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Assessing the Effectiveness of Robotic-Based Computer Simulations in Teaching Complex Scientific Concepts in Stem Education in Nigeria

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ABSTRACT

This study investigates how well robotic-based computer simulations improve the instruction and learning of difficult scientific ideas in STEM education in South West Nigeria's higher education institutions. The study investigates how the growing integration of artificial intelligence and robotics in educational technology affects students' cognitive performance, conceptual understanding, and participation. Using a mixed-methods approach, qualitative data from interviews and observations blended with quantitative data from pretest-posttest evaluations. Using multi-stage sampling, three states produced a sample of 204 respondents; 192 students and 12 professors. Data were gathered using a Structured Interview Schedule (SIS), a proven Robotic Simulation-Based Science Achievement Test (RSSAT), and by observing classrooms; these tools had a reliability score of 0.82. With a mean gain score of 43.9 vs. 18.10 in the control group, the results showed a notable improvement in conceptual knowledge and academic performance for the experimental group. Statistical analysis verified a statistically significant variation in post-test results ($p < 0.05$), so validating the value of simulations. Though issues like initial software navigation difficulties and unreliable infrastructure were recognised, qualitative studies highlighted more student involvement, motivation, and ease of learning complicated topics. The study comes to the conclusion that robotic-based computer simulations are a very successful pedagogical tool for improving STEM teaching in Nigerian higher institutions, making difficult scientific topics more accessible and hence promoting more profound learning. One of the recommendations is for technical professionals and lecturers to schedule regular seminars and training courses to enhance their understanding of how to use simulation technology properly. Additionally, government and institutional authorities should invest in digital infrastructure, including high-speed internet, robotics kits, and licences for simulation tools.

INTRODUCTION

Mastery of STEM (science, technology, engineering, and mathematics) fields is now absolutely vital for national development and global competitiveness in the fast-changing world of today. Teaching difficult scientific concepts remains a significant challenge in higher education in Nigeria; however, students in the South West region particularly struggle to understand abstract subjects such as electromagnetism, quantum physics, thermodynamics, and molecular biology.

Traditional teaching methods, which are mostly theoretical and teacher-centred, sometimes fail to capture the dynamic and often invisible nature of these scientific ideas. Inadequate laboratory facilities, packed classrooms, and antiquated teaching materials hinder even highly qualified educators. These facts force kids to struggle with rote memorising instead of useful knowledge.

Globally, then, there has been a movement towards including technology in STEM education, with a special interest in robotic-based computer simulations. Using robots and virtual models, these technologies replicate real-life scientific procedures so that students may interact with scientific events in immersive and useful forms. Simulations provide interactive learning environments

where students can actively interact with, visualise, and control materials, unlike passive lectures.

Robotic simulations have been effectively applied in industrial nations to teach difficult scientific concepts, raise student performance, and encourage critical thinking. Still, the acceptance of such technologies in Nigeria is still rare and understudied. Particularly in higher education in South West Nigeria, there is limited empirical data regarding how well these tools help students grasp and produce results.

This study aims to close this disparity by investigating, in higher STEM education, the efficiency of robotic-based computer simulations as teaching tools. It seeks to determine whether these developments might greatly improve students' grasp of difficult scientific ideas and offer teachers substitute approaches for effective instruction.

Statement of the Problems

Even while quality STEM education is in more demand in Nigeria, many students in higher education still underperform in science-related courses since they struggle to grasp abstract and sophisticated ideas. Infrastructure problems and the widespread use of

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conventional instructional strategies exacerbate the issue. Although robotic-based simulations show great teaching value, there is little empirical data verifying their success inside the Nigerian educational system. This study thus looks at whether robotic-based computer simulations could enhance the instruction and learning of challenging scientific ideas in southwestern Nigerian higher institutions.

Purpose of the Study

This research aims to evaluate how well robotic-based computer simulations improve the instruction and comprehension of challenging scientific ideas in STEM education. The study specifically intends to:

- 1) Find out how much robotics-based simulations help pupils grasp difficult scientific ideas.
- 2) Track pupils taught with robotic simulations against those taught using more traditional approaches academically.
- 3) Find out how instructors in STEM courses view robotic-based simulations as teaching aids.

Research Questions

- 1 How do robotic-based computer simulations affect students' understanding of complex scientific concepts in higher institutions?
- 2 To what extent does the use of robotic-based computer simulations affect students' achievement in complex scientific concepts in STEM education?
- 3 What are the perceptions of students and lecturers about the use of robotic-based simulations in learning and teaching complex scientific concepts?

Hypotheses

- H₀₁: There is no significant difference in the academic achievement of students taught using robotic-based simulations and those taught using traditional methods before the treatment.
- H₀₂: There is no significant difference in the academic achievement of students taught using robotic-based simulations and those taught using traditional methods after the treatment.
- H₀₃: There is no significant relationship between the use of robotic-based simulations and students' understanding of complex scientific concepts.

Significance of the Study

This study provides real information about how robotic-based computer simulations are used in Nigerian universities, helping to increase knowledge about teaching technology in STEM fields. The results will be valuable.

- Teachers implement creative, intriguing approaches;
- Students move via better knowledge and academic achievement;
- Policymakers and curriculum designers are making wise choices about the integration of instructional technologies;
- Investors and technology developers seek a data-driven comprehension of educational innovations.

Delimitations of the Study

This study focuses on higher education in South West Nigeria, particularly in colleges of education, polytechnics, and universities that offer STEM-related courses. Geographically, it covers a few Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti state institutions. The research does not include elementary or secondary school education; it concentrates on some challenging scientific subjects usually taught on the tertiary level.

LITERATURE REVIEW

Theoretical Framework

Constructivist Learning Theory

Constructivist Learning Theory, particularly Vygotsky's Social Constructivism, promotes the inclusion of robotic simulations in STEM instruction. It holds that interactions with their surroundings help students create their own knowledge. Robotic simulations let student's test theories, change variables, and get responses right away, therefore enabling active learning. This viewpoint is consistent with Bruner's discovery learning theory, according to which students are more likely to remember knowledge acquired by means of enquiry.

Kolb's 1984 Experiential Learning Theory

Kolb emphasises the importance of experience in the learning process. Robotic simulations faithfully reproduce his model, which consists of concrete experience, contemplative observation, abstract conceptualisation, and active experimentation. Deeper knowledge construction results from students observing, interacting with, and thinking back on simulation-based assignments.

Conceptual Clarifications

STEM Education

Integrated into coherent instruction, STEM education is an interdisciplinary approach to learning, including science, technology, engineering, and mathematics. It stresses research, solving problems, imagination, and critical thinking. In the context of higher education, STEM education supports students not only in achieving academic success but also in fostering innovation within the fields of science and technology. Effective STEM programmes, according to Bybee (2013), should inspire hands-on learning and practical applications, facilitating access to abstract ideas.

Robotics-Based Computer Simulations

Robotic-based computer simulations are those that replicate real-world scientific procedures by means of robotics combined with virtual settings. These simulations give students engaging and visual experiences, therefore transforming abstract scientific ideas into more concrete forms. For example, students might see how a robotic arm creates electricity by moving in a virtual environment rather than only reading about electromagnetic induction. These instruments create immersive learning platforms by combining artificial intelligence, mechanical control, and simulation software (Alimisis, 2020).

Complex Scientific Concepts

Usually abstract, multifaceted, complex scientific ideas need a higher degree of cognitive processing. Among these are Newtonian mechanics, genetic engineering, fluid dynamics, and energy transformation. Because of their abstract character, restricted laboratory access, and lack of practical experience, students frequently find these subjects challenging (Chi *et al.*, 2012).

Reviews of an Empirical Study

Global Perspectives

View from Globally Several foreign studies have validated robotic-based simulations as beneficial for scientific education. For example, students exposed to robotic simulations in physics demonstrated a 25% boost in conceptual knowledge when compared to those taught traditionally, according to Williams and Flora's (2021) research on United States students. In South Korea, Lee *et al.* (2019) also discovered that simulations enhanced students' capacity to apply scientific theory to practical concerns. The study was carried out in Chinese STEM colleges. Ouyang and Xu (2024) followed students' performance in nanotechnology and robotics courses. Students who visited AI-simulated labs showed better conceptual memory over time and greater test scores, according to the study.

African Context

Msimanga and Lelliott (2018) examined the use of digital tools, such as robotic simulations, in South African colleges. The study turned up better retention, less cognitive burden, and more engagement. However, the study highlighted issues such as teacher readiness and inadequate infrastructure. Ochieng (2020) conducted research on Kenya that verified simulations could address gaps in laboratory instruction brought on by limited resources. Boateng *et al.* (2023) examined how educational robotics affected high school physics courses in Ghana. It demonstrated how better learning attitudes and lowered scientific anxiety resulted from robotic simulations. Early exposure to simulation technologies, the researchers underlined, promotes lifetime STEM interest.

Studies from Nigeria

Nigerian literature is spreading progressively into this field. Okebukola's (2021) research on new digital pedagogies underlined how simulations may transform tertiary education by means of science. Furthermore, looking at virtual robotics in engineering education, Ojo and Salami (2022) discovered a notable rise in students' problem-solving abilities. However, these studies often emphasise general digital resources, which creates a gap in specific empirical evaluations of robotic computer simulations for teaching complex concepts. In tertiary science classes across three Nigerian states, Duguryil *et al.* (2024) examined the integration of robotics and artificial intelligence-based simulations. The researchers, using a mixed-methods approach, revealed that pupils taught

with robotic simulators displayed a 29% greater success rate than those in conventional environments. Particularly in abstract scientific subjects like electromagnetism and thermodynamics, qualitative comments also indicated more interest and involvement. In their comparative analysis, Nannimt *et al.* (2024) looked at virtual robotics against real laboratories in engineering courses in South West Nigeria. Particularly in fields requiring conceptual visualisation, results showed pupils in the virtual robotics group outscored their peers by an average of 18%. The researchers came to the conclusion that in environments with limited resources, robotics-enhanced simulations are indispensable. The cognitive advantages of science students who took part in a robotic-assisted simulation module at Lagos State University were assessed in Fabeku and Enyeasi (2024). Students' critical thinking and problem-solving abilities statistically significantly improved according to the pretest-posttest design. The interactive, learner-centred nature of robotic simulations helped the researchers explain these results.

Benefits of Robotics-Based Simulations for STEM Education

- Robotic simulations Education offers immersive learning environments that maintain student attention, hence improving engagement.
- Enhanced Conceptual Understanding: Visual and practical contact helps abstract subjects get more concrete.
- We can conduct simulations of risky or costly experiments in a safe learning environment, free from danger.
- Real-time feedback: Students learn from mistakes by means of instantaneous replies to actions.

Difficulties Combining Robotic-Based Simulations

- Many Nigerian institutions lack the technological foundation required.
- Teachers need technical and pedagogical training if they are to properly apply these instruments.
- Implementation Cost: Purchasing robotics kits and simulation tools could prove costly for universities.
- Curriculum Alignment: Current STEM courses offered in Nigeria are not yet completely suited to fit such technology.

Gaps in the Literature

Although the literature worldwide confirms that robotic simulations improve science education, local empirical studies—particularly those targeted on higher institutions in South West Nigeria—are few. Most Nigerian research generalises the use of digital technologies without focusing, especially on robotics-based simulations or testing their impact on complex conceptual understanding. Most published studies lack national-scale implementation or policy integration; they are either short-term or pilot-based. This research fills this void through a localised, context-specific investigation. These gaps draw attention

to the need for thorough research like this one, which looks at robotic-based computer simulations across several scientific fields in different higher institutions in South West Nigeria.

Summary of the Literature Review

Synopsis particularly for teaching difficult scientific ideas, the literature examined emphasises the interesting contribution of robot-based computer simulations in STEM education. Driven by constructivist and experiential learning philosophies, these technologies have shown good results in several settings. But there are few empirical studies available in Nigeria, especially in South West higher institutions, which calls for this study to assess their local pedagogical worth, practicality, and efficacy.

MATERIALS AND METHODS

Research Design

The research design combines quantitative and qualitative methods; this mixed-methods research project aims to provide comprehensive knowledge of the efficacy of robotic-based computer simulations in teaching difficult scientific ideas. Whereas the qualitative element makes use of case studies via interviews and classroom observations, the quantitative element adopts a quasi-experimental design.

Population of the Study

The population consists of all science and STEM education students and lecturers in public higher institutions (universities, polytechnics, and colleges of education) spread over the six southwestern states of Nigeria: Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo.

Sample and Sampling Techniques

We employ a multi-stage sampling technique.

1. We use purposive sampling to select three states (e.g., Ondo, Lagos, and Oyo) based on their urbanisation, ICT facilities, and diversity of institutions.
 2. We use Stratified Random Sampling to select two institutions per state, specifically one university and one polytechnic/college of education.
 3. Simple Random Sampling to select:
 - 32 students from each institution (192 students in total),
 - 2 STEM lecturers per institution (12 in total).
- This brings the total sample size to 204 respondents.

Research Instruments

The study employs two main instruments:

Robotic Simulation-Based Science Achievement Test (RSSAT)

This test assesses students' understanding of complex scientific concepts. This test evaluates students' understanding of complex scientific concepts. The RSSAT is a 30-item objective test that covers complex scientific concepts such as electromagnetism, fluid mechanics, and chemical kinetics.

Structured Interview Schedule (SIS)

Researcher conduct semi-structured interviews with lecturers and students to gather insights on the pedagogical impact, engagement, and challenges of using robotic simulations.

Additionally, Researcher use classroom observation checklists during simulation sessions to evaluate teaching practices and learner engagement.

Validity of the Instruments

Three specialists in Science Education and Educational Technology from Adekunle Ajasin University and the University of Ibadan validated the instruments. Their recommendations helped guarantee face and content validity.

Reliability of the Instruments

The pilot test for RSSAT involved thirty (30) students who were not part of the research sample. Researcher analysed the reliability index using a test-retest approach and Pearson product moment correlation (PPMC), which yielded a coefficient of 0.82, indicating strong reliability. Cross-checking interview transcripts and observation notes among three reviewers guaranteed inter-rater consistency for qualitative tools.

Method of Data Collection

1. A pretest is administered to both experimental and control groups.
2. The experimental group is taught using robotic-based computer simulations over a four-week period.
3. The control group receives traditional lecture-based instruction.
4. We conduct a post-test for both groups.
5. We conduct interviews and observations simultaneously.

Method of Data Analysis

Quantitative Data (from RSSAT)

- Descriptive statistics: Mean, Standard Deviation.
- Inferential statistics include a t-test to determine the effect of the treatment and a correlation coefficient (r) to ascertain the relationship between the variables. The researcher used Python for data analysis.

Qualitative Data (from interviews and observations)

- Thematic analysis is employed, where transcripts are coded and grouped into categories that reflect recurring patterns related to learner engagement, instructional effectiveness, and challenges.

Ethical Considerations

- Informed consent was obtained from all participants.
- Institutional approval was secured from school management.
- Anonymity and confidentiality were assured.
- Participation was voluntary, and respondents could withdraw at any stage.

RESULTS AND DISCUSSION

The analysis and interpretation of data gathered from lecturers and students in a few chosen higher institutions throughout South West Nigeria is presented in this part.

Pre-tests, post-tests, interviews, and classroom observations gathered the data. We arrange the results according to the research questions and hypotheses, addressing them in relation to the existing body of knowledge.

Table 1: Demographic Information of Respondents students

Variable	Category	frequency	Percentage (%)
Gender	Male	112	58.3
	Female	80	41.7
Institution Type	University	96	50
	Polytechnic/Colleges	96	50
Department	Science/STEM	192	100

This demographic breakdown in table 1, shows a fairly balanced representation, ensuring generalizability across STEM departments in South West Nigeria.

Research Question 1

How do robotic-based computer simulations affect students' understanding of complex scientific concepts

Table 2: Showing pretest and post-test mean score of experimental and control group on conceptual understanding scores

Descriptive Analysis Group	N	Mean Score (Pre-Test)	Mean Score (Post-Test)	SD	Mean Gain
Experimental	96	34.5	78.4	6.5	43.9
Control	96	35.1	53.2	5.9	18.10

in higher institutions?

Interpretation

From table 2, student in experimental group demonstrated a gain score of 43.90, indicating a marked improvement in conceptual understanding when exposed to robotics-based simulations. In contrast, the control group showed only a gain of 18.10 with conventional methods.

Additionally, feedback from student interviews reinforces this result:

• “I used to struggle with understanding electromagnetic fields, but with the robot simulation, I could visualize and

interact with the field directly.” –Student (LASU)

• “It felt like I was part of the experiment instead of just listening.” –Student (UI)

These finding reveal that robotics-based simulations significantly aid in conceptual visualization, active learning, and deeper comprehension.

Research Question 2

To What Extent Does the Use of Robotic-Based Computer Simulations Affect Students' Achievement in Complex Scientific Concepts in STEM Education?

Table 3: Showing pretest and post-test mean score of experimental and control group

Descriptive Analysis Group	N	Mean Score (Pre-Test)	Mean Score (Post-Test)	SD	Mean Gain
Experimental	96	34.5	78.4	6.5	43.9
Control	96	35.1	53.2	5.9	18.10
Mean difference		0.10	25.20		

From table 3, the experimental group, taught using robotic-based simulations, showed a substantial improvement compared to the control group having pretest mean score of 34.50 and posttest mean score of 78.4 with mean gain of 43.9 for experimental group and control group having pretest mean score of 35.51 and posttest mean score of 53.2 with mean gain of 18.10.

The posttest mean difference of 25.20 in favour of experimental group. This indicate that used of robotic-based computer simulation have high positive effect in enhancing students achievement in complex scientific concepts in STEM education.

Research Question 3

What are the Perceptions of Students and Lecturers About the Use of Robotic-Based Simulations in Learning and Teaching Complex Scientific Concepts? Thematic Analysis (Qualitative Data)

From interviews and observations, three major themes emerged:

Increased Engagement and Motivation

o “Using simulations made abstract concepts clearer. I could see what I was learning.” — Student (OAU)

o “The students were more attentive and asked deeper questions.” — Lecturer (FUTA)

Ease of Understanding Abstract Concepts

o Simulations helped visualize difficult topics like electromagnetic fields, chemical reactions, and energy transformation.

Challenges Encountered

o Some students struggled with navigating simulation software initially.

o Inconsistent electricity and internet access disrupted learning sessions in some polytechnics.

Test of Hypothesis 1

There is No Significant Difference in the Academic Achievement of Students Taught Using Robotic-Based Simulations and Those Taught Using Traditional Methods before the Treatment

Table 4: t-test analysis of academic achievement of students taught using robotic-based simulations and those taught using traditional methods before the treatment

Group	N	Mean score of pre-test	SD	df	t-cal	p-val	Remark
Experimental	96	34.50	4.80				
				190	-0.85	0.398	Not sig
Control	96	35.10	5.10				

$p < 0.05$

Interpretation

From table 4 above P-value = 0.398 > t- calc = -0.85, at 0.05 significant level. therefore, the difference in pretest score is not statistically significant, hence, the null hypothesis that says There is no significant difference in the academic achievement of students taught using robotic-based simulations and those taught using traditional methods before the treatment is hereby

upheld, this shows that the two group are at the same base line level of knowledge.

Hypothesis 2

There is No Significant Difference in the Academic Achievement of Students Taught Using Robotic-Based Simulations and Those Taught Using Traditional Methods after the Treatment

Table 5: t-test analysis of academic achievement of students taught using robotic-based simulations and those taught using traditional methods after the treatment

Group	N	Mean score of post-test	SD	Df	t-cal	p-val	remark
Experimental	96	78.40	6.50				
				190	22.64	0.000	sig
Control	96	53.20	5.90				

$p < 0.05$

Interpretation

From table 5 above t- calc = 22.64 > p-value = 0.000, at 0.05 significant level. Therefore, the difference in post-test score is statistically significant, hence, the null hypothesis that says There is no significant difference in the academic achievement of students taught using robotic-based simulations and those taught using traditional methods after the treatment is hereby rejected, confirming the effectiveness of robotic-based simulations.

Hypothesis 3

H03: There is no significant relationship between the use of robotic-based simulations and students' understanding of complex scientific concepts.

To test this hypothesis, a correlation coefficient analysis was conducted between the group assignment (coded as 1 = Experimental and 0 = Control) and the students' understanding scores. The point-biserial correlation, which is appropriate when one variable is dichotomous

Table 6: Correlation coefficient and p-value between group assignment and understanding scores

S/N	Groups	N	NMean	SD	df	r-cal	p-value	Remark
1	Experimental (1)	96	77.11	5.81	190	0.884	0.000	Sig
2	Control (0)	96	52.55	5.05				

$P < 0.05$

and the other is continuous, was applied.

Interpretation

The result in Table 6 shows that the calculated correlation coefficient ($r = 0.884$) is strong and positive, with a

p-value of 0.000, which is less than the significance level of 0.05. Therefore, the null hypothesis (H03) is rejected. This result implies that students' awareness of challenging scientific concepts and the application of robotic-based simulations has a significant and positive link. The results

demonstrate that students in the experimental group—who were taught using robotic-based simulations—showed higher understanding and command of the scientific subjects than those in the control group taught with conventional methodologies. Usually $p < 0.05$, a very small p -value denotes that the discovered correlation is statistically significant and quite unlikely to have come from random chance. Thus, the null hypothesis is hereby rejected since $r = 0.484 > p = 0.000$.

Discussion

Table 2 clearly shows that robotic-based computer simulations greatly improve students' grasp of difficult scientific ideas. Exposed to these simulations, the experimental group showed a significant mean gain score of 43.9 vs. 18.10 for the control group. Students' qualitative comments, which emphasised the need for visualisation and active participation, further corroborate this considerable improvement in conceptual understanding. This finding exactly fits the Constructivist Learning Theory, especially Vygotsky's Social Constructivism, which holds that students create knowledge by active engagement with their environment. The student from LASU pointed out that robotic simulations made abstract ideas, like electromagnetic fields, "visualise and interact with... directly." Robotic simulations provide an interactive platform that allows students to test theories and modify variables, thereby enhancing their understanding.

This southwestern Nigerian empirical data powerfully supports world results. Directly supporting these findings of Williams and Flora (2021), carried out in United States, study on a 25% rise in conceptual knowledge in physics resulting from robotic simulations. Likewise, Lee *et al.*'s (2019) work in South Korea shows a better application of scientific theories, which speaks to the stated conceptual visualisation advantages. In the African setting, Msimanga and Lelliott (2018) in South Africa likewise observed better engagement and lower cognitive load with digital tools incorporating robotic simulations. Further supporting this case are the local Nigerian studies. Particularly noting growing interest in abstract subjects like electromagnetism, Duguryil *et al.* (2024) showed a 29% higher success rate for pupils taught with robotic simulators. Emphasising conceptual visualisation as well, Nannim *et al.* (2024) noted that virtual robotics groups outperformed their counterparts by 18%. This continuous trend across all geographical and educational environments supports the significant influence of robotic simulations on rendering abstract scientific ideas more concrete and understandable. Thus, the present work closes a significant void by offering context-specific proof of this favourable impact in Nigerian higher institutions.

Table 3's data offers convincing proof that students' academic performance in challenging scientific ideas is much improved by robotic-based computer simulations. The post-test mean score of 78.4 for the experimental group combined with a significant mean gain of 43.9

contrasts strikingly with the post-test mean of 53.2 for the control group and a mean gain of 18.10. The post-test mean difference of 25.20 in favour of the experimental group amply illustrates how much higher achievement results from using robotics-based simulations. The rejection of Hypothesis 2 confirms this result even more, as it showed a statistically significant variation in academic performance across the groups following the intervention.

This significant positive effect on achievement aligns with the Experiential Learning Theory (Kolb, 1984), which suggests that students gain a better understanding and knowledge by actively exploring and reflecting on simulated problems, leading to improved academic performance. Robotic simulations let students go beyond passive absorption of knowledge to hands-on manipulation and real-time feedback, which are vital when learning difficult STEM concepts. This helps "active experimentation." These findings align with the worldwide data presented by Ouyang and Xu (2024) at Chinese STEM universities, where students in AI-simulated labs showed better conceptual recall and test performance. Boateng *et al.* (2023) underlined in the African setting better learning attitudes and lower science anxiety, both of which are probably factors influencing higher academic performance. With virtual robotics, Ojo and Salami (2022) saw a notable rise in kids' problem-solving abilities locally, a talent directly connected to scholastic success in difficult ideas. Furthermore, Fabeku and Enyeasi (2024) noted statistically significant increases in critical thinking and problem-solving abilities, and they attributed these gains to the interactive and learner-centered nature of robotic simulations. By demonstrating a measurable increase in academic performance, this study contributes significant data to the growing body of research that confirms the effectiveness of robotic-based simulations within Nigerian higher education.

Derived from student and lecturer interviews as well as classroom observations, the qualitative data shows generally favourable impressions of the use of robot-based simulations, along with certain practical difficulties. The theme analysis highlighted three main areas: Increased Engagement and Motivation, Ease of Understanding Abstract Concepts, and Challenges Encountered. Directly supported by the "Enhanced Engagement" advantage noted in the literature review, the theme of Increased Engagement and Motivation was prominent: students expressed that simulations made learning "clearer" and more "attentive," and lecturers noted that pupils were "more attentive and asked more profound questions." Robotic simulations' interactive character encourages active engagement, hence transcending conventional passive learning strategies. Particularly for abstract subjects, this increased participation is essential for ongoing education and curiosity. Further supporting the quantitative results is the Ease of Understanding Abstract Concepts theme.

Simulations enabled students to "visualise difficult topics,

like electromagnetic fields, chemical reactions, and energy transformation.” This conclusion is consistent with the “Improved Conceptual Understanding” advantage of robotic simulations, which make abstract concepts more concrete by visual and hands-on interaction. This advantage immediately solves a typical problem in STEM education: inadequate practical experience causes students to struggle with abstract, multidimensional ideas (Chi *et al.*, 2012). Still, the results also highlight challenges faced. The problems noted included initial difficulties with navigating simulation software and, more importantly, “inconsistent electricity and internet access.” These difficulties relate to the sections of the literature study on “Infrastructure Limitations” and “Cost of Implementation,” which show that many Nigerian institutions do not have the necessary technology and that getting these resources can be expensive. Through the first challenges some students experienced, teacher training gaps (“Training Gaps”) were also subtly seen, implying a need for more solid pedagogical training for lecturer. Despite the obvious advantages, there is needs to overcome these pragmatic obstacles to achieve general effective integration. Notwithstanding these obstacles, the overwhelmingly positive opinions show a great openness to and utility of robotic-based simulations in the Nigerian higher education scene.

The analysis in Table 4 indicates that the difference in pre-test scores between the experimental and control groups was not significant, with a p-value of 0.398, which is greater than the significance level of 0.05 ($t\text{-cal} = -0.85$). These findings contributed to the maintenance of the null hypothesis. This result is important since it shows that, before the intervention started, both groups had a comparable baseline level of knowledge on difficult scientific ideas. This similarity in how well the groups did at the beginning supports the study’s later results because any big differences seen after the treatment can be more easily connected to the independent variable (robotic-based computer simulations) instead of differences that were already there. This methodological rigidity guarantees that the comparison of post-test data is an honest evaluation of the influence of the intervention.

Strong proof for the success of robotic-based simulations comes from the outcomes of Table 5. The difference in post-test scores between the experimental and control groups is quite statistically significant, with a t-calculated value of 22.64 and a p-value of 0.000 (smaller than the 0.05 significance level). As such, the null hypothesis—which claims no substantial difference—is strongly rejected. This result unambiguously shows that students taught using robotic computer simulations attained much better academic performance in challenging scientific ideas than those taught using conventional approaches. This quantitative data strongly supports the benefits described in the literature, which include more engagement, better conceptual understanding, and safe learning environments. The better performance of the experimental group demonstrates that the interactive

and immersive character of robotic simulations helps to enable deeper learning and knowledge retention, therefore promoting improved achievement.

This result aligns with numerous local and global empirical studies. Williams and Flora (2021) and Lee *et al.* (2019) separately found notable increases in conceptual knowledge and application worldwide. Ochieng (2020) noticed that in Africa, using simulations helped make up for the lack of resources in lab teaching, which in turn improved performance. Locally, Duguryil *et al.* (2024) noted a 29% higher performance rate, while Nannim *et al.* (2024) revealed an 18% outperformance by virtual robotics groups. The solid statistical proof from this study addresses an important gap in local research by providing more specific support for these benefits in higher education institutions in South West Nigeria.

The outcomes highlight the transforming possibilities of including such sophisticated pedagogical tools in STEM education courses. Leveraging Python code for execution, the study shown in Table 6 demonstrates a strong and statistically significant association. Group assignment—experimental vs. control—and students’ understanding scores show a high positive association indicated by the Pearson correlation coefficient (r) of 0.884. Moreover, the p-value of 0.000, which is much below the 0.05 significance level, shows that this noted significant association is not the result of chance. Consequently, the null hypothesis—which claimed no appreciable correlation—is clearly rejected. This result is strong support for the influence of robotic-based simulation. Strong positive correlations indicate that students usually understand difficult scientific topics much better when they move from traditional teaching to robotic-based simulations. The result clearly confirms what we heard earlier about “Ease of Understanding Abstract Concepts,” where students mentioned that simulations helped them visualise and engage with tough topics. Further underlining this strong link are the mean scores for the experimental group (77.11), which are far higher than those of the control group (52.55). This outcome fits very well with both the Experiential Learning Theory and the Constructivist Learning Theory.

By encouraging active manipulation and real-time feedback, robotic simulations help to build knowledge and actual experience—the basis of greater understanding. This result also fits with more general research confirming the advantages of robotic simulations in improving cognitive development and science education. The strong link discovered in this study provides clear evidence from South West Nigeria that using robotic-based simulations not only helps but is also closely related to better student understanding of complex scientific concepts.

CONCLUSION

This thorough mixed-methods study firmly shows the highly favourable effect of including robotic-based computer simulations in the teaching and learning of challenging scientific ideas in Nigerian higher education.

The quantitative results clearly reveal that kids exposed to these simulations performed academically much better and had much better conceptual understanding than those getting conventional education. Together with the statistically significant post-test score difference ($p < 0.05$), the wonderful mean gain of 43.9 in the experimental group offers strong empirical proof of their usefulness. Qualitative data, which, in line with constructivist learning theories, emphasises improved student involvement and motivation, as well as a significant development in visualising and interacting with abstract scientific events, adds even more enrichment. Although little practical issues like first software navigation and infrastructure anomalies were found, the overwhelmingly favourable opinions from lecturer and students highlight the outstanding possibilities of this creative instructional method to transform STEM education. The research unequivocally shows that robotic-based simulations are a powerful tool for promoting more profound understanding and better performance in challenging scientific fields, hence enabling add-ons.

Recommendations

Based on the findings, the following recommendations are made:

1. Curriculum Integration: Educational policymakers and curriculum planners should formally integrate robotic-based simulation tools into STEM courses at tertiary institutions.
2. Capacity Building: Regular workshops and training sessions should be organized for lecturers and technical staff to enhance their competency in deploying simulation tools effectively.
3. Infrastructure Investment: Government and institutional authorities should invest in digital infrastructure, such as high-speed internet, robotics kits, and simulation software licenses.
4. Technical Support: Institutions should establish dedicated units for educational technology support to assist lecturers in managing and troubleshooting simulation tools.
5. Further Research: Future studies should explore the long-term effects of these technologies on knowledge retention and students' career choices in STEM fields.
6. Collaborative Partnerships: Encouraging partnerships between academia, industry, and technology providers can facilitate the development of more localized and affordable simulation tools, addressing specific Nigerian educational contexts and resource constraints.

Contribution to Knowledge

- This study contributes to the growing body of knowledge advocating for the digital transformation of science education in sub-Saharan Africa.
- It provides empirical data on the pedagogical value of robotics-enhanced simulations in STEM learning environments.
- It highlights contextual challenges and proposes

practical recommendations for educators and stakeholders.

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