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PhET MANIPULATIVE INSTRUCTION AND STUDENTS' PERFORMANCE IN QUADRATIC GRAPHS IN UYO METROPOLIS, AKWA IBOM STATE

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Abstract
In this study, PhET Manipulative Instruction (a form of virtual manipulative instruction) was explored in enhancing the performance of students in quadratic graphs in Uyo Metropolis in Akwa Ibom State, Nigeria. This study was guided by three research questions and three hypotheses. The population of the study consisted of all senior secondary I students across schools in the Uyo metropolis. One hundred and five (105) students were purposively selected as the sample for the study. Quadratic Graphs Performance Test was used as the instrument for data collection in the study. The validated instrument had a reliability coefficient of 0.81 obtained using the Kuder-Richardson-21 formula. A quasi-experimental design with the assumption of non-equivalent control groups was adopted for the study. The two groups consisting of experimental and control were taught quadratic graphs using PhET Manipulative Instruction and Concrete Manipulative Instruction respectively. Mean, Standard Deviation, Percentage and Analysis of Covariance were used to analyze the data. The findings showed that students taught quadratic graphs using PhET Manipulative Instruction performed significantly higher than those taught using Concrete Manipulative Instruction. Gender, however, had a non-significant influence on the performance of students in the quadratic graph. Furthermore, the interaction of gender and manipulative instructions yielded a non-significant effect on the performance of students in the quadratic graph. It was therefore recommended that Virtual Manipulative Instructions such as PhET Manipulative Instructions, should be used to teach the concept of quadratic graphs in secondary schools.

Keywords: PhET Manipulative Instruction, Concrete Manipulative Instructions, Quadratic Graphs, Performance, Gender.

Introduction
Mathematics Education is currently witnessing an exponential growth of technology-enhanced learning. A digital learning environment, which can be physical or virtual, provides alternative ways of engaging learners in processes that enable a better knowledge and understanding of mathematical concepts. A digital resource system for learning is built on either a synchronous or asynchronous platform. According to Aldon et al. (2019) and Gogus (2015), examples of such include open courseware, blended learning tools, use of virtual learning apps, computer-supported learning and web-based resources. This paradigm shift in the design and delivery of instruction in Mathematics leads to the inculcation of twenty-first-century skills in the learners, as well as the promotion of metacognitive competence, conceptual, procedural, and experiential knowledge of the subject matter. This paradigm shift provides learners with greater options for reconstructing and shaping their own mathematical experiences and creativity. In this twenty-first century, learners are envisioned as digital citizens and technologically savvy while seeking to utilize myriads of digital resources such as virtual manipulatives. In the view of Moyer-Pakenham and Westenskow (2013), virtual manipulation is a technology-enabled visual representation of a dynamic mathematical object, which has programmable features that enable interaction, manipulation and opportunity to construct knowledge of mathematical concepts. They preserve the two elements of virtual manipulatives; interactivity, and manipulability, subject to the emergence of new programmable languages. The visual depiction of a dynamic item is accompanied by all of its programmable elements because the object would not be interactive or dynamic without these features. Virtual Manipulatives allow students to manipulate vast amounts of information instantly and concurrently examine

variations in multi-representation which can be numerical, symbolic, and visual. Invariably, this allows students to explore and manage real-world problems more readily (Calder & Brown, 2010). Virtual Manipulatives are used as the embedded features for smart pedagogical practice and robust instructional strategy. It entails the use of screen-based instantiations of physical manipulatives to teach a lesson in Mathematics. Learning mathematics using virtual manipulatives can take place synchronously or asynchronously in the Mathematics/Science Laboratory equipped with computer facilities or other digital tools such as mobile applications. Students have a range of challenging opportunities to master various concepts of interest in Mathematics such as quadratic graphs as they virtually and dynamically represent mathematical objects.

A robust virtual manipulative for teaching and learning difficult mathematical concepts is the renowned Physics Education Technology (PhET) Interactive Simulation. It was initiated by visionary Nobel Laureate Carl Wieman at the University of Colorado in 2002. There are more than 1.1 billion virtual PhET applets available online via http://phet.colorado.edu. PhET facilitates students' engagement of Mathematical concepts in quadratic graphs. It acts as a computer-enhanced learning software, available both online and offline on Android digital devices. PhET Interactive makes explicit use of dynamic graphics to animate visual and conceptual models for usage by topic specialists or mathematics teachers. The applets can be used as examples for connecting to ordinary life activities and as an assistive technology instrument. With animation and simulations, all of the PhET applets directly influence the learners' actions. Adjustment of any control keys, results in an immediate animated response in the visual representations, making these artefacts particularly useful for establishing cause-and-effect relationships. There is potential to enhance student's abilities when connected to multiple representations, and PhET is well known for it. It gives appropriate feedback and a feed-forward mechanism with gamification components. PhET interactive applets are designed to be used as a standalone learning aid, allowing instructors to choose which ones to use and how to use them for a given lesson. Each applet has an attached lesson package and how to implement it (teachers' tips and activities) it using PhET manipulatives. There are different virtual applets in PhET interactive simulation. Figure 1 shows some snapshots of quadratic graphs applet in PhET.

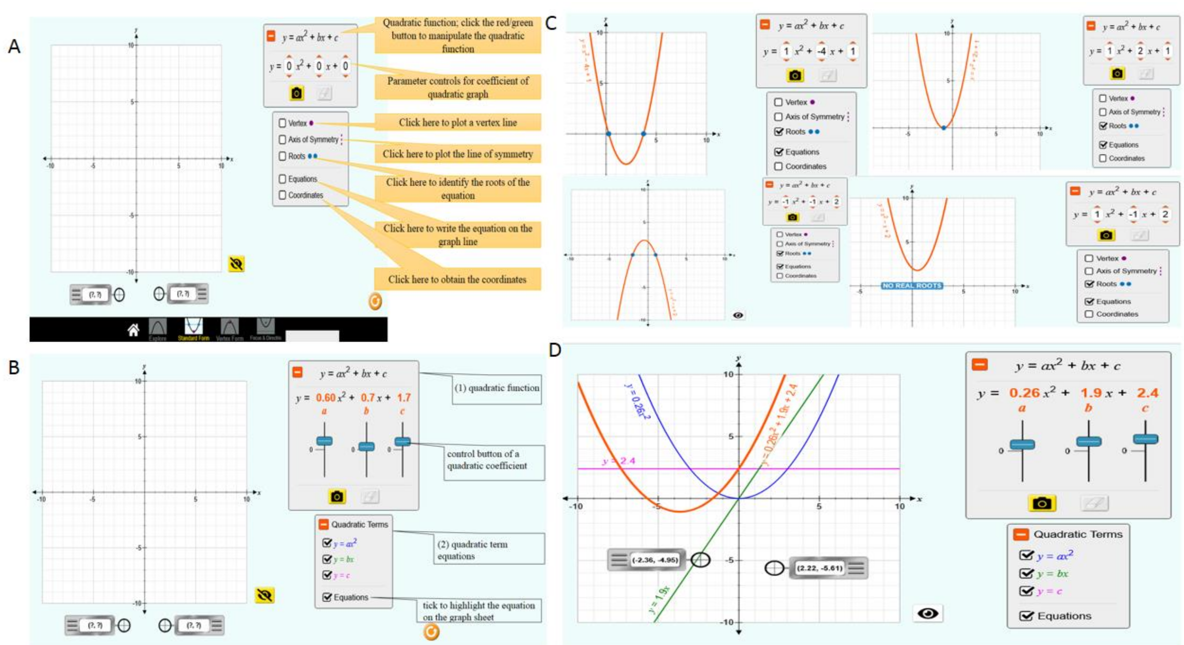

Figure 1: Snap shots of quadratic graphs applet in PhET Interactive Simulations

In Figure 1, sections A, and B depict the user interface of the graphing applet, while C and D are visualization and manipulation of the graphing icons to yield different quadratic graphs.

PhET offers different kinds of virtual affordance for understanding Mathematical concepts such as quadratic graphs. It is advantageous to the learners in the following ways: (i) learners can colour and change the configurations and outlook of a graphical object; (ii) the resources become rampant and readily available for usage (iii) they provide conceptual connections in which equations and graphs can be represented at a go for clearer connections (iv) they give essence to immediate evaluation and assessment of the learners, (v) they are user friendly, and easy to manipulate at any time, and anywhere (vi) they are void of digital divides, accessible in non-internet connected areas, and (vii) they create opportunity for learners to be inquisitive and discover connections to concepts during problem-solving. To achieve efficient usage of Virtual Manipulatives, however, teachers need to build professional competency. The use of virtual manipulatives in technology does not automatically result in learning; rather, the level of interaction with the technology creates opportunities for mathematical learning.

Ganasen and Shamuganathan (2017) investigated how interactive simulations in Physics Education Technology (PhET) might help students learn chemical equilibrium topics and correct their mistakes. The results showed that the proportion of students who had misunderstandings decreased for both groups, but the experimental group outperformed the students in the conventional group. Mallari and Lumanog (2020) found that after employing interactive simulation-based activities in the PhET, there was a noticeable improvement in the academic performance of pupils. It was also discovered that students were intensely motivated, engaged, and challenged while taking part in interactive tasks in class. Ojo (2020) from a study on the effect of computer simulation instructional strategy and pupils' achievement in Basic Sciences, found that the pupils taught using the computer simulation strategy performed significantly better in Basic Science than pupils taught using the conventional strategy. Ozcan et al. (2020) investigated students' success with the idea of greenhouse gases at a Science School in the Central Anatolia Region of Turkey using the Physics Education Technology (PhET) Simulation-Based Instruction. The learning process employing PhET interactive simulation resulted in greater student accomplishment compared to classes using laboratory kit activities in the concept of gas kinetic theory. Arifin et al. (2022) examined how students' mathematical understanding of fractions might be supported by mathematics learning design using PhET simulation. The findings of the study demonstrated how students' mathematical grasp of fractions was greatly enhanced through PhET Interactive Simulation. Physics Education Technology (PhET) was also used by Najib et al. (2022) as interactive simulation activities to measure students' Physics Achievements in Kedah, Malaysia. It was found that there is a significant difference in pretest and post-test scores between the two intervention groups. This result suggested that PhET simulation, if well-designed in an integrated learning environment can improve students' achievement in Physics.

The tremendous effort of stakeholders in education to ensure high mathematical literacy among its citizenry has hitherto not yielded much success. This is evident from the persistent failure rate of students in Mathematics in internal and external examinations at the secondary school level. The WAEC Chief Examiner has consistently reported students' inadequate knowledge of drawing, reading and interpreting values from the graphs (WASSCE, 2017, 2018, 2019). Similarly, in the 2020 WAEC Chief Examiner's report for General Mathematics, students found the sections containing quadratic graphs and graphically related problems to be very challenging (WAEC, 2020). Could this persistent failure be attributed to teachers' ineffective instructional strategies? Can the use of Virtual Manipulative Instruction such as PhET manipulative instruction be used to reduce the misconceptions and abstraction of Mathematical concepts, consequently building connections between concepts and their representations? This research therefore investigated the effect of PhET Manipulative Instruction on students' performance in quadratic graphs in Secondary Schools.

Aim and Objectives of the Study

This study aimed to ascertain the effect of PhET Manipulative Instruction on the performance of secondary school students in the concept of Quadratic graphs.

The following were the specific objectives of the study:

1. to determine the effect of instructional strategy (PhET Manipulative Instruction and Concrete Manipulative Instruction) on the performance of students in Quadratic graphs.
2. to ascertain the influence of gender on the performance of students in Quadratic graphs.
3. to examine the joint effect of instructional strategy (PhET Manipulative Instruction and Concrete Manipulative Instruction) and gender on the performance of students in Quadratic graphs.

Research Questions

The study was guided by the following research questions:

1. What is the effect of instructional strategy (PhET Manipulative Instruction and Concrete Manipulative Instruction) on the performance of students in Quadratic graphs?
2. What is the influence of gender on the performance of students in Quadratic graphs?
3. What is the joint effect of instructional strategy (PhET Manipulative Instruction and Concrete Manipulative Instruction) and gender on the performance of students in Quadratic graphs?

Research Hypotheses

The following hypotheses were tested at a 0.05 level of significance:

1. There is no significant difference between the students taught using PhET Manipulative Instruction, and those taught using Concrete Manipulative Instruction in their performance in Quadratic graphs.
2. There is no significant difference between the performance of male and female students in Quadratic graphs.
3. There is no significant joint effect of instructional strategy and gender on the performance of students in Quadratic graphs.

Materials and Methods

This study adopted a pretest-posttest, non-equivalent quasi-experimental design. The population of the study consisted of four thousand nine hundred and sixteen (4916) Senior Secondary one (SSI) students having two thousand and twenty-one (2021) male and two thousand eight hundred and ninety-five (2895) female students of the 2021/2022 Academic session in Akwa Ibom State (State Secondary Education Board [SSEB], 2022). For the study, a purposive sampling technique was used to select two secondary schools based on the following criteria: (i) well-equipped and functional Computer Laboratory, (ii) science and mathematics teachers with quantifiable years of experience, and (iii) schools that presented students for the Senior Secondary Schools Certificate Examinations (SSCE) in the last five (5) academic sessions. Thereafter, using a simple random sampling technique, one intact class was selected from each of the two schools having a total of one hundred and five (105) students. Students assigned to the experimental group were taught the concept of Quadratic graphs using PhET Manipulative Instruction, while students assigned to the control group were taught the same concept using Concrete Manipulative Instruction. Quadratic Graphs Performance Test (QGPT) consisting of twenty (20) multiple choice test questions on Quadratic graphs was the research instrument. The validated instrument was subjected to the Kuder Richadson-21 formula to obtain a reliability coefficient of 0.81. QGPT was administered to the students as pretest and posttest to obtain data for the study. Mean, standard deviation, percentage, and Analysis of Covariance (ANCOVA) were used for data analyses.

Results

Research Question 1: What is the effect of instructional strategy (PhET Manipulative Instruction and Concrete Manipulative Instruction) on the performance of students in Quadratic graphs?

Table 1: Mean and standard deviation of students' performance classified by instructional strategy

Instructional Strategy		Pretest		Posttest		Mean Gain	Percentage Mean gain
	N	M	SD	M	SD	M_g	%
PhET Manipulative Instruction	48	61.67	13.50	80.52	11.68	18.85	30.57
Concrete Manipulative Instruction	57	59.30	16.41	64.82	16.85	5.52	9.31

Table 1 presents the descriptive statistics of the pretest scores of students taught the concept of quadratic graphs using PhET Manipulative Instruction (n = 48, M = 61.67, SD = 13.50) and those taught using Concrete Manipulative Instruction (n = 57, M = 59.30, SD = 16.41) respectively. Table 1 also describes the descriptive statistics of the post-test scores of students taught quadratic graphs using PhET Manipulative Instruction (n = 48, M = 80.52, SD = 11.68) and those taught Concrete Manipulative Instruction (n = 57, M = 64.82, SD = 16.85). There are mean gains within each group's mean performance scores when taught the concept of quadratic graphs. The mean gain (M_g = 18.85) of students taught quadratic graph using PhET Manipulative Instruction is higher than the mean gain (M_g = 5.52) of students taught the same concept using Concrete Manipulative Instruction. Similarly, students exposed to the use of PhET manipulative had a higher percentage mean gain of 30.57 while students exposed to Concrete Manipulative Instruction had a percentage mean gain of 9.33.

Research Question 2: What is the influence of gender on the performance of students in quadratic graphs?

Table 2: Mean and standard deviation of students' performance classified by gender

Gender	Pretest			Post-test		Mean Gain	Percentage mean gain
	n	*M*	*SD*	*M*	*SD*	$\lvert M_g \rvert$	%
Male	44	61.02	13.58	70.45	15.47	9.43	15.45
Female	61	59.92	16.24	72.00	17.44	12.08	20.16

Table 2 shows the classification of the student's performance scores by gender for both pretest and post scores respectively. Table 2 shows the pretest score for males (*n* = 44, *M* = 61.05, *SD* = 13.58) and females (*n* = 61, *M* = 59.92, *SD* = 16.24), as well as the post-test scores for males (*n* = 44, *M* = 70.45, *SD* = 15.47) and female (*n* = 61, 72.00, *SD* = 17.44) students taught quadratic graph. There is a gain in the mean performance scores within the male (M_g = 9.43) and female (M_g= 12.08) students when taught quadratic graphs. Table 2 further shows that female students had a higher percentage mean gain of 20.16 2 while their male counterparts had a percentage mean gain of 15.45.

Research Question 3: What is the joint effect of instructional strategy and gender on the performance of students in quadratic graphs?

Table 3: Mean and standard deviation of students' performance classified by instructional strategy and gender

Instructional strategy	Gender	Pretest			Post-post test		Mean Gain	Percentage gain
		n	*M*	*SD*	*M*	*SD*	$\lvert M_g \rvert$	%
PhET Manipulative Instruction	Male	19	58.68	12.57	76.32	13.52	17.64	30.06
	Female	29	63.62	13.94	83.28	9.57	19.66	30.90
Concrete Manipulative Instruction	Male	25	62.80	14.29	66.00	15.61	3.20	5.10
	Female	32	56.56	17.62	63.91	17.95	7.35	12.98

Table 3 shows the classification of students' mean performance scores by instructional strategy and gender for both pretest and posttest scores respectively. In the use of PhET Manipulative Instruction, Table 3 indicates the pretest score for male (*n* = 19, *M* = 58.68, *SD* = 12.57) and female (*n* = 29, *M* = 63.62, *SD* = 13.94), as well as the posttest score for male (*n* = 19, *M* = 76.32, *SD* = 13.52) and female (n = 29, *M* = 83.28, SD = 9.57). There is a mean gain score within the male (M_g = 17.63) and female (M_g= 19.66) students' performance scores when taught quadratic graph using PhET Manipulative Instruction. Female students had a higher percentage mean gain of 30.90, while their male counterparts had a percentage mean gain of 30.06.

For the group taught using Concrete Manipulative Instruction, Table 3 shows the pretest score for males (*n* = 25, *M* = 62.80, *SD* = 14.29) and females (*n* = 32, *M* = 56.56, *SD* = 17.62), as well as the post-test scores for male (*n* = 25, *M* = 66.00, *SD* =15.61) and female (n = 32, *M* = 63.91, SD = 17.95). There is a mean gain score within the male (M_g = 3.2) and female (M_g= 7.35) students' performance when taught quadratic graphs using Concrete Manipulative Instruction. The percentage mean gain for females was 12.98, whereas the percentage mean gain for males was 5.10.

Hypothesis 1: There is no significant difference between the students taught using PhET Manipulative Instruction, and those taught using Concrete Manipulative Instruction in their performance in quadratic graphs.

Table 4: Summary of ANCOVA of students' performance classified by instructional strategy using pretest as covariate

Dependent Variable: Posttest Scores

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	12769.337[a]	2	6384.669	40.803	0.000
Intercept	10391.733	1	10391.733	66.411	0.000
Pretest	6349.562	1	6349.562	40.578	0.000
Strategy	5421.423	1	5421.423	34.647	0.000
Error	15960.663	102	156.477		
Total	573050.000	105			
Corrected Total	28730.000	104			

a. R Squared = 0.444 (Adjusted R Squared = 0.434)

Table 4 shows the summary of the Analysis of Covariance (ANCOVA) of students' performance classified by instructional strategy using pretest as a covariate. The table shows $F_{1,102}$ =34.647, p = 0.00 (p < 0.05) for strategy. The null hypothesis was therefore rejected, which indicates a significant difference between the performance of students taught quadratic graphs using PhET Manipulative Instruction and those taught using Concrete Manipulative Instruction.

Hypothesis 2: There is no significant difference between the performance of male and female students in quadratic graphs.

Table 5: Summary of ANCOVA of students' performance classified by gender using pretest as covariate

Dependent Variable: Posttest Scores

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7622.311[a]	2	3811.155	18.417	0.000
Intercept	8791.420	1	8791.420	42.483	0.000
Pretest	7441.417	1	7441.417	35.960	0.000
Gender	274.396	1	274.396	1.326	0.252
Error	21107.689	102	206.938		
Total	573050.000	105			
Corrected Total	28730.000	104			

a. R Squared = 0.265 (Adjusted R Squared = 0.251)

Table 5 shows the summary of Analysis of Covariance (ANCOVA) of students' performance classified by gender using a pretest as a covariate. The table shows $F_{1,102}$ =1.326, p = 0.252 (p > 0.05) for strategy. The null hypothesis was therefore retained, which indicates that there is no significant difference between the performance of male and female students in Quadratic graphs.

Research Hypothesis 3: There is no significant joint effect of instructional strategy and gender on the performance of students in quadratic graphs.

Table 6: Summary of ANCOVA of students' performance classified by instructional strategy and gender using pretest as covariate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	13010.928[a]	4	3252.732	20.693	0.000
Intercept	10116.269	1	10116.269	64.357	0.000
Pretest Scores	5973.545	1	5973.545	38.002	0.000
Strategy	5002.383	1	5002.383	31.824	0.000
Gender	193.159	1	193.159	1.229	0.270
Strategy * Gender	67.924	1	67.924	0.432	0.512
Error	15719.072	100	157.191		
Total	573050.000	105			
Corrected Total	28730.000	104			

a. R Squared = 0.453 (Adjusted R Squared = 0.431)

Table 6 shows the summary of the Analysis of Covariance (ANCOVA) of students' performance classified by instructional strategy and gender using a pretest as a covariate. The table shows $F_{1,100} = 0.432$, $p = 0.512$ ($p > 0.05$) for strategy. The null hypothesis was hence retained, which indicates that there is no significant joint effect of instructional strategy and gender on the performance of students in quadratic graphs.

Discussion

Students taught quadratic graphs using PhET Manipulative Instruction performed significantly higher than students taught using Concrete Manipulative Instruction. The differences in performance could be attributed to the interactive dynamic, and flexible features embedded in the use of PhET Manipulative applets. PhET Manipulative Instruction facilitates engagement and manipulative skills of the learners during the learning process. PhET Manipulative could foster cognitive growth and conceptual understanding of the concept of quadratic graphs. This finding is supported by Banda and Nzabahiman (2023) who discovered improvement in students' learning outcomes in oscillation. Similarly, Charles-Ogan and Ndubisi (2022) found that the performance scores between treatment groups, while learning solid geometry using computer-supported simulation differ significantly. On the contrary, when explicit teaching strategy and concrete representational abstract strategy were used, Nwabueze (2020) found that the mean achievement scores of students with dyscalculia in mathematics were not statistically significant.

Female students had a higher mean gain in performance when compared to male students. The difference found between the performance of male and female students was however not statistically significant. Moreover, Manipulatives are gender-responsive, where males and females can explore, experiment, interpret, and manipulate the learning environment virtually and concretely respectively. Similarly, male and female students have been assumed to exhibit equal cognitive capacity to assimilate, accommodate and adapts to the learning environment, while executing learning task in both virtual and non-virtual learning scenarios. Flore et al. (2018), considered the impact of gender stereotype threat on mathematics exam performance, in support of the current study. They found that despite the use of domain identification, gender identification, math anxiety, and test difficulty, there was no overall effect of stereotype threat on arithmetic performance. Wisely, this finding is supported by Omeodu and Charles-Owaba (2020) who reported that the use of Kpokirikpo-Manipulative Patterns for teaching number-based and arithmetic counting, gender exerted no significant influence on students' performance in the learning of probability. The findings of this study are contrary to the finding of Allahnana et al. (2018) who found that male students performed significantly higher in Mathematics than female students.

In the group taught using PhET Manipulative Instruction, female students gained more than their male counterparts.

Similarly, in the group taught using Concrete Manipulative Instruction, female students gained more than their male counterparts. In general, female students taught using PhET Manipulative Instruction had the highest mean gain, followed by the male students taught using PhET Manipulative Instruction. The male students taught using Concrete Manipulative Instruction had the least mean gain. However, there is no joint effect of instructional strategy and gender on students' academic performance in quadratic graphs. This could happen due to the multiple representational effects of PhET manipulatives, as well as the inclusivity effect of mathematical manipulatives. Manipulatives facilitate germane cognitive load irrespective of gender. This result corroborates the finding of Akhigbe et al. (2020) on the use of gender-responsive collaborative learning strategy to improve students' achievement and attitude towards learning science. They emphasized that gender-responsive collaborative learning strategy (GR-CLS) is a successful educational approach for raising students' achievement in biological science, independent of gender. The finding of this study is also in consonance with the finding of Abumchukwu et al. (2021) who discovered no significant interaction of instructional strategy and gender on students’ performance in Chemistry as well as Obafemi and Rowland (2022) who found no significant joint effect of strategy and gender on students' performance in Basic Science. On the contrary, however, Ugwu (2014) found that the interaction of strategy and gender had a significant effect on students' performance in Basic Science.

Conclusion

This study has revealed that the use of PhET Manipulative instruction enhances students' academic performance in quadratic graphs, male and female students performed effectively in quadratic graphs while the interaction of instructional strategy and gender did not have a significant effect on students' performance in quadratic graphs. The onus now lies on all stakeholders in education especially sciences to provide an enabling environment for the use of manipulative instruction for the students. This will remedy students' performance in Quadratic graphs and Mathematics generally.

Recommendations

Recommendations made include the following:

1. Students should be taught quadratic graphs using PhET Manipulative Instruction at the secondary school level.
2. Curriculum designers should design robust learning content that facilitates gender inclusivity and flexible learning resources such as PheT Manipulative Instruction for teaching quadratic graphs.
3. Parents and guardians should provide assistive technological devices at home, such as smart handheld tools that will support students’ manipulative skills in the learning of quadratic graphs.

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