EFFECT OF PHET SIMULATIONS ON SECONDARY SCHOOL STUDENTS' ACHIEVEMENT IN ELEMENTARY ALGEBRA

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Abstract
Students often experience difficulty understanding abstract algebraic concepts, prompting the need for more effective instructional strategies. This study examined the effect of PhET simulations on junior secondary school students' achievement in elementary algebra. Three research questions guided the study, and three hypotheses were tested. Two schools were randomly selected from Education District VI. The study adopted a pretest–posttest quasi-experimental design involving two intact classes in each school, randomly assigned to experimental and control groups. The experimental group received instruction supported with PhET simulations, whereas the control group was taught using the conventional chalk-and-talk method. The instrument for data collection was the Achievement Test in Elementary Algebra (ATEA). Data were analyzed using mean, standard deviation, and analysis of covariance (ANCOVA). The results revealed a statistically significant improvement in the achievement of students taught using PhET simulations compared to those in the control group. Based on these findings, the use of PhET simulations is recommended as an effective tool for enhancing students' understanding of algebraic concepts in mathematics instruction.

Keywords: PhET simulations, algebra, students' achievement, educational technology

Introduction

Mathematics remains a foundational subject for developing problem-solving skills and critical thinking abilities among learners. However, many secondary school students struggle particularly with elementary algebra, owing to its abstract nature and symbolic representations that require higher-order cognitive processing. This challenge is further heightened in the present volatile, uncertain, complex, and ambiguous (VUCA) world, where learners must not only understand mathematical concepts but also apply them meaningfully in real-life contexts (Akinoso, 2018). Research has shown that making mathematics instruction more engaging, learner-centered, and conceptually rich can significantly improve students' attitudes and achievement (Odewale, 2021). To achieve this, contemporary mathematics education increasingly embraces diverse instructional approaches, including the integration of digital technologies that support visualization, exploration, and deeper conceptual understanding.

One emerging technological tool widely gaining prominence in mathematics education is the Physics Education Technology (PhET) Interactive Simulations developed by the University of Colorado Boulder. Although originally designed for physics instruction, PhET simulations have expanded across disciplines, including mathematics, providing dynamic, interactive, and visually appealing platforms for teaching abstract concepts. These simulations concretize mathematical ideas by offering multiple representations, real-time manipulation, and exploratory environments that allow students to observe relationships, test hypotheses, and build conceptual understanding at their own pace (PhET Interactive Simulations, 2024). Research confirms that PhET simulations enhance learning through visual scaffolding, interactive engagement, and reduction of cognitive load associated with abstract concepts (Wieman, Adams, & Perkins, 2008).

Empirical studies further support the effectiveness of PhET simulations in enhancing student learning outcomes. Banda and Nzabahimana (2023) reported that PhET simulations improve learners’ achievement and motivation by providing accessible visualizations that simplify complex ideas. Dy, Lagura, and Baluyos (2024) also found that PhET interactive simulations significantly enhanced learners' performance in science, highlighting their potential across STEM disciplines. However, some studies in mathematics education, such as Akinoso (2018), documented no significant effect of multimedia tools on students’ performance, indicating the need for further research on technology-based instructional tools particularly those with unique interactive capabilities like PhET simulations. This mixed empirical evidence suggests a gap in understanding the specific impact of PhET simulations on mathematics learning, especially in areas such as elementary algebra where conceptual difficulties are common.

Gender remains a recurring factor in mathematics achievement research, yet findings remain inconclusive. While some studies suggest that societal expectations contribute to the belief that males perform better in mathematics (Herts & Levine, 2020), others, including Akinoso (2018), found no significant gender differences when technology-based instruction is used. With increasing emphasis on gender equity in education, it is essential to determine whether male and female students benefit equally from PhET simulations in learning elementary algebra. Given the persistent difficulty students face in acquiring algebraic proficiency, the growing availability of interactive technological tools, and the need to clarify gender-related learning outcomes, this study investigates the effect of PhET simulations on secondary school students’ achievement in elementary algebra.

Statement of the Problem

Despite the central role of mathematics in developing problem-solving skills and preparing learners for real-life applications, many secondary school students continue to experience persistent difficulties in understanding elementary algebra. These challenges are often traced to limited conceptual understanding, the abstract nature of algebraic concepts, and the predominant use of traditional teaching methods that do not adequately support visualization and active engagement. Consequently, students’ achievement in algebra remains generally low, as reported in several national and international assessments. In response to these challenges, interactive technological tools such as the Physics Education Technology (PhET) simulations have emerged as potential resources for enhancing students' understanding of abstract concepts through visualization, exploration, and real-time feedback. Although research has shown the effectiveness of PhET simulations in science instruction, empirical evidence on their impact on students' achievement in mathematics particularly elementary algebra is still limited and inconclusive. Additionally, findings on gender differences in technology-supported mathematics learning remain inconsistent, necessitating further investigation. Therefore, the problem of this study is the persistent low achievement of secondary school students in elementary algebra and the need to determine whether the use of PhET simulations can improve learning outcomes. The study also seeks to examine whether male and female students benefit equally from PhET supported instruction.

Purpose of the Study

The purpose of this study is to determine the effect of PhET simulations on secondary school students' achievement in elementary algebra. Specifically, the study seeks to:

i. Examine the main effect of PhET simulation-based instruction on students' achievement in elementary algebra.

ii. Determine the influence of gender on students' achievement in elementary algebra.

iii. Assess the interaction effect of PhET simulations and gender on students' achievement in elementary algebra.

Research Questions

The study was guided by the following research questions:

RQ1: What is the effect of PhET simulation-based instruction on students' achievement in elementary algebra?

RQ2: What influence does gender have on students' achievement in elementary algebra?

RQ3: What is the interaction effect of PhET simulations and gender on students' achievement in elementary algebra?

Hypotheses

The following hypotheses were tested in this study at a 0.05 level of significance.

H_{01}: There is no significant effect of PhET simulations on secondary school students' achievement in elementary algebra.

H_{02}: There is no significant difference in the achievement of male and female students taught elementary algebra using PhET simulations.

Theoretical Framework

The theories that form the base of this study include the constructivist learning theory developed by Piaget (1952), Vygotsky (1978) that learners actively construct knowledge based on their experiences rather than receiving information passively. The relevance of this theory to this study is that PhET simulations promote active and inquiry-based learning where the variables can be manipulated, concepts visualized, and mathematical relationships can be discovered through exploration.

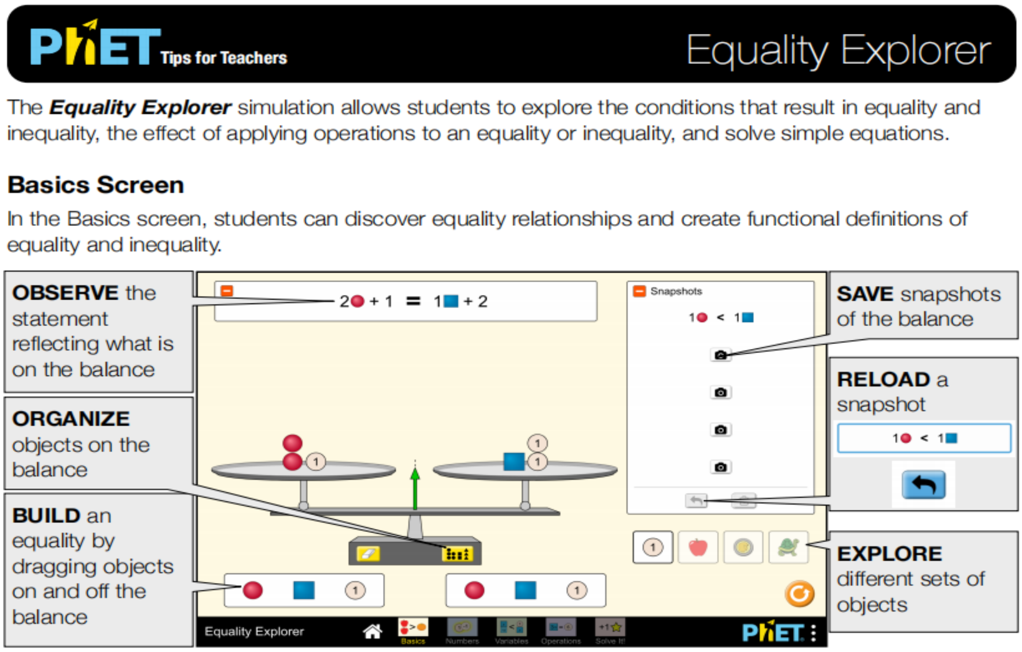
Sweller, (1988) is another theory of learning that supports this study that learning is more effective when the cognitive load is optimized. PhET simulations simplify complex concepts using interactive visualizations, reducing extraneous cognitive load and enhancing understanding of abstract mathematical concepts.

Methodology

This study employed a pre-test, post-test, control group, and quasi-experimental design to investigate the effects of PhET simulations on Junior Secondary School Students' achievement in elementary algebra to measure the effectiveness of the intervention. The experimental group used PhET simulations as a supplementary tool for learning algebra, while the control group followed the traditional chalk-and-talk teaching method. The population for this study comprised all secondary schools in educational district VI in Lagos state. Two schools were selected randomly from the selected district and an intact class was then selected from each of the schools. The sample size was 75 students, 35 for the control and 40 for the experiment.

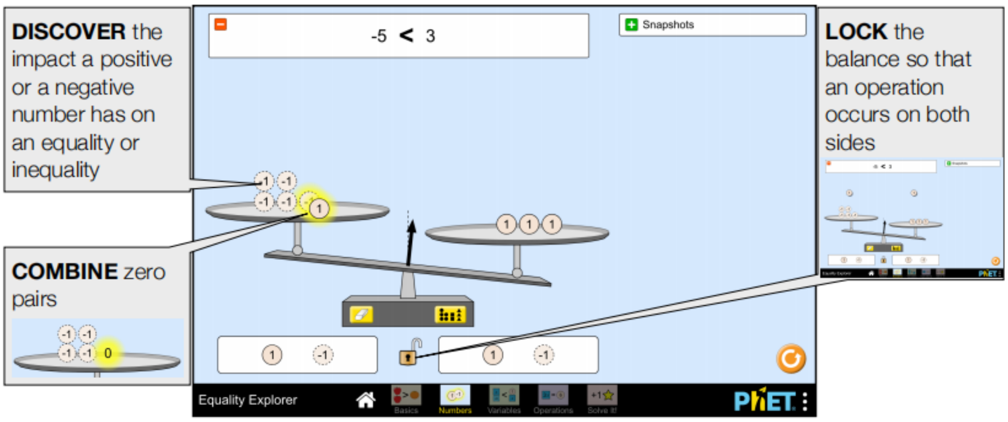
The Instrument for data collection for this study include the Achievement Test in Elementary Algebra (ATEA). The selected topic was based on elementary algebra which involves simple equations. The materials related to algebra topics, such as linear equations and inequalities, were used as part of the instructional material for the experimental group. The instrument was validated for face, content, and criterion validity. The reliability of this study was ensured and assessed through a pilot study conducted using the same Achievement Test in Elementary Algebra (ATEA) for a school not part of the study. KuderRichardson-20 (KR-20) was used to determine the coefficient of alpha and the value obtained was 0.85. The data collected were analyzed using mean, standard deviation, and Analysis of Covariance (ANCOVA).

The figures below show the features in PhET simulations for solving mathematical equations designed by the University of Colorado which is a free interactive research-based science and Mathematics simulation.



Numbers Screen

In the Numbers screen, students can turn on the lock to perform the same operation to both sides of the balance and explore what happens to the state of equality.

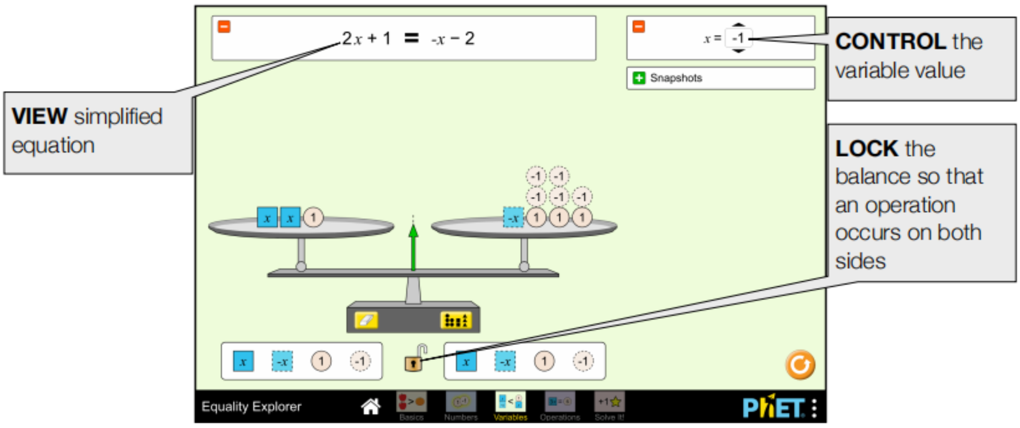


McGarry, August 2023

Source:https://phet.colorado.edu/en/simulations/equality-explorer/teaching-resources

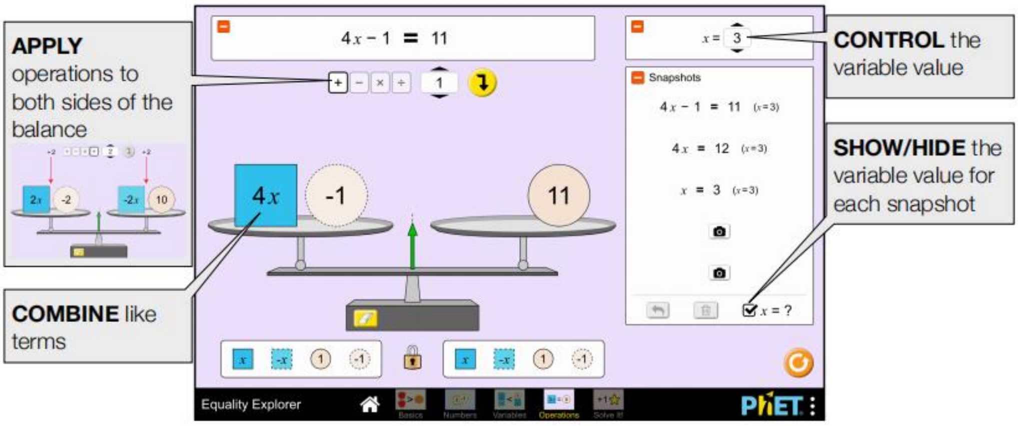
Variables Screen

In the Variables screen, students explore how different values for a variable impact the state of equality.



Operations Screen

In the Operations screen, students can build an inequality or equation and apply universal operations to explore what happens to each term, and discover how to undo an operation.



Insights into Student Use

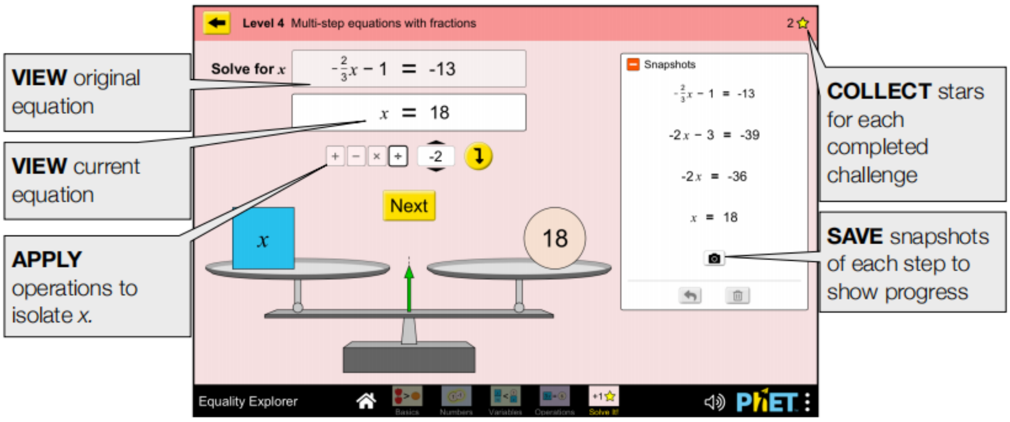
- Students naturally want to find balanced situations. Encourage them to find as many as possible.
- Students enjoy applying operations to create the largest or smallest numbers.
- Students might realize that an operation is "unproductive" or doesn't do exactly what they want. Challenge them to find the operation that will "undo" their last one.

McGarry, August 2023

Solve It! Screen

In the Game, students solve equations using the universal operation control to isolate the variable.

Level 1: one-step equations
Level 2: one-step equations with negative coefficients
Level 3: two-step equations
Level 4: multi-step equations with fractions
Level 5: multi-step equations with variables on both sides of the equation



Source:https://phet.colorado.edu/en/simulations/equality-explorer/teaching-resources

Suggestions for Use

- Explore proportional relationships on the Basics screen.
- Using the Variables screen, set up a balanced equation and minimize the variable value. Trade computers with a partner and figure out the value of x.

Sample Challenge Prompts

- Find as many equations as possible using the objects on the Basics screen.
- What happens to an equation or inequality if you add 1 to both sides with the lock on? What happens if you add -1 to both sides with the lock on?
- Explain what happens to an equation if you try to remove 1 from both sides (with the lock on) and you don't have a 1 available. Why does this happen?

Customization Options

Query parameters allow for customization of the simulation, and can be added by appending a '`?`' to the sim URL, and separating each query parameter with a '`&`'. The general URL pattern is:
`...html?queryParameter1&queryParameter2&queryParameter3`

For example, in Equality Explorer, if you only want to include the 1st and 2nd screens (`screens=1,2`), with the 2nd screen open by default (`initialScreen=2`) use:
https://phet.colorado.edu/sims/html/equality-explorer/latest/equality-explorer_all.html?screens=1,2&initialScreen=2

McGarry, August 2023

To run this in Spanish (`locale=es`), the URL would become:
https://phet.colorado.edu/sims/html/equality-explorer/latest/equality-explorer_all.html?locale=es&screens=1,2&initialScreen=2

Query Parameter and Description	Example Links
`gameLevels` - specifies which levels appear in the game.	`gameLevels=1,2,3`
`rewardScore` - sets the number of challenges that must be solved before being prompted to try another level (default is 10).	`rewardScore=5`
`screens` - specifies which screens are included in the sim and their order. Each screen should be separated by a comma. For more information, visit the Help Center.	`screens=1` `screens=2,1`
`initialScreen` - opens the sim directly to the specified screen, bypassing the home screen.	`initialScreen=1` `initialScreen=3`
`locale` - specify the language of the simulation using ISO 639-1 codes. Available locales can be found on the simulation page on the Translations tab. Note: this only works if the simulation URL ends in "_all.html".	`locale=es` (Spanish) `locale=fr` (French)

Source:https://phet.colorado.edu/en/simulations/equality-explorer/teaching-resources

Results

Table 1: Distribution of Students based on Group

Table 1 presents the distribution of students based on the group assignment. Of the total 75 participants, 35 (46.7%) were assigned to the control group, and 40 (53.3%) were assigned to the experimental group.

Group	Frequency	Percentage (%)
Control	35	46.7
Experimental	40	53.3
Total	75	100

This indicates that a slightly larger proportion of participants were in the experimental group compared to the control.

Table 2: Distribution of Students based on Gender

Gender	Frequency	Percentage (%)
Male	42	56.0
Female	33	44.0
Total	75	100

Table 2 presents the distribution of Students based on gender. Of the total 75 participants, 42 (56.0%) were male, and 33 (44.0%) were female. This indicates that the majority of the participants in the study were male.

RQ1: What is the main effect of the treatment on students' achievement in algebra?

Table 3: Main Effect of the Treatment on Students' Achievement in Algebra

		Pre-test		Post-test		
Treatment	N	Mean	SD	Mean	SD	Mean Gain
Control	35	57.65	4.26	77.94	4.44	20.29
Experimental	40	61.47	5.83	85.72	3.27	24.25

Table 3 shows the main effect of the treatment on students' achievement in algebra, comparing the control and experimental groups. The control group had a pre-test mean score of 57.65 (SD = 4.26) and a post-test mean score of 77.94 (SD = 4.44), resulting in a mean gain of 20.29 points. The experimental group had a pre-test mean score of 61.47 (SD = 5.83) and a post-test mean score of 85.72 (SD = 3.27), leading to a mean gain of 24.25 points.

The results suggest that both groups experienced an improvement in their achievement in algebra, with the experimental group showing a larger mean gain (24.25 points) compared to the control group (20.29 points). This indicates that the treatment had a positive effect on students' achievement, with the experimental group achieving a greater level of improvement. Further statistical analysis would be necessary to determine if the differences in the mean gains are statistically significant.

RQ2: What is the influence of gender on students' achievement in algebra?

Table 4: Influence of Gender on Students' Achievement in Algebra

		Pre-test		Post-test		
Treatment	N	Mean	SD	Mean	SD	Mean Gain
Male	42	59.61	5.95	76.61	3.72	17.00
Female	33	59.78	4.87	76.93	4.36	17.15

Table 4 shows the influence of gender on students' achievement in algebra, comparing the performance of male and female students. For the pre-test, male students had a mean score of 59.61 (SD = 5.95), while female students had a slightly higher pre-test mean of 59.78 (SD = 4.87). In the post-test, male students scored a mean of 76.61 (SD = 3.72), and female students scored 76.93 (SD = 4.36). The mean gain for male students was 17.00 points, while female students showed a slightly higher mean gain of 17.15 points. These results suggest that both male and female students experienced similar improvements in their achievement in algebra, with female students showing a marginally higher gain than male students. While the differences in mean scores and mean gains are minimal, further statistical analysis would be needed to assess whether the observed gender differences are statistically significant. Overall, the influence of gender on students' achievement appears to be relatively small based on these results.

Hypotheses

H_{01}: There is no main effect of the treatment on students' achievement in algebra.

Table 5: **Analysis of Covariance (ANCOVA) to Test Treatment, Gender, and Interaction of Treatment and Gender on Students' Achievement in Algebra**

Tests of Between-Subjects Effects

Dependent Variable: Posttest

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	161.289[a]	4	40.322	2.766	.034
Intercept	2979.406	1	2979.406	204.391	.000
Pretest	4.066	1	4.066	.279	.599
Gender	7.718	1	7.718	.529	.469
Group	114.613	1	114.613	7.863	.007
Gender * Group	58.401	1	58.401	4.006	.049
Error	1020.391	70	14.577		
Total	443089.000	75			
Corrected Total	1181.680	74			

a. R Squared = .136 (Adjusted R Squared = .087)

The ANCOVA results reveal a significant main effect of the treatment on students' achievement in algebra ($F(1, 70) = 7.863$, $P = .007$). This indicates that the treatment groups had a statistically significant impact on students' post-test achievement scores. Therefore, the null hypothesis (H_{01}) is rejected, suggesting that the treatment had a significant effect on students' achievement in algebra.

H_{02}: There is no influence of gender on students' achievement in algebra.

The ANCOVA results show that the main effect of gender on students' achievement in algebra was not significant (F(1, 70) = 0.529, P = .469). This implies that gender did not have a significant influence on students' achievement in algebra. Thus, the null hypothesis H_{02} is not rejected, suggesting that gender did not contribute significantly to differences in algebra achievement.

H_{03}: There is no interaction effect between the treatment and gender on students' achievement in algebra.

The interaction effect between treatment and gender on students' achievement in algebra was found to be significant (F(1, 70) = 4.006, P = .049). This suggests that the effect of the treatment on students' achievement in algebra differs depending on gender. Therefore, the null hypothesis **H_{03}**: is rejected, indicating that there is a significant interaction effect between treatment and gender.

Discussion

Students who used PhET Simulations demonstrated a significant improvement in their algebraic skills compared to those who did not use these tools. The interactive nature of the simulations allowed students to visualize abstract concepts, leading to a deeper understanding and retention of the topics (simple equations, algebraic expressions, and substitution) taught using the simulations. Dy, Lagura, Baluyos, (2024), reported an outstanding improvement in learners' performance following the use of PhET interactive simulations in science learning. This is in line with the result of this study that proved the PhET effectiveness in Mathematics learning. Akinoso, (2018), in a study of the effect of the use of multimedia on students' performance in secondary school Mathematics, found no significant effect on the use of multimedia in Mathematics instruction. This study negates the findings of the study that proved abortive the effectiveness of the use of Physics Education technology. The findings of this study also indicated that PhET simulations were particularly effective in promoting collaborative learning. Students often worked together to solve problems presented in the simulations, fostering a sense of teamwork and collective problem-solving.

Gender did not have a significant influence on students' achievement in algebra using PhET simulations. This suggested that gender did not contribute significantly to differences in algebra achievement using Physics education technology.

Conclusion

The effectiveness of PhET simulations in teaching mathematics and science is well-supported by research and practical classroom implementation. These interactive simulations enhance student engagement, conceptual understanding, and problem-solving skills by providing a dynamic, inquiry-based learning environment. Grounded in constructivist learning theory, PHET enables students to actively explore mathematical concepts rather than passively receive information.

Additionally, from the perspective of cognitive load theory, PhET reduces extraneous cognitive demands, allowing students to focus on core mathematical principles.

Research evidence indicates that students who use PhET simulations show improved comprehension, higher retention, and greater motivation than those taught with traditional methods. The visual and interactive features help bridge the gap between abstract mathematical theories and real-world applications, making learning more accessible and enjoyable. As a result, PhET simulations serve as an effective tool for educators seeking to enhance student-centered learning and foster deeper mathematical understanding.

Recommendation

PhET simulation should be integrated into Mathematics instruction due to its effectiveness in teaching algebra in Mathematics. PhET simulations also enhance conceptual understanding and promote an active learning of Mathematics.

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