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## Gender as a Predictor of Students' Performance in PhET Simulation of Chemistry Content in Secondary Schools

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### ABSTRACT

This study investigated gender as a predictor of students' performance in PhET simulation-based Chemistry learning in secondary schools in Kwara State, Nigeria. A quasi-experimental pretest-posttest control group design was used. The study involved 80 Senior Secondary School I Chemistry students selected through purposive sampling, with equal representation of male and female students. PhET simulations were used to teach Chemistry concepts to the experimental group, while students' performance was measured using a Chemistry Performance Test. The findings showed improved posttest performance after exposure to PhET simulations. However, gender did not significantly influence students' performance, as male and female students achieved comparable outcomes. The study supports gender-inclusive technology-assisted Chemistry instruction.

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## 1. INTRODUCTION

Students' academic performance is an important indicator of the effectiveness of teaching and learning in secondary education. In science education, performance reflects not only students' ability to recall information but also their capacity to understand concepts, apply knowledge, and solve problems. Chemistry is one of the core science subjects needed for students who intend to pursue careers in science, technology, medicine, engineering, agriculture, and related fields. However, many secondary school students continue to experience difficulty in Chemistry because several topics are abstract, symbolic, and difficult to visualize through traditional teaching methods alone. Students' low performance in Chemistry has been a persistent concern in many educational contexts, including Nigeria. Previous studies have linked poor Chemistry performance to factors such as ineffective teaching methods, inadequate laboratory facilities, limited instructional materials, overcrowded classrooms, and students' difficulty understanding abstract concepts (Hassan *et al.*, 2015; Nnanna and Chukwunazo, 2021; Nnoli and Nwafor, 2023). In Kwara State and other parts of Nigeria, students' performance in public examinations has also raised concern, especially because Chemistry is an important requirement for science-related academic and career pathways. Therefore, there is a need for instructional approaches that can make Chemistry concepts clearer, more engaging, and easier for students to understand.

The trend of students' academic performance in WAEC Chemistry from 2015 to 2018 is presented in **Table 1**. More than half of the students passed Chemistry at credit level each year, but a substantial proportion still performed below credit level. This pattern indicates that Chemistry performance remains a concern and supports the need for instructional strategies that can improve students' understanding, engagement, and achievement in the subject.

**Table 1.** Students' academic performance in WAEC Chemistry from 2015 to 2018.

YEAR	TOTAL SAT	CREDIT PASSED (A1-C6)	% PASS	BELOW PASS (D7-F9)	% BELOW PASS
2015	680357	412323	60.6	268034	39.40
2016	706873	408122	57.74	298751	42.26
2017	704494	441576	62.68	262918	37.32
2018	728998	451614	61.95	277384	38.05

One instructional strategy that can support Chemistry learning is the use of interactive simulations. Physics Education Technology (PhET) provides digital simulations that allow students to explore science concepts through visualization, manipulation of variables, and virtual experimentation. In Chemistry learning, PhET simulations are useful because they help students visualize particles, atoms, molecules, chemical equations, reactions, and other abstract processes that are difficult to observe directly in ordinary classroom settings. Previous studies have reported that PhET and other computer simulations can improve students' performance, retention, engagement, science process skills, and conceptual understanding in science subjects (Ajijolajesu *et al.*, 2019; Alabi *et al.*, 2023; Laurence, 2022; Ouahi *et al.*, 2021).

In addition to improving performance, technology-assisted learning environments should also promote inclusive participation. Gender remains an important issue in science education because male and female students may experience science learning differently due to social expectations, classroom participation patterns, access to resources, confidence, and prior

learning experiences. In Chemistry education, it is important to examine whether digital learning tools such as PhET simulations support both male and female students equitably. If simulations improve learning without producing gender-based disparities, they may serve as useful tools for gender-inclusive science education.

Gender-inclusive science education means providing learning environments where all students, regardless of gender, have fair opportunities to participate, engage, and perform successfully. This issue is relevant because inclusive education is not limited to disability or special learning needs; it also includes reducing barriers related to gender, access, participation, and learning support. A gender-responsive analysis of PhET simulation-based Chemistry learning can therefore help teachers understand whether technology-enhanced instruction benefits students equitably or whether additional support is needed to ensure balanced participation and performance.

Although several studies have examined the effectiveness of PhET simulations and other computer-based simulations in science education, there remains a need to examine the role of gender in students' Chemistry performance within simulation-based learning environments. In particular, limited attention has been given to whether gender significantly predicts students' performance after exposure to PhET simulation-based Chemistry instruction in secondary schools in Kwara State. Addressing this gap can provide evidence for designing technology-supported Chemistry instruction that is both effective and inclusive.

This study investigated gender as a predictor of students' performance in PhET simulation-based Chemistry learning in secondary schools in Kwara State, Nigeria. Specifically, the study sought to:

- (i) determine the performance of senior secondary school Chemistry students in a PhET simulation learning environment;
- (ii) examine the difference between students' pretest and posttest performance after exposure to PhET simulation-based Chemistry instruction;
- (iii) determine whether there was a significant difference between male and female students' pretest performance; and
- (iv) examine whether gender significantly influenced students' posttest performance in the PhET simulation learning environment.

Based on these objectives, the following research questions guided the study:

- (i) What is the performance of senior secondary school Chemistry students in a PhET simulation learning environment? And
- (ii) What is the difference between students' pretest and posttest performance after exposure to PhET simulation-based Chemistry instruction?

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

- (i) H01: There is no significant difference between the male and female pretest performance of Chemistry students in the PhET simulation learning environment; and
- (ii) H02: Gender has no significant influence on the posttest performance of senior secondary school Chemistry students in the PhET simulation learning environment.

## **2. METHODS**

This study employed a quasi-experimental pretest-posttest control group design to examine students' performance in PhET simulation-based Chemistry learning and to determine whether gender predicted students' performance. This design was appropriate

because intact classes were used, and the participants could not be randomly assigned to groups.

The population of the study consisted of senior secondary school Chemistry students in Kwara State, Nigeria. The target population was Senior Secondary School I Chemistry students. This level was selected because the students were beginning formal senior secondary Chemistry and were learning topics that could be supported through PhET simulations. Chemistry is often perceived by students as abstract and difficult, especially when concepts involve particles, atoms, molecules, and chemical equations that are not easily observed directly.

Purposive sampling was used to select two intact classes from two secondary schools. One class served as the experimental group, while the other served as the control group. The sample consisted of 80 Senior Secondary School I Chemistry students, with 40 students in each group. Gender representation was balanced, with 40 male and 40 female students included in the study. Stratified sampling was also used to categorize students based on their previous Chemistry performance. The scoring categories are presented in **Table 2**.

**Table 2.** Scoring range of Kwara State senior secondary school Chemistry students.

SCORE RANGE	REMARK
1-49	Low
50-69	Average
70-100	High

The instruments used for data collection were PhET simulations and the Chemistry Performance Test. The PhET simulations served as the instructional intervention for the experimental group, while the Chemistry Performance Test was used to measure students' performance before and after the intervention. The test covered selected Chemistry topics, including matter, atoms, molecules, and chemical equations.

The instruments were validated by seven experts. These included four lecturers from the Department of Science Education, Al-Hikmah University, Ilorin, Nigeria, and three senior secondary school Chemistry teachers from selected schools in Kwara State. The experts examined the instruments for content relevance, clarity, suitability, and appropriateness for the students. Their observations, suggestions, and corrections were incorporated into the final version of the instruments. A pilot study was then conducted outside the study area, and the reliability of the Chemistry Performance Test was determined using Cronbach's Alpha. A reliability coefficient of 0.79 was obtained, indicating that the instrument was reliable for the study.

Before the intervention, both the experimental and control groups were given a pretest to determine their initial understanding of the selected Chemistry concepts. After the pretest, the experimental group was taught using PhET simulations, while the control group was taught using the conventional teaching method. The treatment lasted for six weeks. After the instructional period, both groups were given a posttest to determine the effect of the intervention on students' Chemistry performance.

Data collected from the pretest and posttest were analyzed using descriptive and inferential statistics. Frequency count, mean, and standard deviation were used to answer the research questions, while t-test analysis was used to test the null hypotheses at the 0.05

level of significance. The analysis focused on students' overall performance in the PhET simulation learning environment, differences between pretest and posttest scores, gender differences in pretest performance, and the influence of gender on posttest performance.

### 3. RESULTS AND DISCUSSION

PhET, or Physics Education Technology, refers to interactive digital simulations designed to help students explore scientific and mathematical concepts through visualization, manipulation, and virtual experimentation. Although the term PhET originally comes from physics education, its application has expanded to other science subjects, including Chemistry. In Chemistry learning, PhET simulations are useful because many Chemistry concepts are abstract, microscopic, and symbolic. Students are often required to understand particles, atoms, molecules, chemical equations, reactions, and relationships that cannot easily be observed directly in ordinary classroom settings. Through PhET simulations, these abstract concepts can be represented visually and interactively, allowing students to observe processes, manipulate variables, and connect theoretical explanations with concrete visual models.

The use of PhET simulations is especially relevant in secondary school Chemistry because students often experience difficulty understanding concepts that involve invisible or microscopic processes. Traditional teaching methods may explain these topics verbally or through static diagrams, but students may still struggle to imagine how particles interact or how chemical changes occur. PhET simulations provide a learning environment where students can actively explore the concept rather than only listen to explanations. For example, students may observe how changes in variables affect a reaction, how particles behave, or how symbolic representations relate to observable outcomes. This active engagement may help students develop better conceptual understanding because they are able to test ideas, receive immediate visual feedback, and repeat activities until the concept becomes clearer.

In this study, PhET simulation-based instruction appears to have supported students' Chemistry performance, as shown by the improvement from pretest to posttest scores. The increase in students' mean score after the intervention suggests that interactive simulations helped learners understand the selected Chemistry content more effectively. This may be because PhET simulations combine visual representation, student interaction, and exploratory learning. These features can reduce the difficulty of abstract Chemistry topics and make learning more engaging. Previous studies have also shown that PhET and computer simulations can improve students' performance, retention, engagement, science process skills, and conceptual understanding in science learning ([Alabi et al., 2023](#); [Laurence, 2022](#); [Ouahi et al., 2021](#)).

PhET simulations are also important because they can complement laboratory-based and teacher-led instruction. In many schools, especially where laboratory facilities, materials, or time are limited, simulations can provide alternative ways for students to explore scientific ideas. They do not replace real laboratory activities, but they can prepare students before laboratory work, support classroom explanation, and provide additional practice after lessons. In Chemistry, this is valuable because some experiments may be difficult, unsafe, expensive, or impossible to conduct frequently in school laboratories. PhET simulations allow students to explore related concepts in a controlled virtual environment while still requiring teacher guidance to ensure that students interpret the simulation correctly.

From the perspective of gender-inclusive science education, PhET simulations may help provide equal learning opportunities for male and female students. Since both groups are exposed to the same visual models, interactive tasks, and exploratory activities, simulation-based instruction can support equitable participation when properly implemented. In this study, gender did not significantly influence students' posttest performance, indicating that male and female students benefited in comparable ways from the PhET simulation learning environment. This suggests that PhET simulations can be used as gender-inclusive instructional tools in Chemistry education. However, the inclusive value of PhET does not depend on technology alone. Teachers must provide clear instructions, guide students during exploration, encourage participation from all learners, and connect simulation activities with lesson objectives and assessment tasks.

Therefore, PhET should be understood as a supportive instructional tool that strengthens Chemistry learning through visualization, interaction, and guided exploration. Its effectiveness depends on how well it is integrated into classroom instruction. When simulations are used with appropriate teacher facilitation, structured activities, and inclusive classroom practices, they can help students understand difficult Chemistry concepts while supporting equitable participation across gender groups. This makes PhET simulation-based learning a promising approach for improving Chemistry performance and promoting gender-inclusive science education in secondary schools.

The results present students' performance in PhET simulation-based Chemistry learning and examine whether gender predicted students' performance. The analysis includes the gender distribution of participants, students' performance in the PhET simulation learning environment, the difference between pretest and posttest scores, and the influence of gender on students' performance.

The gender distribution of the participants is presented in **Table 3**. The study involved 80 Senior Secondary School I Chemistry students, consisting of 40 male and 40 female students. This equal distribution indicates that both genders were represented fairly in the study. It also strengthens the analysis of gender as a predictor of students' performance because the comparison was based on balanced male and female participation. All participants completed both the pretest and posttest. The absence rate was 0.0%, indicating that there was no attrition during the study. This supports the reliability of the comparison between male and female students and between pretest and posttest performance.

**Table 3.** Gender distribution of the participants.

TEST STAGE	MALE	FEMALE	TOTAL	MALE (%)	FEMALE (%)	ABSENT (%)
Pretest	40	40	80	50.0	50.0	0.0
Posttest	40	40	80	50.0	50.0	0.0

Students' performance in the PhET simulation learning environment is presented in **Table 4**. The mean score was 30.60 out of 40, with a standard deviation of 5.688. The minimum score was 20, while the maximum score was 38. Most students scored within the upper range, indicating that the students generally performed well after exposure to PhET simulation-based Chemistry instruction. Students' performance in the PhET simulation learning environment was generally strong. A large proportion of students scored 33 and above, suggesting that simulation-supported instruction helped many students understand the Chemistry concepts. This finding supports previous studies showing that interactive

simulations can improve students' performance, engagement, retention, and understanding of science concepts (Ajijolajesu *et al.*, 2019; Alabi *et al.*, 2023; Ouahi *et al.*, 2021). PhET simulations may have helped students visualize abstract Chemistry concepts, manipulate variables, and observe relationships that are difficult to demonstrate through conventional instruction alone.

**Table 4.** Performance of senior secondary school Chemistry students in a PhET simulation learning environment.

SCORE	FREQUENCY	PERCENT
20	1	2.5
21	1	2.5
22	1	2.5
23	1	2.5
24	3	7.5
25	6	15.0
26	3	7.5
30	1	2.5
31	1	2.5
33	3	7.5
34	5	12.5
35	4	10.0
36	4	10.0
37	4	10.0
38	2	5.0
<b>Total</b>	<b>40</b>	<b>100.0</b>
<b>Mean</b>	<b>30.60</b>	
<b>Standard deviation</b>	<b>5.688</b>	
<b>Minimum</b>	<b>20</b>	
<b>Maximum</b>	<b>38</b>	

The difference between students' pretest and posttest scores in the experimental group is presented in **Table 5**. The pretest mean score was 17.15, while the posttest mean score increased to 30.60. This shows a clear improvement in students' performance after exposure to PhET simulation-based Chemistry instruction. Students' performance improved substantially after the intervention. The increase from a mean score of 17.15 to 30.60 suggests that PhET simulation-based learning supported students' comprehension of Chemistry content. The increase in the minimum score from 9 to 20 also shows that lower-performing students improved after the intervention. Similar findings have been reported in studies showing that simulations can improve students' performance in science and Chemistry learning (Ajijolajesu *et al.*, 2019; Laurence, 2022; Ouahi *et al.*, 2021). Through these simulations, students are not only passive recipients of information; they can interact with models, test relationships, observe immediate changes, and connect symbolic representations with visual experiences. This may explain why students in the experimental group showed higher posttest performance after the intervention. The interactive and visual nature of PhET may reduce the difficulty of abstract Chemistry content and help students construct clearer conceptual understanding.

**Table 5.** The difference between pretest and posttest scores of students in the PhET simulation of Chemistry content.

TEST	N	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Pretest experimental	40	9	32	17.15	4.167
Posttest experimental	40	20	38	30.60	5.688
Valid N	40				

The first hypothesis tested whether there was a significant difference between male and female students' pretest performance. The result is presented in **Table 6**. Male students had a mean pretest score of 16.35, while female students had a mean pretest score of 17.95. Although female students had a slightly higher mean score, the difference was not statistically significant because the p-value was 0.215, which is greater than 0.05. Male and female students had comparable pretest performance before the intervention. Since the difference was not significant, the null hypothesis was accepted. This means that gender did not significantly differentiate students' initial Chemistry performance before exposure to PhET simulation-based instruction. This finding suggests that both male and female students began the intervention with relatively similar levels of prior understanding.

**Table 6.** T-test of significant difference between male and female pretest performance of Chemistry students in PhET simulation.

Gender	Mean	Standard deviation	Standard error of the mean	N	df	t	Sig. (2-tailed)	Decision
Male	16.35	4.196	0.938	20	19	-1.283	0.215	Accept H01
Female	17.95	4.084	0.913	20				

The second hypothesis tested whether gender significantly influenced students' posttest performance in the PhET simulation learning environment. The result is presented in **Table 7**. Male students had a mean posttest score of 29.25, while female students had a mean posttest score of 31.95. Although female students had a slightly higher mean score, the difference was not statistically significant because the p-value was 0.086, which is greater than 0.05. Gender did not significantly influence students' posttest performance in the PhET simulation learning environment. Although female students recorded a slightly higher mean score, the difference was not statistically significant. Therefore, the null hypothesis was accepted. This suggests that PhET simulation-based Chemistry instruction supported both male and female students in comparable ways.

**Table 7.** The t-test of the significant influence of gender on the posttest performance of senior secondary school Chemistry students in the PhET simulation learning environment.

Gender	Mean	Standard deviation	Standard error of the mean	N	df	t	Sig. (2-tailed)	Decision
Male	29.25	6.265	1.401	20	19	-1.811	0.086	Accept H02
Female	31.95	4.828	1.080	20				

This finding is important for gender-inclusive science education. It indicates that PhET simulations can provide a learning environment where both male and female students have fair opportunities to engage with Chemistry concepts and improve their performance. Previous studies have similarly reported that interactive simulations can enhance students' learning outcomes without producing significant gender-based differences (Ajjolajesu *et al.*, 2019; Alabi *et al.*, 2023). This suggests that simulation-based learning may help reduce gender-related barriers by providing visual, interactive, and learner-centered Chemistry instruction.

The findings also show that PhET simulations can address some common challenges in Chemistry learning. Chemistry is often perceived as abstract because many concepts involve particles, molecules, reactions, and processes that students cannot easily observe directly. Interactive simulations can make these concepts more visible and concrete, allowing students to manipulate variables and observe outcomes. This may explain the improvement in students' posttest performance. However, the variability in scores also suggests that students may benefit differently from simulation-based learning depending on their prior knowledge, motivation, teacher support, and access to learning resources.

The findings of this study should also be understood within the broader context of academic performance, teacher quality, learning environment, and students' individual differences. Academic performance is commonly used as an indicator of educational success because it reflects the extent to which students achieve learning goals, demonstrate knowledge, and meet institutional expectations (Badri *et al.*, 2006; Rilwanu *et al.*, 2019; York *et al.*, 2019). Previous studies have shown that students' academic achievement is shaped by many factors, including motivation, learning habits, self-efficacy, school engagement, socio-economic background, language proficiency, and institutional support (Bilge *et al.*, 2014; Fernandes *et al.*, 2019; Gultom and Oktaviani, 2022; Kumar *et al.*, 2021; Minh and Van Hoi, 2023; Rodríguez-Hernández *et al.*, 2020). Therefore, although PhET simulations improved Chemistry performance in this study, students' achievement should not be attributed to technology alone. Learning outcomes are also influenced by students' readiness, previous academic background, interest, effort, and the wider classroom environment.

Teacher-related factors are also important in explaining the success of simulation-based Chemistry learning. Effective teachers can guide students in using simulations meaningfully, connect virtual activities with lesson objectives, provide feedback, and help students interpret scientific representations. Studies have emphasized that teacher competence, teaching quality, teacher motivation, classroom clarity, feedback, and professional development influence students' learning outcomes (Andriani *et al.*, 2018; Annan, 2020; Ayeniyi and Jajua, 2020; Copur-Gencturk *et al.*, 2024; Fauth *et al.*, 2019; Fryer and Leenknecht, 2023; Kayode and Ayodele, 2015; Kim *et al.*, 2018; Wiggan *et al.*, 2021). This suggests that PhET simulations are most effective when teachers are able to integrate them with explanation, questioning, guided practice, and assessment. In Chemistry classrooms, the simulation itself may provide visual and interactive support, but the teacher remains central in helping students transform observation into conceptual understanding.

The result is also relevant to the wider challenge of improving Chemistry and science education in contexts where students experience low performance, limited instructional resources, and unequal access to quality learning support. Previous studies have reported concerns about students' underachievement, mass failure, poor instructional conditions, and

the need for more effective teaching strategies in science and general education (Anwer, 2019; Dodd et al., 2021; Fatade et al., 2013; Hiliya et al., 2023; Olufemioladebinu et al., 2018; Ononye and Obiakor, 2020; Saviour et al., 2022; Stone, 2021). In this regard, PhET simulations can serve as one practical response to resource limitations because they provide virtual access to scientific processes that may not always be available through physical laboratory facilities. However, the use of technology should be supported by appropriate pedagogy, sufficient access, and continuous teacher preparation.

The non-significant gender difference found in this study also strengthens the argument that interactive digital tools can support inclusive science learning when they are implemented appropriately. Studies on educational technology and online learning indicate that students' engagement, motivation, and learning experience may vary depending on access, teaching design, and support systems (Erdem, 2019; Sinaga and Pustika, 2021). In addition, students with diverse backgrounds and learning needs may require different forms of support to develop academic confidence and ability (Kim and Kutscher, 2021). Therefore, gender-inclusive Chemistry instruction should not only ensure that male and female students have equal access to PhET simulations but also provide differentiated guidance so that all learners can participate meaningfully. The comparable performance of male and female students in this study suggests that PhET simulation-based instruction can promote equitable learning opportunities, but its inclusive potential depends on how teachers organize, monitor, and support students during the learning process.

PhET simulation-based Chemistry instruction improved students' performance and did not create gender-based disparities. The balanced participation of male and female students, combined with non-significant gender differences in pretest and posttest scores, supports the conclusion that PhET simulations can be used as tools for gender-inclusive Chemistry instruction. For inclusive science education, the key implication is that learning technologies should not only improve achievement but also support equitable participation and performance across student groups.

#### 4. CONCLUSION

This study examined gender as a predictor of students' performance in PhET simulation-based Chemistry learning in secondary schools in Kwara State, Nigeria. The findings showed that students' performance improved after exposure to PhET simulations, as reflected in the increase between pretest and posttest scores. This suggests that PhET simulation-based instruction can support students' understanding of Chemistry concepts by making abstract topics more visual, interactive, and easier to explore.

The findings also showed that gender did not significantly influence students' performance. Male and female students had comparable pretest performance before the intervention and comparable posttest performance after exposure to PhET simulations. Although female students recorded slightly higher mean scores in both comparisons, the differences were not statistically significant. Therefore, the null hypotheses were accepted.

The study concludes that PhET simulations can serve as effective tools for improving Chemistry performance without creating gender-based disparities. This is important for gender-inclusive science education because it suggests that interactive simulation-based learning can provide both male and female students with equitable opportunities to engage with Chemistry content and improve their performance. Teachers are encouraged to integrate PhET simulations into Chemistry instruction, especially for abstract topics such as

matter, atoms, molecules, and chemical equations. Future studies may examine the long-term effects of PhET simulations, compare different simulation tools, and explore their use across rural, urban, mixed-gender, and single-gender school contexts.

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## 6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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