%) (table 5), whereas table 6 indicated that the experimental group achieved a much lower fail rate of 262 (29%) and a significantly higher pass rate of 638 (71%). This 22% increase in pass rate highlights a dramatic improvement in performance due to the use of simulation-based instruction. The finding is similar to Oyeniran et al. (2021) findings which was conducted in Osun Sate in Nigeria.

Also, the results demonstrated that simulations had a stronger effect on student outcomes in Physics than in Chemistry, this likely due to the abstract and experimental nature of Physics concepts, which benefit more from interactive, visual learning environments.

Table 5. Physics Control Group.

Physics Assessment: Traditional method				
Ques	**Fail**		**Pass**	
	Freq.	**%**	**Freq.**	**%**
1	20	33%	40	67%
2	58	97%	2	3%
3	44	73%	16	27%
4	50	83%	14	23%
5	20	33%	40	67%
6	14	23%	46	77%
7	16	27%	44	73%
8	18	30%	42	70%
9	18	30%	42	70%
10	18	30%	42	70%
11	20	33%	40	67%
12	16	27%	44	73%
13	48	80%	12	20%
14	48	80%	12	20%
15	40	67%	20	33%
Total	448	50%	456	51%

Table 6. Chemistry Experimental Group.

Physics Assessment: Simulation				
Ques	**Fail**		**Pass**	
	Freq.	**%**	**Freq.**	**%**
1	6	10%	54	90%
2	24	40%	36	60%
3	10	17%	50	83%
4	30	50%	30	50%
5	8	13%	52	87%
6	8	13%	52	87%
7	6	10%	54	90%
8	10	17%	50	83%
9	26	43%	34	57%
10	42	70%	18	30%
11	26	43%	34	57%
12	18	30%	42	70%
13	10	17%	50	83%
14	16	27%	44	73%
15	22	37%	38	63%
Total	262	29%	638	71%

Hypotheses Result

Research Hypothesis One is divided into two sub hypotheses – hypothesis 1a and hypothesis 1b

H_{o1}: There is no significant difference in learning outcomes between students exposed to adaptive simulations and those in traditional classrooms in secondary schools in Ijebu, Ogun State Nigeria.

The results of one-sample t-tests comparing simulation-based and traditional in Table 7, shows that both teaching methods significantly improve student performance in chemistry compared to a baseline score of 0. Students exposed to simulations achieved higher mean scores 0.7067 with a confidence interval .6606 to .7527 while those taught through traditional methods achieved 0.6333 with a confidence interval .5959 to .6707, indicating a slight advantage of simulations. The statistically significant p-values equals 0.000.

Table 7. Simulation versus Traditional Method.

	Mean Score	p_value	Confidence Interval
Chemistry			
Adoption of Simulation	.7067	.000	.6606 to .7527
Traditional Teaching Method	.6333	.000	.5959 to .6707
Physics			
Adoption of Simulation	.7089	.000	.6564 to 7614
Traditional Teaching Method	.4889	.000	.4474 to 5304

Also, Table 7 reveals that the Physics students taught with simulations achieved a higher mean score of 0.7089, supported by a highly significant p-value (0.000) and a confidence interval of 0.6564 to 0.7614. While those taught using traditional methods had a lower mean score of 0.4889, but this was also statistically significant, with a p-value of 0.000 and a confidence interval of 0.4474 to 0.5304. Overall, while both methods are effective, simulations demonstrate a greater positive impact on student performance in Physics.

H_{o2}: The perceptions and experiences of teachers, and educational administrators have no positive influence on adaptive simulations integration and effectiveness in Ijebu, Ogun State, Nigeria.

Table 8 shows a strong positive correlation (r = 0.763, p = 0.000) between the adoption of adaptive simulations and the perceptions and experiences of teachers and administrators in secondary schools in Ijebu, Ogun State.

This statistically significant result indicates that positive perceptions and experiences among educators strongly support the successful implementation of simulations. The findings reject the null hypothesis and highlight the crucial role of professional development, training, and leadership in promoting educational technology. When educators are confident and informed, they are more likely to adopt adaptive simulations, leading to improved student outcomes.

Table 8. One-Sample Statistics for Chemistry.

	Perception _Principals	Simulation _adoption
Pearson Correlation Sig. (2-tailed) N	1 46	. 763** .000 46
Pearson Correlation Sig. (2-tailed) N	.763** .000 46	1 46

Source: Field Work 2024.

H_{o3}: There is no significant impact of adaptive simulations on student engagement, motivation, and satisfaction in secondary schools in Ijebu, Ogun State, Nigeria.

Table 9 reveals a strong positive correlation (r = 0.779, p = 0.000) between the adoption of adaptive simulations and students' engagement, motivation, and satisfaction in secondary schools in Ijebu Ode, Ogun State. This statistically significant result rejects the null hypothesis and confirms that adaptive simulations positively impact students' learning experiences. As simulation use increases, student participation and enthusiasm also rise. These findings underscore the value of interactive, technology-driven learning and suggest that integrating adaptive simulations can enhance both academic performance and overall student satisfaction.

Table 9. One-Sample Statistics for Physics.

	Students Engagement	Simulation adoption
Pearson Correlation Sig. (2-tailed) N	1 46	. 779** .000 46
Pearson Correlation Sig. (2-tailed) N	.779** .000 46	1 46

Source: Field Work 2024.

DISCUSSION

This study provides compelling evidence that adaptive simulations significantly enhance student learning outcomes in Chemistry and Physics among secondary school students in Ijebu, Ogun State, Nigeria. The data compared student performance using two instructional methods: traditional teaching (control group) and simulation-based instruction (experimental group). In Chemistry, the simulation-based group had a pass rate of 71%, compared to 63% in the traditional group, marking an 8% improvement. However, the impact was even more pronounced in Physics, where the experimental group recorded a 71% pass rate, compared to 51% in the control group—an impressive 22% increase. These results demonstrate that simulation-based learning is not only more effective in conveying complex science concepts but also significantly improves comprehension and retention, especially in abstract subjects like Physics.

The stronger effect of simulations in Physics can be attributed to the subject's abstract and experimental nature. Concepts such as motion, electricity, and force are difficult to visualize through traditional teaching but become more accessible through interactive simulations. This aligns with the principles of constructivist and social constructivist theories, which advocate for hands-on, active, and collaborative learning. Simulations allow students to manipulate variables, conduct virtual experiments, and receive immediate feedback—fostering a deeper understanding of scientific phenomena.

Moreover, the study found strong positive correlations between simulation adoption and educators' perceptions ($r = 0.763$), as well as student engagement, motivation, and satisfaction ($r = 0.779$), all statistically significant. These findings highlight the critical role of teacher and administrator support in the successful integration of technology in the classroom.

The implications for Nigerian educational policy are far-reaching. The demonstrated improvement in student performance—especially in Physics—calls for urgent integration of technology-enhanced learning into the national curriculum. Policymakers should prioritize the adoption of adaptive simulations, particularly in STEM subjects where laboratory infrastructure is lacking or underdeveloped. Investing in simulation software, e-learning platforms, and teacher training programs is essential. In states like Ogun, where disparities in educational quality exist between urban and rural schools, simulations can help bridge the gap by offering consistent, high-quality instructional content.
From a cost-benefit perspective, simulation-based instruction offers a practical and sustainable solution for resource-constrained settings. Although the initial costs of software acquisition and teacher training may appear substantial, the long-term benefits outweigh these expenses. Digital simulations eliminate the need for costly and consumable laboratory materials, and they are reusable and scalable across multiple classrooms and schools. They also enable wider access to practical science education through shared ICT labs or mobile devices, significantly reducing per-student costs. Thus, in the long run, simulations represent a high return on investment by enhancing learning outcomes, reducing failure rates, and promoting equity in science education.

Overall, the study underscores the effectiveness and necessity of adopting adaptive simulations in Nigerian secondary education. It provides evidence-based justification for educational reforms focused on technology integration, capacity building, and curriculum redesign—crucial steps toward modernizing science education and preparing students for future scientific and technological careers.

CONCLUSION

This study assessed the impact of adaptive simulations versus traditional teaching methods on student performance in Chemistry and Physics in secondary schools in Ijebu, Ogun State.

The findings of this study provide empirical evidence that adaptive simulations significantly improve student learning outcomes, particularly in science subjects like Chemistry and Physics. Simulation-based instruction enables a more interactive, visual, and personalized learning environment, resulting in greater comprehension, engagement, and retention compared to traditional methods. The pronounced impact in Physics suggests that simulations are especially beneficial in subjects with abstract and experimental content. Furthermore, the study demonstrates that educator perception and student satisfaction are crucial to the successful implementation of such innovations. These results advocate for educational reform that embraces technology-enhanced learning as a core component of the Nigerian secondary school curriculum, particularly in STEM education.

Future research should focus on the following. Firstly, investigating their long-term impact on student learning by tracking retention and academic progress over extended periods. Secondly, broaden the geographical reach across Nigeria to identify regional differences and improve the generalizability of findings. Thirdly, exploring the effectiveness of these simulations in non-STEM subjects (like Social Sciences and Languages) will determine their wider educational use. Lastly, developing a cost-efficiency models to assess the economic feasibility and scalability of simulation-based instruction, especially in schools with limited resources.

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