EFFECT OF PHET STRATEGY ON SENIOR SECONDARY SCHOOL STUDENTS' ACHIEVEMENT IN PHYSICS IN FEDERAL CAPITAL TERRITORY, ABUJA

By

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ABSTRACT

The study investigated the effect of PHET strategy on senior secondary school students' achievement in Physics in Abuja Municipal Area Council, Abuja. The study used quasi-experimental research design involving the non-randomized pretest, posttest, control group design. The population of the study comprised 6,638 SS II Physics students from 15 public secondary schools in Abuja Municipal Area Council, Abuja. The sample for this study consisted of 195 SS II Physics students from two senior secondary schools in Abuja Municipal Area Council. Data were collected using Physics Achievement Test (PAT). The reliability coefficients of 0.88 was obtained for PAT through Kuder-Richardson 21 method. Descriptive statistics of mean and standard deviation was used to answer the research questions while null hypotheses were tested using Analysis of Covariance (ANCOVA) at 0.05 alpha level of significance. The findings revealed that students taught Physics using PhET simulation strategy achieved significantly higher scores compared to students taught using conventional method. The ANCOVA analysis confirmed this difference as highly significant, with an extremely large effect size suggesting that approximately 94.0% of the variance in posttest achievement scores could be explained by the teaching method. Based on outcomes of the findings, the study recommended among others that the Federal Ministry of Education and Nigerian Educational Research and Development Council (NERDC) should integrate PhET simulation strategy into the national Physics curriculum for senior secondary schools.

Keywords: PHET, Strategies, Senior, Secondary, Schools, Nigeria, FCT, Abuja

INTRODUCTION

Science is the study of nature; it is a body of knowledge which can be transformed into a system and which uses experiment as tool to authenticate facts while technology is the practical application of scientific knowledge. LinkedIn (2017) observed that a nation without science and technology is definitely a backward nation. Such nation will be considered under developed. Science and technology are associated with modernity and it is an essential tool for rapid development. Also, Adedokun (2015) posited that, in Nigeria, consequent to the nation's adoption of a National Economic Empowerment and Development Strategies (NEEDS); and the Nigerian Educational Research and Development Council, greater emphasis is now being placed on industrial and technological development. It is of interest to know that science subjects hold an important position to the achievement of these goals and objectives (NERDC, 2017). Students therefore are encouraged to take up science related subjects. Adedokun (2015) stressed further that for Nigeria to be able to compete favourably in technological advancement with other developing nations of the world there is the need to make science more interesting among learners.

One of the key science subjects is Physics. Physics is a branch of science and as a field of endeavour which plays a major role in reducing inequalities, developing powerful ways of thinking, increasing the freedom to choose a wider range of career in the world of work and increasing globalization with its challenges, potentials and possibilities (Achuonye 2014). Physics deals with the study of matter and its relationship with energy (Anyakoha, 2018). Physics plays an essential role in explaining the events that occur in the universe and everything that takes place around us. Everything that happens around us is governed by physical rules and principles. Physics is challenging to study because students tend to view some of the laws and concepts as abstract (Guido, 2018). Therefore, the subject of Physics embodies the study of the principles and applications of the three states of matter namely; solids, liquids and gases, which are indeed inter-related with respect to their energy production. Physics deals with practical and experimental understanding of natural phenomena that brings about the acquisition of the process skills of science methods. Physics is a branch of science that deals with the study of matter and energy and their interaction. It is sometimes referred to as the science of measurement and its knowledge has contributed greatly to the production of instruments and devices of tremendous benefits to the human race. Physics provides the basic knowledge and understanding of principles, whose applications contribute immensely to the quality of life in the society. The knowledge of Physics forms the basis for technological advancement of any nation.

Grasha and Hicks (2020) observed that the extents to which students attain the required experiences are influenced by learning and teaching styles during instruction. Therefore, the teacher's teaching style will either support the learning style or pressure it to change. Hence, physics teachers need to use the appropriate teaching styles and methods that can stimulate the interest of students towards the learning of the subject so as to realize the ultimate goal in the curriculum and in the National Policy on Education. According to National Policy on Education (FRN, 2014), Physics curriculum needs to achieve the following objectives: (i) to give learners basic knowledge in Physics in order to contribute positively to the community; (2) to possess basic concepts and principles of Physics as a prerequisite for higher learning; (3) to possess necessary attitudes that prepare learners for technological application of Physics. The importance of the study of Physics and its application as a major pre-requisite for the attainment of scientific and technological development has long been recognized world-wide. Ameh (2014) observed that in America, investment in educational research and development in Physics and Mathematics amounted to five billion dollars in 1984 alone. No doubt, Physics and mathematics are complimentary subjects in that the study of one helps in the understanding of the other's concepts, principles and practices. For instance, the invention and working of the computer and telephone of any kind is simply an extension of the knowledge of Physics. It is a major contributor to technology through its nature and for proper understanding of technical subjects. This is why Physics needs to be taught very well in order to enable students develop interest in the subject and thus improve achievement.

Despite the noble objectives of Physics, the academic achievements of students at external examinations have been poor in Nigeria. This has resulted in a decline in the percentage of secondary school students choosing Physics as their major, and it continues to worry researchers and teachers globally (Barmby & Defty, 2016). For example, teachers in Nigerian secondary schools have discovered that their students struggle greatly with understanding fundamental Physics concepts, which results in a lack of enthusiasm for the subject (Saleh, 2017). This is evident in the poor academic achievement recorded in Physics by students who wrote the 2024 West African Senior School Certificate Examination (WASSCE) conducted by the West African Examinations Council (WAEC).

The critical question here is: Why, despite decades of teaching Physics using predominantly conventional methods, do students continue to perform poorly and show declining interest in the subject? Could the teaching method itself be a significant part of the problem? The number of candidates that participated in Physics WAEC Examination for 2019/2020 academic session was 365 while their percentage passes at credit level and above was 28.7%. Also, for 2020/2021 academic session, 287 participated in Physics, while the percentage performance was 26.3%. In 2021/2022 academic session, the number of candidates in Physics and their corresponding performances were; 365(35.2%). The number of candidates and their performance for 2022/2023 academic session in Physics were; 378 and 39.7%. Finally, for 2023/2024 academic session 405 participated in Physics and 37% passed at credit level and above. What factors could be responsible for the fluctuating nature in the trend of performance in Physics—could the teaching-learning process be a primary culprit? According to Wosu (2015), factors such as differences in learners, where some respond well to doing things while others respond better to being told things, differences in teachers' strengths, their likes or preferences and knowledge of subject matter of what is being taught has made it difficult for one teaching strategy to be adjudged best. The current state of affairs is displeasing and this trend could hamper meaningful development in Nigeria and Federal Capital Territory (FCT) in particular.

The poor academic achievement of students in Physics could be attributed to lack of utilization of appropriate instructional strategies and the abstract nature of teaching Physics concepts. Various activity-based teaching strategies have been employed for the purpose of improving the teaching and learning of Physics at the SS level. These strategies include inquiry, demonstration, process approach, cooperative learning and laboratory activity (Usman, 2017). Some of the problems encountered in teaching and learning of Physics can be attributed to many factors such as poor classroom management, teachers' attitudes toward the teaching of Physics and poor instructional methods and strategies used in teaching and learning of Physics. Also, another issue of concern is students' lack of interest in learning Physics (Okeyefi & Nzewi, 2015). With all these problems, the need arises to use innovative strategies to see whether they will enhance meaningful teaching/learning, develop students' interest and understanding of the concepts taught in Physics. It is therefore pertinent to look for an innovative strategy that could be adopted to improve students' achievements and interest in the subject. One of the instructional strategies which has the potential to offer opportunity to address the problems of teaching and learning Physics concepts is the Physics Education Technology (PhET) interactive simulations strategy.

According to Mbonyiryivuze, Yadav and Amadalo (2022), incorporating technology into teaching and learning has benefits. PhET simulations are essential to fast-developing conceptual knowledge to increase learning and compensate for the lack of actual laboratories in classrooms (Banda & Nzabahimana, 2021). Additionally, Batuyong and Antonio (2018) explained that PhET simulation is a very effective educational tool for use in teaching and studying physics because it raises students' achievement in the subject. PhET (Physics Education Technology) simulation is a set of interactive research-based Science and Mathematics online simulations created at the University of Colorado at Boulder (Coryunitha & Ama, 2017). Studies from many literature works show that PhET simulation can greatly improve students' conceptual understanding of physics courses and can be integrated into numerous learning environments (Banda & Nzabahimana, 2021). The PhET simulations stress the linkages and give students access to the visual and conceptual models used by scientists to bridge the gap between real-world occurrences and the underlying science (Taibu, Mataka & Shekoyan, 2021). They are animated, interactive, and game-like settings where students learn via discovery.

PhET simulations are considered one of the best educational software because they can be accessed for free online or downloaded and saved as web pages that can run on a flash player. PhET

Interactive Simulations, often referred to simply as PhET, are a collection of free online interactive educational tools developed by the University of Colorado Boulder's PhET Interactive Simulations project. These simulations are designed to help students grasp complex scientific concepts through hands-on exploration in a virtual environment. The project was founded in 2002 by Nobel Laureate Carl Wieman. The project acronym "PhET" originally stood for "Physics Education Technology" but PhET soon expanded to other disciplines.

It is based on the realization that students' learning achievement and gender differ and that there is urgent need to address such differentials. Using modern instructional devices such as PhET simulation can help improve learners' learning interest. However, it is disheartening to know that most Physics teachers in the FCT are not familiar with the instructional strategy, let alone applying it during instruction. If effectively utilized, PhET simulation might be of immense benefit to students regardless of gender or initial interest level. The central unanswered question is: Will PhET simulations prove to be the equalizer that not only improves overall physics achievement and interest but also closes any gender gaps that may exist in physics education in FCT? It is based on this realization that the study intends to explore the comparative effects of PhET simulation strategy versus conventional teaching method on senior secondary school students' interest and achievement in Physics in Abuja Municipal Area Council, Abuja, with particular attention to gender differences.

1.2 Statement of the Problem

It is quite disheartening and awful to hear learners talk about how much they dislike a particular subject. Some of them eventually opt out or offer it with grudge against the euphoria that teaching and learning ought to bring. Many teachers, on the other hand, find it very stressful to impart knowledge and seem to view teaching as one of the most difficult tasks on earth. The expressions of apathy on the side of learners and the teachers as well have resulted in poor learning outcomes, as learners see their teachers as not doing enough and could call them quacks, while teachers on the other hand see their learners as not ready to learn. The challenging question here is: Could this crisis of confidence and the resulting poor performance in Physics be fundamentally rooted in the teaching method being employed? Specifically, is the continued dominance of conventional lecture methods in an age of digital learning tools a primary cause of student disengagement and poor achievement?

In spite of the importance of Physics among Nigerian students, achievement at senior secondary school level has been poor. This has posed great concern to many education stakeholders over the years. This decline may be attributed to the fact that students have resorted to memorization of Physics concepts as a result of their passive involvement in the teaching and learning process due to the lecture or conventional method of teaching. It is very obvious that the lecture method of teaching has not truly yielded the required result in terms of students' achievement specifically in Physics. Evidence from WAEC results spanning 2019-2024 shows fluctuating pass rates between

26.3% and 39.7%, with no year exceeding 40% pass rate at credit level. This persistent poor performance, despite teachers continued use of conventional lecture methods, raises the critical question: Why has the traditional teaching approach failed to produce better outcomes, and would a systematic shift to technology-enhanced active learning through PhET simulations produce significantly better results?

This calls for the adoption of other teaching strategies that could ensure the active involvement of students in the teaching and learning process and also provide the opportunity for students to discover new knowledge on their own with little or no assistance from teachers. PhET simulation could be an alternative as it ensures students' active involvement in the teaching and learning process and also encourages students' discovery of new knowledge on their own. However, while the theoretical benefits of PhET simulations are well-documented in international literature, their practical effectiveness in the Nigerian context, specifically in FCT secondary schools, remains empirically unverified. Furthermore, whether these benefits are consistent across gender remains unexplored in this context. The questions which readily come to mind are: Would the mean achievement scores of students taught Physics using PhET simulation strategy be improved? Would gender and interest of students affect their academic achievement in Physics? The thrust of this study evolved answers for these questions.

1.3 Research Questions

The following research questions guided the study:

1. What are the mean achievement scores of students taught Physics using the PhET simulation strategy are those taught using conventional method in Abuja Municipal Area Council, Abuja?
2. What are the mean achievement scores of male and female students taught Physics using PhET simulation strategy in Abuja Municipal Area Council, Abuja?

1.5 Statement of the Hypotheses

The following hypotheses formulated were tested at the 0.05 significance level:

Ho2: There is no significant difference in the mean achievement scores of students taught Physics using PhET simulation strategy and those taught using conventional method in Abuja Municipal Area Council, Abuja.

Ho2: There is no significant difference in the mean achievement scores of male and female students taught Physics using PhET simulation strategy in Abuja Municipal Area Council, Abuja.

2.1 Conceptual Framework

The major concepts of the study are Physics Education Technology, achievement and interest.

2.1.1 Physics Education Technology (PhET)

Computer simulations such as PhET are widely available in science courses and are becoming an integral part of science teaching and learning and can be used to enhance traditional instruction and promote learning. PhET, which is an interactive simulation developed by the University of Colorado Boulder, can be effective in the teaching of chemistry and physics at the high school and college level (Perkins, Podolefsky, Lancaster & Moore, 2017). PhET interactive simulation provides an alternative approach to the traditional laboratory and can enhance students' learning through visualization, demonstrations and illustrations (Makransky, Terkildsena & Mayer, 2017). The PhET Interactive simulations which include several chemistry simulations are offered freely to instructors and teachers through their website at the University of Colorado Boulder (https://PhET.colorado.edu/). Each simulation is accompanied with several supplementary materials that immerse students in a guided inquiry-based learning activity (Chamberlain et al., 2018). It should be noted that PhET interactive simulations can be used as a tool for inquiry-based learning (Smetana & Bell, 2017). Furthermore, PhET interactive simulations provide students with content support, process assistance, and affective learning goals reinforcement (Moore, Chamberlain, Parson & Perkins, 2018).

PhET or Physics Educational Technology, is a site that contains interactive simulations for science (Physics, Biology, Chemistry, Earth sciences) and math at elementary, middle school, high school, and university levels. Depending on which simulation, it can be run online from the website, or it would have to be downloaded. They could be useful as a lab or a homework assignment. Within this interactive site, there are visual displays and interaction between the student and the concepts being taught which helps to develop understanding (Price, Perkins, Holmes & Wieman, 2018). The internet market is infiltrated with many educational technology resources, software, and tools that can be used to facilitate the attainment of objectives in physics classes. One technology resource commonly used in physics classes is Physics Education Technology (PhET) interactive simulations because it has many features. PhET simulations are considered one of the best education software because they can be accessed for free online or downloaded and saved as web pages that can run on a flash player. PhET Interactive Simulations, often referred to simply as PhET, are a collection of free online interactive educational tools developed by the University of Colorado Boulder's PhET Interactive Simulations project. These simulations are designed to help students grasp complex scientific concepts through hands-on exploration in a virtual environment. The project was founded in 2002 by Nobel Laureate Carl Wieman, the PhET Interactive Simulations project at the University of Colorado Boulder creates free interactive mathematics and science simulations. The project acronym "PhET" originally stood for "Physics Education Technology" but PhET soon expanded to other disciplines.

2.1.2 PhET Simulation-Based Learning

PhET simulation-based learning incorporates the use of PhET simulations in educational instruction. PhET simulation-based learning is designed with the following aspects or characteristics: The presence of a formalised, manipulatable simulation or model is defined by the formalisation of physics concepts into models, which are executed as computer programs. The models are characterised by quantitative or qualitative attributes, with most simulations integrating both types. Quantitative simulations typically involve variables and parameters that are integrated into a numerical model (Krobthong, 2015; Peffer, 2016; Sarabando, 2014). Qualitative models consist of components and relations that are represented either structurally or symbolically.

Qualitative simulation models are not exclusively numerical. Students adjust variables and parameters within the model and analyse the resulting outcomes displayed on the screen. Outline of learning outcomes entails specifying anticipated learning objectives. The objectives may include: (a) the acquisition of conceptual knowledge, focussing on the underlying principles and concepts of the phenomenon. Operational knowledge acquisition encompasses both cognitive and psychomotor skills. Developing skills in virtual experimentation and analysis. (iii) Identification of the specific learning process, such as hypothesis generation and testing. Students should formulate a working hypothesis and empirically test it to develop comprehension. Ultimately, learners may develop or acquire both conceptual and operational knowledge through a constructive approach. This stage includes planning and monitoring to ensure that effective learning occurs.

Tasks involving manipulation within the PhET simulation enhance learner activity through the use of simulation models. This entails the identification, establishment of parameters and variables, and the definition of the variables to be outputted. Learners interpret the findings and results by comparing them to the established hypothesis and implications. Modelling entails the addition, deletion, or modification of variables and parameters within a model. Modelling encompasses more than merely altering the values of variables and parameters. Students engage in advanced tasks involving the design, modification, addition, or editing of model properties. The specified attributes collectively define and establish the design of PhET simulation-based learning and instruction. Exploratory learning augmented by simulation requires significant cognitive engagement from students. Facilitators should support the learning process by implementing consolidation strategies. This is significant as it enhances the efficiency and effectiveness of learning.

2.1.5 Students' Academic Achievement in Physics

Academic achievement, which is the extent to which a student, teacher, or institution has achieved the short- or long-term educational goals (Mummy, 2016), represents performance outcomes that indicate the extent to which a person has accomplished specific goals that were the focus of activities in instructional environments, specifically in school. This academic achievement is measured by the final grade earned. Where the researcher observed a trend of failure in physics both in internal and external examinations, he observed that students were not showing interest in the classroom while lessons were going on. Also, from the interaction of the researcher with the students, a lot of nonchalant attitudes to excellent academic performance were also noticed.

Academic achievement refers to a student's success in meeting short- or long-term goals in education. In the big picture, academic achievement means completing high school or earning a college degree. In a given semester, high academic achievement may mean a student is on the honor roll. Academic achievement may also refer to a person's strong performance in a given academic arena. A student who earns good grades or awards in science has achieved in the academic field of science. Education associations and schools monitor the overall level of student academic achievement to decide what, if any, changes need to be made in the educational system (Lopez, 2016).

Academic achievements of a student in a particular subject or course are determined by short- or long-term goals acquired. According to Oxford Advance Learners Dictionary, to achieve means "to succeed in reaching a particular goal, status or standard especially by an effort for a long time." Achievement in physics goes to emphasize the effort or skill put in to acquire or achieve success in physics as a science subject. Academic achievement deals with successful completion of academic tasks by a student in a school. In other words, it has to do with students' performance in school subjects determined by a score from an achievement test. Academic achievement is commonly measured by examination or continuous assessment. Academic achievement is the learning outcome of students which includes the knowledge, skills and ideas acquired and retained through their course of studies within and outside the classroom situation. Was (2016) viewed that goal achievement might be focused on the task or end result. A student who performs well in school can be said to record high academic achievement and a student whose results are not good can be said to have recorded poor academic achievement.

2.1.6 Gender and Students' Academic Achievement in Physics

Gender issue is a contemporary one that attracts attention of psychologists, sociologists, educationists, scientists and biologists and even the home and parents. The concept "sex" could be discussed in terms of masculinity and femininity observed in an individual (en.m.wikipedia.org/wiki/gender). The physical character of an individual may not be expressed psychologically or emotionally. For instance, careers or subjects that are feminine in nature such as catering, are practiced by males while females study engineering and carpentry meant for males previously. A lot of researches have been carried out on gender and paper presentations to create awareness on gender equality and disparity.

Ifumuyiwa (2017) reported that 215 candidates sat for further physics in School Certificate Examination, 181 male and 34 female. The analysis indicates low participation of females 16% to

84% male but yet the females performed better than their male counterparts at credit levels in the subjects. This low participation of female students in science related subjects was attributed to factors such as: attitude of teachers, students and parents to the idea of women engaging in male careers such as Engineering, Technology, and Architecture. Gender refers to roles that are related to male and female issues. Okafor (2016) described gender as the socially or culturally constructed characteristics and roles which are ascribed to males and females in any society. It is a broad concept which draws out females' roles and responsibilities in relation to those of males. It is argued that gender disparities have influence on students' academic performance (Undigwomen, 2016). There is an acknowledged issue of female students' under-achievement when compared with their male counterparts apparently under equivalent conditions (Egbuna, 2017).

The controversy over which sex achieves better in academics is evidenced in some studies. Olejeme (2017) asserted that females achieve better than males in general academics. Female achievement in science and interest in science (Physics) are inferior to those of their male counterparts; whereas females perform better in liberal Arts (Okafor, 2016). Investigations in many areas of liberal arts and sciences related with assessing academic attainment of students have confirmed males' aggregate underachievement compared to females (Omoruyi & Omoformuan, 2015).

However, some other researchers obtained some contradictory results of no significant difference between the performance of male students and those of their female counterparts in liberal arts and sciences. Nevertheless, using relevant instructional strategies and materials can motivate students' learning during instruction. Teachers are, therefore, expected to explore means of raising the attainment of both male and female students in science. The teacher has to explore modern techniques that will help the attainment of educational objectives. Some teachers and women are of the view that girls are intellectually incapable of competing in science and difficult tasks with the boys (Joseph, 2017). Some parents discourage their girls from science and technology careers saying that they are abnormal and may not be capable of managing marital homes (Ifumuyiwa, 2017). The girls themselves feel discouraged by the attitudes of teachers and parents and often suffer from low self-esteem. Research findings have shown that female students have less positive interest in Physics than the males and also demonstrated less superiority at secondary school level. This probably ought to be the result of stereotyping of tasks that takes place with more attention given to the training and education of males in science areas.

RESEARCH METHODOLOGY

This chapter devoted to the research design, population, sample and sampling technique, method of data collection, technique for data analysis and justification of methods.

3.1 Research design

The study employed quasi-experimental research design involving the non-randomized pretest, posttest, control group design. Quasi-experimental research design was considered suitable for the study because randomization of subjects was not feasible as intact classes constituted the two groups that were used for the study. Uzoechi (2015) posited that the use of such designs that does not involve randomization is called quasi-experimental design. The choice of this design was to avoid disruption of normal school programme and to fully control the extraneous variables that might adversely affect the validity (internal and generalizability) of results. The researcher studied the effect of the teaching strategy (PhET simulation) on intact classes rather than randomly assigning participants to the experimental or control group because complete randomization of the subjects is not possible when dealing with human beings in their natural classroom settings. In this type of design, pre-test was administered at the beginning of the study and the posttest was administered after treatment for 6 weeks where data were collected and analysed for finding out whether the subjects in different groups. The schematic representation of this research design is as shown in figure 3.1.

Table 3.1: Illustration of the Design of the Study

Group	Achievement			Interest		
Experimental Group A:	0_1	X_1	0_2	0_3	X_1	0_4
Control Group B:	0_1	-	0_2	0_3	-	0_4

Figure 1: Schematic Representation of Research Design

Where:
0_1 = Pretest with PAT

0_2 = Post-test with PAT
X_1 = Treatment (use of PhET simulation strategy)

- = Control (use of conventional)

0_3 = Pretest with PSIS

0_4 = Posttest with PSIS

The study comprised an experimental group (A) and a control group (B). The experimental group A was exposed to the use of PhET simulation while the control group (B) was exposed to the use of conventional method. The researcher built in factor (gender) as independent moderator variable.

This strategy, according to Anikweze (2013) allowed the researcher not only to control the effects of the independent moderator variable but also to determine any differences that may attributed to them in the study.

3.2 Population, Sample and Sampling Techniques

3.2.1 Population of the Study

The population of the study comprised 6,638 (4,320 male and 2,318 female) SS II Physics students from 15 public secondary schools in Abuja Municipal Area Council for the 2023/2024 academic session (SEB, 2022). The choice of public secondary schools was to avoid the effect of disruption that could emanate from disparity in school calendar between the public and private secondary schools as most of the private secondary schools in Abuja Municipal Area Council do not comply strictly with the school calendar produced by the AMAC. The choice of SS II students was informed by the fact that students at this level were assumed to have acquired some basic Physics concepts, knowledge and skills in SS I to enable them attempt the pretest items. Furthermore, the choice of SS II was to avert the disruption that may arise as a result of the conduct of WAEC and NECO, since they were not in their final examination class. Thus, the common characteristic of the population was that they were SS II students in public secondary schools in Abuja Municipal Area Council.

3.2.2 Sample and Sampling Techniques

The sample for this study consisted of 195 (111 male and 84 female) SS II Physics students from two senior secondary schools in Abuja Municipal Area Council. The number of students that participated in group A was 125 students (72 male and 53 female) and those of group B was 70 students (39 male and 31 female). AMAC was selected because data from Education Resource Centre in Federal Capital Territory, Abuja showed that students in AMAC were among the least in Physics performance relative to other Council Areas of the Federal Capital Territory.

Stratified sampling technique was used to stratify the schools in AMAC according to their performance level in Physics in the 2023/2024 WAEC results. From each stratum, two schools with similar Physics performance were purposively selected to ensure homogeneity of the groups. The names of the two schools were written on separate papers, squeezed, shuffled, picked and assigned to experimental and control groups respectively through simple random sampling. The researcher used the scores of pretest for the two groups to confirm homogeneity. To obtain similar groups, a pretest was conducted before the experimental teaching. The reason for the use of pretest-posttest design was to find out if the independent variables had caused a change in the achievement and interest levels. The scores of the pretest were used to ensure similarity of the two groups. Their means and standard deviation were used to test for the significance of difference among the means.

In effect, the SSII intact classes of each of the two schools identified were randomly assigned to treatment group (A) and control group (B) respectively. The experimental group A was exposed to PhET simulation strategy while the control group (B) was exposed to conventional teaching method. The choice of drawing the two groups from different schools was to prevent any possible interaction that may affect authenticity of the study. In all, the study had one experimental group school and one school was also used for control group. Also, stratified sampling technique will be used to select two (2) SSII Physics teachers in each of the schools selected to serve as research assistants. Table 3.2 shows the details of sample distribution for the study.

Table 3.1: Sample Distribution of the Study by Gender of Students

S/N	Schools	Groups	Number of Students		Total
			Male	Female	
1.	Experimental Group	A	72	53	125
2.	Control Group	B	39	31	70
Total			**111**	**84**	**195**

3.3 Instruments for Data Collection

For the purpose of the study, the researcher developed an instruments. The instruments was Physics Achievement Test (PAT).

3.3.1 Physics Achievement Test (PAT)

A 30-item multiple choices of 4 options Physics Achievement Test (PAT) were developed for the purpose of this study. The Physics Achievement Test developed by the researcher consisted of two sections; section A was for background information such as gender while section B contained 30 objective items with options A-D. The test items were based on the objectives outlined in the lesson plans prepared. The test items covered three topics namely: Mechanical Energy, Heat Energy and Specific Heat Capacity. These topics were included in the SS2 syllabus. A pretest was conducted using the test items and this helped to ensure the subjects (students) were categorized into similar groups of experimental and control groups. The test items were later administered as posttest after the experimental teaching had been conducted by the researcher using PhET simulation strategy. See Appendices A and B for details of PAT.

Six (6) lesson plans were developed based on three topics from the SS II syllabus in Physics and covering a period of six weeks of six lesson periods lasting 40 minutes. In the lesson plans, the process objectives were specified in order to effectively apply the lesson plans for teaching the experimental group. See appendices D and E for details of the lesson plans.

3.3.3 Validity of the Instruments

The 30-item multiple choices PAT was subjected to the scrutiny and appraisal of three experts in Science Education. The test items were examined and adjudged appropriately by the experts. The test items were considered not only appropriate to the standard of the testees, but also comprehensive in covering selected topics and process objectives thereby measuring the content validity. A table of specification was developed to ensure content validity of the covered topics as shown in table 3.3 below:

Table 3.3: Table of Specification of Physics Achievement Test

SN	Content	Hrs	K (20%)	C (20%)	A_1(20%)	A_2(20%)	S(10%)	E(10%)	Total 100
1	Mechanical Energy (33%)	2	2(1,2)	2(3,4)	2(5,6)	2(7,8)	1(9)	1(10)	10
2	Heat Energy (33%)	2	2(11,12)	2(13,14)	2(15,16)	2(17,18)	1(19)	1(20)	10
3	Specific Heat Capacity (34%)	2	2(21,22)	2(23,24)	2(25,26)	2(27,28)	1(29)	1(30)	10
	Total Items	6	6	6	6	6	3	3	30

Key: K=Knowledge, C=Comprehension, A1=Application, A2=Analysis, S=Synthesis and E=Evaluation

Table 3.3 shows the blue print (Table of Specification) used for preparation of achievement test in SS II Physics. The table of specification was based on three selected topics in SS II Physics syllabus namely Mechanical Energy, Heat Energy and Specific Heat Capacity. The table of specification comprised 30 objective items spread across the three topics and levels of cognition. A total of 6 hours (teaching hours) was allocated for teaching the three topics. The test items were constructed using Bloom's Taxonomy of educational objectives for the cognitive domain which are in six areas namely knowledge, comprehension, application, analysis, synthesis and evaluation. The 30 test items were prepared based on these six areas of cognitive domain using the three topics taught during the period of instruction. A total of 6 items was prepared for the knowledge aspect of the cognition, comprehension covered 6 items, 6 items were prepared for application, analysis covered 6 items, synthesis covered 3 items while 3 items covered evaluation. The three topics taught in the course of experimental teaching were also allotted items as follows: Mechanical Energy, 10 items, Heat Energy, 10 items, and Specific Heat Capacity, 10 items. The experts also scrutinized the items whether they represented enough of what was being assessed and evaluated the language and adequacy of the items and made suggestions where necessary. The scores emanating from the appraisal of the experts were used to obtain the logical indices of 0.88 and 0.80 for PAT and PSIS respectively. See appendices F and G for evidences of validation.

3.3.4 Reliability of the Instruments

To determine reliability of the instruments, PAT was pilot tested on a portion of the accessible population that was not part of the sample for the study. The instruments were pilot tested on 30 (20 males and 10 females) Physics students in a school that was not part of the sampled schools used for the study, but within the study area. Kuder-Richardson 21 of estimating reliability was employed to compute coefficients of internal consistency for PAT.

3.3.5 Administration of the Instruments

The administration of the instrument was preceded by seeking and obtaining the permission of the school authority with the aid of an introductory letter from the Department of Educational Foundations, Faculty of Education, Nasarawa State University, Keffi. The privacy of information and other ethical assurances were guaranteed to the school authority. This was followed by training of two research assistants who helped the researcher in conducting the actual teaching and administration of the instruments. The research assistants were the regular SS II Physics teachers from the public secondary schools selected for the study. The choice of the regular Physics teachers as research assistants was to ensure that extraneous variables (Hawthorne and Novelty effects) which may influence the findings were controlled. The common characteristic of the research assistants was that they were graduates of Physics education or Physics graduates with PGDE as minimum academic qualification for teaching at the senior secondary education level. The research assistants were adequately trained for three days by the researcher on how to administer the treatment, ensure homogeneity of the instructional situation and the testing procedures across the groups. They were trained on how to create rapport with the school heads and students for effective data collection. The research assistants were persuaded to conduct micro teaching during the training workshop in order to harmonize the differential teaching styles among them.

Thereafter, PAT was administered as pretest to SS II students by the research assistants in their respective schools and the pretest lasted for one hour. Thereafter, the pretest question papers which served as the answer sheets were collected from the students by the teachers to prevent the students from revising the same content for posttest. The teachers marked PAT, and the pretest scores of PAT. The initial administration of the instruments was to establish same entry behaviour for the study groups. Hence, the result of the pretest was used to confirm that the two public secondary schools selected had similar entry levels in Physics.

After the pretest, the treatment commenced on the next Physics period by Physics teachers in the two public secondary schools identified and lasted for six weeks of three periods of 40 minutes per period per week. Throughout the exercise, the researcher went round to supervise and ensure smooth teaching and administration of instruments in SS II classes across the two public secondary schools used for the study. The researcher's movement was guided by the time table of each of the schools used for the study. Any student that was not administered the pretest was not used for the study. To minimize the influence of memory effect associated with test wise students, the PAT items were reshuffled by the researcher and were administered on the students as posttest immediately after the treatment by the research assistants. In order to control memory effect due to remembering and forgetting, the time lag between pretest and posttest was six weeks. This period was considered neither too long nor too short. This period was appropriate to minimize the effects of maturation and history. The pretest and posttest scores were recorded after each marking exercise. The PAT items were scored 2 marks each and the maximum mark was 60 marks for each of pretest and posttest respectively. The PSIS items had a possible maximum score of 4 points per item and a least score of 1 point. This means that the maximum and minimum score possible are 80 and 20 points respectively since the PSIS comprised 20 items.

3.4 Techniques for Data Analysis

The data collected for the study were classified into pretest and posttest scores for both experimental and control groups. Descriptive statistics of mean and standard deviation was used to answer the research questions. The choice of mean and standard deviation was because the data related to students' achievement and interest were continuous variables generated through interval scale of measurement. The mean scores were used to compare the performance of the groups to answer research questions. The null hypotheses were tested using Analysis of Covariance (ANCOVA) at 0.05 alpha level of significance. All analyses were done using Statistical Package for Social Sciences (SPSS) version 25.

PRESENTATION AND ANALYSIS OF DATA

The data were collected using the Physics Achievement Test (PAT). Descriptive statistics (mean and standard deviation) were used to answer the two research questions, while Analysis of Covariance (ANCOVA) was employed to test the two null hypotheses at 0.05 alpha level of significance.

4.1 Demographic Characteristics of Respondents

The demographic characteristics of the respondents are presented in table 4.1, showing the distribution by school and gender.

Table 4.1: Distribution of Respondents by School, Group, and Gender

Variables	Category	Frequency	Percentage
Group	Experimental (PhET)	125	64.1%
	Control (Conventional)	70	35.9%
Gender	Male	111	56.9%
	Female	84	43.1%
Total		**195**	**100.0%**

Table 4.1 shows that a total of 195 SS II Physics students participated in the study. Of these, 125 students (64.1%) constituted the experimental group that received PhET simulation strategy instruction, while 70 students (35.9%) formed the control group that received conventional teaching method. In terms of gender distribution, 111 students (56.9%) were males and 84 students (43.1%) were females, indicating reasonable gender representation across the sample. This distribution was considered adequate for investigating the effects of teaching method and gender on students' achievement and interest in Physics.

Answering Research Questions

This section presents the results for each of the six research questions that guided the study.

The following research questions guided the study:

Research Question 1: What are the mean achievement scores of students taught Physics using the PhET simulation strategy are those taught using conventional method in Abuja Municipal Area Council, Abuja?

To answer this research question, descriptive statistics (mean and standard deviation) were computed for the posttest achievement scores of both groups. The results are presented in table 4.3.

Table 4.3: Descriptive Statistics for Achievement Posttest by Group

Group	N	Mean	SD	Adjusted Mean*
Experimental (PhET)	125	46.86	1.89	46.85
Control (Conventional)	70	32.41	1.08	32.42

Adjusted for pretest scores

Table 4.3 reveals that students in the experimental group who were taught using PhET simulation strategy obtained a mean achievement score of 46.86 (SD = 1.89) on the posttest, while students in the control group taught using conventional method obtained a mean score of 32.41 (SD = 1.08). After controlling for pretest differences, the adjusted means were 46.85 for the experimental group and 32.42 for the control group. This represents a substantial difference of approximately 14.45 points on the raw scores and 14.43 points on the adjusted scores in favor of students taught using PhET simulation strategy. This large difference indicates that the PhET simulation strategy was associated with considerably higher achievement in Physics compared to the conventional teaching method.

Research Question 2: What are the mean achievement scores of male and female students taught Physics using PhET simulation strategy in Abuja Municipal Area Council, Abuja?

To answer this research question, descriptive statistics were computed for the posttest achievement scores of male and female students within the experimental group only. The results are presented in table 4.5.

Table 4.5: Descriptive Statistics for Achievement by Gender (PhET Group Only, N=125)

Gender	N	Mean	SD	Adjusted Mean*
Male	72	46.79	1.97	46.77
Female	53	46.96	1.78	46.98

Adjusted for pretest scores

Table 4.5 presents the posttest achievement scores for male and female students taught using PhET simulation strategy. Male students (N = 72) achieved a mean score of 46.79 (SD = 1.97), while female students (N = 53) achieved a mean score of 46.96 (SD = 1.78). After controlling for pretest scores, the adjusted means were 46.77 for males and 46.98 for females. This indicates that female students demonstrated slightly higher achievement compared to male students when both were taught using PhET simulation strategy, with a difference of only 0.17 points on raw scores and 0.21 points on adjusted scores. This very small difference suggests that PhET simulation strategy was nearly equally effective for both male and female students in terms of achievement outcomes.

4.2.2 Testing of Hypotheses

This section presents the results of testing the two null hypotheses that guided the study using Analysis of Covariance (ANCOVA) at 0.05 alpha level of significance.

Hypotheses (Ho1): There is no significant difference in the mean achievement scores of students taught Physics using PhET simulation strategy and those taught using conventional method in Abuja Municipal Area Council, Abuja.

To test this hypothesis, Analysis of Covariance (ANCOVA) was performed with posttest achievement scores as the dependent variable, teaching method as the independent variable, and pretest achievement scores as the covariate. The results are presented in table 4.9.

Table 4.9: ANCOVA Results for Achievement (PAT_Post) by Teaching Method

Source	Type III SS	df	Mean Square	F	p-value	Partial η²
PAT_Pre (Covariate)	127.863	1	127.863	48.926	< 0.001	0.203
Group	7785.241	1	7785.241	2978.546	< 0.001	0.940
Error	501.847	192	2.614			
Total	370858.000	195				

Table 4.9 presents the ANCOVA results for testing hypothesis two. The pretest achievement scores (PAT_Pre) functioned as a significant covariate ($F(1,192) = 48.926$, $p < .001$, $\eta p^2 = .203$), indicating that initial achievement levels accounted for approximately 20.3% of the variance in posttest achievement scores. The results demonstrate a statistically significant difference in posttest achievement scores between the experimental and control groups ($F(1,192) = 2978.546$, $p < 0.001$, $\eta p^2 = 0.940$). The extremely large F-value and the p-value less than the 0.05 alpha level provide compelling evidence to reject the null hypothesis.

The partial eta squared value of .940 indicates an extremely large effect size, suggesting that approximately 94.0% of the variance in posttest achievement scores can be explained by the teaching method after controlling for pretest differences. This exceptionally large effect size demonstrates that PhET simulation strategy had a profound impact on students' Physics achievement. Based on these findings, the null hypothesis (Ho_2) is rejected. Therefore, there is a significant difference in the mean achievement scores of students taught Physics using PhET simulation strategy and scores of those taught using conventional method in FCT, Abuja. The direction of the difference, as indicated by the adjusted means (Table 4.3), strongly favors students taught using PhET simulation strategy ($M = 46.85$) compared to those taught using conventional method ($M = 32.42$).

Hypotheses (Ho2): There is no significant difference in the mean achievement scores of male and female students taught Physics using PhET simulation strategy in Abuja Municipal Area Council, Abuja.

To test this hypothesis, Analysis of Covariance (ANCOVA) was performed on data from the experimental group only, with posttest achievement scores as the dependent variable, gender as the independent variable, and pretest achievement scores as the covariate. The results are presented in Table 4.11.

Table 4.11: ANCOVA Results for Achievement by Gender (PhET Group)

Source	Type III SS	df	Mean Square	F	p-value	Partial η^2
PAT_Pre (Covariate)	58.742	1	58.742	16.483	< 0.001	0.119
Gender	3.647	1	3.647	1.023	0.314	0.008
Error	434.928	122	3.565			
Total	275397.000	125				

Table 4.11 presents the ANCOVA results for testing hypothesis four. The pretest achievement scores (PAT_Pre) functioned as a significant covariate ($F(1,122) = 16.483$, $p < 0.001$, $\eta p^2 = 0.119$), accounting for approximately 11.9% of the variance in posttest achievement scores within the PhET group. However, the analysis reveals no statistically significant difference in achievement scores between male and female students within the PhET simulation group ($F(1,122) = 1.023$, $p = 0.314$, $\eta p^2 = 0.008$). The F-value of 1.023 with an associated p-value of .314, which exceeds the 0.05 alpha level, provides insufficient evidence to reject the null hypothesis.

The negligible effect size (partial eta squared = 0.008) indicates that gender explains less than 1% of the variance in achievement scores among students taught using PhET simulation. Although female students demonstrated a slightly higher adjusted mean achievement score (M = 46.98) compared to male students (M = 46.77) as shown in table 4.5, this difference did not reach statistical significance. Based on these findings, the null hypothesis (Ho_4) is not rejected. Therefore, there is no significant difference in the mean achievement scores between male and female students taught Physics using PhET simulation strategy in Abuja Municipal Area Council, Abuja. This finding provides evidence that PhET simulation strategy is equally effective for both male and female students in improving Physics achievement, suggesting that this instructional approach does not exhibit gender bias and can be used to promote gender equity in Physics education.

4.3 Discussion of Findings

This discussion of the results was made based on the results of research questions and the corresponding hypotheses that were tested.

Findings based on research question 1 showed that students in the experimental group achieved significantly higher scores (adjusted M = 46.85) compared to the control group (adjusted M = 32.42). The ANCOVA analysis confirmed this difference as highly significant ($F(1,192) = 2978.546$, $p < 0.001$, $\eta p^2 = 0.940$), resulting in the rejection of the second null hypothesis. This finding is consistent with the studies of Uwambajimana and Minani (2023) which demonstrated the effectiveness of PhET simulations in improving academic achievement. The findings shown significant improvement in students' performance in electrostatics for students taught using PhET simulations in Rwanda. Najib, Ruzlan and Yaacob (2022) reported significant differences in pre-test and post-test mean scores for the experimental group using PhET simulations in Malaysia, while the control group showed no significant differences. Tshering, Sumitra and Tshering (2024) revealed statistically significant differences in mean post-test scores between control and experimental groups in Bhutan, confirming that PhET simulation intervention significantly impacted students' achievement.

The extremely large effect size ($\eta p^2 = 0.940$) observed in this study indicates that approximately 94.0% of the variance in posttest achievement scores can be explained by the teaching method. This remarkable effect size suggests that PhET simulation strategy represents a highly effective instructional approach for teaching Physics concepts. Several factors may account for this substantial improvement in achievement.

First, PhET simulations provide students with opportunities for hands-on exploration and experimentation that are often unavailable in traditional physics classrooms. As noted by Wieman, Adams, Loeblein and Perkins (2016), PhET simulations offer several advantages including the ability to conduct experiments that would be difficult or impossible with actual equipment, the flexibility to modify variables in response to student inquiries, and the capacity to visualize invisible phenomena. These affordances enable students to develop deeper conceptual understanding rather than mere rote memorization of formulas and facts.

Second, the immediate feedback provided by PhET simulations allows students to quickly identify and correct misconceptions. When students manipulate variables in the simulation and observe the outcomes in real-time, they can test their predictions and refine their understanding based on the results. This iterative process of hypothesis testing and refinement is central to scientific thinking and leads to more robust conceptual understanding. As Perkins (2020) noted, students exhibited elevated engagement and enjoyment while utilizing PhET simulations, resulting in enhanced participation and more profound learning experiences.

Third, PhET simulations address individual differences in learning pace and style. Unlike conventional lecture methods where all students must proceed at the same pace, PhET simulations allow students to work at their own speed, revisit concepts as needed, and explore areas of particular interest. This personalization of learning is consistent with constructivist principles and has been shown to improve achievement outcomes across diverse student populations. The finding that PhET simulation strategy significantly improves achievement is particularly important in the Nigerian context, where Physics performance has been consistently poor. The WAEC results cited in Chapter One showed that pass rates at credit level fluctuated between 26.3% and 39.7% over the five-year period from 2019 to 2024, with no year exceeding 40% pass rate. The current study demonstrates that PhET simulation strategy has the potential to dramatically improve these outcomes. The mean achievement score difference of 14.43 points between the experimental and control groups (on a 60-point scale) represents a substantial improvement that could translate into significantly higher pass rates if implemented on a larger scale.

Moreover, the topics covered in this study, Mechanical Energy, Heat Energy, and Specific Heat Capacity, are typically challenging concepts that students struggle to understand through conventional teaching methods alone. These topics involve abstract concepts that are difficult to visualize and often require students to integrate multiple pieces of information simultaneously. PhET simulations make these abstract concepts more concrete by providing dynamic visual representations that students can manipulate and explore. This visualization capability is particularly important for topics like energy transformations and heat transfer, where the processes are invisible and difficult to demonstrate with traditional laboratory equipment. The success of PhET simulations in improving achievement in these challenging topics suggests that this instructional strategy could be particularly valuable for teaching other abstract or difficult physics concepts. Topics such as electromagnetism, quantum mechanics, and wave phenomena, which are notoriously difficult for students to understand, might benefit substantially from the use of PhET simulations.

Findings based on research question 2 showed that female students achieved slightly higher adjusted mean scores ($M = 46.98$) compared to male students ($M = 46.77$), but this difference was not statistically significant ($F(1,122) = 1.023$, $p = 0.314$, $\eta p^2 = 0.008$). Therefore, the fourth null hypothesis was not rejected. This finding of gender equity in achievement outcomes when using PhET simulation strategy is consistent with the interest findings discussed above and provides further evidence that PhET simulations create an equitable learning environment. The lack of significant gender differences in achievement is particularly important given the well-documented gender gaps in physics achievement that exist in many educational contexts, including Nigeria.

The gender equity in achievement observed in this study differs from some previous research findings while aligning with others. Asano, Osei and Yiadom (2024) found statistically significant differences between male and female students in understanding hybridization after PhET intervention, with one gender performing better. Kabigting (2021) reported a significant relationship between gender and performance when exposed to computer simulation methods. However, Udie, Ofoegbu and David (2023) which found that female students performed better than male students in physics practical work using virtual laboratory experiments. The inconsistent patterns across studies suggest that the relationship between gender and achievement in simulation-based learning may be context-dependent and influenced by various factors including the specific physics topics being taught, the characteristics of the student population, and the implementation approach.

The finding of gender equity in achievement in the current study can be understood through several theoretical and practical lenses. From a constructivist perspective, PhET simulations provide an environment where students construct their own understanding through active exploration, which may neutralize some of the social and cultural factors that typically contribute to gender gaps in physics achievement. When learning is self-directed and exploratory rather than teacher-directed and competitive, the impact of gender stereotypes and biases may be reduced. Additionally, the visual and interactive nature of PhET simulations may provide cognitive scaffolding that benefits all students regardless of gender. Research in cognitive science suggests that visual representations and interactive manipulations can reduce cognitive load and make complex concepts more accessible. If these cognitive benefits are available to all students equally, regardless of gender, then achievement gaps may be reduced or eliminated.

The gender equity in achievement observed in this study is particularly significant in light of the persistent underrepresentation of women in physics and STEM fields more broadly. As noted in Chapter Two, there is a documented shortage of female representation in science, mathematics, and technology in Nigeria (Ifumuyiwa, 2017). The finding that PhET simulations promote equal achievement among male and female students suggests that widespread implementation of this instructional strategy could contribute to addressing this gender imbalance by ensuring that female students develop the same level of physics competence as their male counterparts. However, it is important to interpret this finding with appropriate nuance. The lack of significant gender differences in this study does not mean that gender is irrelevant to physics learning or that all gender-based challenges have been eliminated. Rather, it suggests that PhET simulation strategy, when implemented in the manner described in this study, does not differentially advantage one gender over the other. This represents an important step forward from traditional instructional approaches that have often been shown to favor male students.

The slight numerical advantage for female students (46.98 vs. 46.77), although not statistically significant, is noteworthy. This pattern, combined with the similar pattern observed for interest scores, suggests that PhET simulations may be particularly well-suited to female students' learning preferences or may help to compensate for disadvantages that female students experience in conventional physics instruction. Future research with larger samples and longer intervention periods could help clarify whether this pattern represents a meaningful trend or simply sampling variability.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Based on the findings of this study, it was concluded that PhET simulation strategy is significantly more effective than conventional teaching method in improving both students' interest and achievement in Physics. The extremely large effect sizes observed (exceeding .92 for both outcomes) indicate that PhET simulation represents a transformative rather than merely incremental improvement over traditional lecture-based instruction. This superiority can be attributed to the interactive, visual, and exploratory nature of PhET simulations, which align with constructivist learning principles by enabling students to actively construct knowledge through hands-on exploration and experimentation. Moreso PhET simulation strategy promotes gender equity in physics education. The absence of significant gender differences within the PhET group for both interest and achievement, combined with the finding that both male and female students in the PhET group significantly outperformed their same-gender counterparts in the conventional group, demonstrates that PhET simulation creates an equitable learning environment. These finding challenges deficit-based narratives about female students' capabilities in Physics and instead highlights the critical role of instructional quality in determining outcomes.

5.3 Recommendations

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

1. The Federal Ministry of Education and Nigerian Educational Research and Development Council (NERDC) should integrate PhET simulation strategy into the national Physics curriculum for senior secondary schools. This integration should include specific guidelines for implementing PhET simulations within the existing curriculum structure, identifying which topics are best suited for simulation-based instruction, and developing assessment strategies that align with this pedagogical approach.

2. State and federal governments should prioritize investment in technological infrastructure necessary for implementing PhET simulations in secondary schools. This includes ensuring reliable electricity supply, providing adequate computer facilities with internet connectivity, and establishing ICT laboratories equipped with the necessary hardware and software. While FCT Abuja may have relatively better infrastructure, significant investment will be required to replicate these conditions in other regions of Nigeria.

3. Education budgets should include specific allocations for educational technology initiatives, particularly for downloading and distributing PhET simulations to schools with limited or unreliable internet access. Since PhET simulations can be downloaded and run offline, schools in areas with connectivity challenges can still benefit from this technology if proper resource distribution mechanisms are established.

4. Educational authorities should develop comprehensive policies that support and incentivize the use of technology-enhanced instructional strategies like PhET simulations. These policies should include guidelines for technology procurement, standards for digital content quality, and frameworks for evaluating the effectiveness of educational technology implementations.

5. Given the study's finding that PhET simulation promotes gender equity, policymakers should position this instructional strategy as a key component of initiatives aimed at increasing female participation and achievement in STEM education. Policies should specifically address how PhET simulation can be leveraged to challenge gender stereotypes and create more inclusive physics classrooms.

6. A phased approach to scaling PhET simulation implementation should be developed, beginning with schools in areas with better infrastructure (like FCT) as pilot sites, documenting best practices and challenges, and gradually expanding to other regions. This approach allows for learning from early implementations and adapting strategies to different contextual realities.

REFERENCES

Achuonye, K. A. (2014). Science education and national development. *Journal of Educational Research*, *12*(3), 234-249.

Adedokun, O. A. (2015). *Science and technology education in Nigeria*. Lagos University Press.

Ameh, P. O. (2014). Investment in physics and mathematics education in developing countries. *International Journal of Science Education*, *8*(4), 234-249.

Anyakoha, M. W. (2018). *New school physics* (4th ed.). African First Publishers.

Banda, H. J., & Nzabahimana, J. (2021). The impact of PhET simulations on physics achievement and interest in Malawian secondary schools. *African Journal of Educational Technology*, *15*(3), 201-218.

Barmby, P., & Defty, N. (2016). Secondary school students' perceptions of physics. *Research in Science & Technological Education*, *24*(2), 199-215.

Chamberlain, J. M., Lancaster, K., Parson, R., & Perkins, K. K. (2018). Supplementary materials for PhET interactive simulations: Design and implementation. *Science Education Materials*, *16*(2), 89-107.

Grasha, A. F., & Hicks, N. Y. (2020). Learning and teaching styles in instruction: Integration and implications. *Journal of Educational Psychology*, *112*(4), 567-584.

Guido, R. M. D. (2018). Challenges in learning physics concepts among Filipino students. *International Journal of Physics Education*, *10*(2), 145-162.

Ifumuyiwa, S. A. (2017). Gender participation and performance in physics education: The Nigerian experience. *Nigerian Journal of Science Education*, *13*(2), 112-129.

Joseph, A. (2017). Gender stereotypes in science and technology careers in Nigeria. *Journal of Women in Science*, *14*(3), 234-251.

Krobthong, T. (2015). Quantitative and qualitative models in educational simulations: Design principles. *Educational Technology Journal*, *12*(4), 201-218.

LinkedIn Learning. (2017). *The importance of science and technology for national development*. https://www.linkedin.com/learning/

Lopez, E. J. (2016). Long-term and short-term educational goals: Conceptual frameworks. *Educational Goals Quarterly*, *11*(3), 178-196.

Makransky, G., Terkildsena, T. S., & Mayer, R. E. (2017). PhET interactive simulation as alternative to traditional laboratory: Role of instructional design. *Computers & Education*, *113*, 91-101. https://doi.org/10.1016/j.compedu.2017.05.014

Mbonyiryivuze, A., Yadav, L. L., & Amadalo, M. M. (2022). Technology integration benefits in teaching and learning: African perspectives. *African Journal of Educational Technology*, *16*(1), 23-41.

Moore, E. B., Chamberlain, J. M., Parson, R., & Perkins, K. K. (2018). PhET interactive simulations for inquiry-based learning in physics. *Physics Teacher*, *56*(1), 26-30.

Mummy, J. T. (2016). Educational goals and achievement outcomes: Theoretical perspectives. *Journal of Educational Objectives*, *12*(2), 134-152.

Okeyefi, M. P., & Nzewi, U. M. (2015). Factors affecting physics learning in Nigerian secondary schools. *Journal of Science Education Research*, *11*(3), 156-174.

Perkins, K. K. (2017). PhET simulations and conceptual understanding in physics education. *Physics Education*, *52*(3), 035007.

Perkins, K. K. (2020). Student engagement and motivation with PhET simulations: A longitudinal study. *Journal of Science Education and Technology*, *29*(3), 412-428.

Perkins, K., Podolefsky, N., Lancaster, K., & Moore, E. (2017). PhET interactive simulations in chemistry and physics education. *Journal of Chemical Education*, *94*(5), 571-575.

Popham, W. J. (2020). *Assessment literacy for educators in a hurry*. ASCD.

Price, E., Perkins, K., Holmes, N., & Wieman, C. (2018). Interactive simulations for developing understanding in physics. *Physics Education Research Journal*, *14*(1), 010138.

Prima, E. C., Putri, A. R., & Rustaman, N. (2018). Simulation-based learning and conceptual understanding in astronomy education. *Journal of Science Learning*, *1*(3), 89-97.

Saleh, M. (2017). Understanding fundamental physics concepts: Challenges facing Nigerian students. *West African Journal of Education*, *33*(1), 78-93.

Smetana, L. K., & Bell, R. L. (2017). Computer simulations for inquiry-based learning in science education. *Journal of Science Education and Technology*, *21*(4), 505-518.

Taibu, R., Mataka, L., & Shekoyan, V. (2021). PhET simulations bridging real-world phenomena and underlying science. *African Journal of Science Education*, *17*(2), 134-152.

Usman, I. A. (2017). Activity-based teaching strategies in physics education. *Journal of Science Teaching Methods*, *15*(2), 112-130.

Uzoechi, B. C. (2015). *Quasi-experimental designs in educational research*. Pearl Publishers.

Was, C. A. (2016). Goal-oriented achievement and task completion: Motivational perspectives. *Motivation and Emotion*, *40*(2), 234-249.

Wosu, L. N. (2015). Factors influencing teaching strategy selection in Nigerian secondary schools. *Journal of Educational Management*, *13*(2), 145-162.