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UTILIZATION OF PHYSICS EDUCATION TECHNOLOGY (PHET) - MATH SIMULATION IN GRADE 9 MATHEMATICS

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ABSTRACT

This study determined the effect of utilizing PhET-Math Simulation on the mastery level of Grade 9 students in Mathematics at Sunflower Trilingual School, Samut Sakhon, Thailand. Specifically, it compared the performance of students taught through traditional instruction and those taught using PhET-Math Simulation. The study employed a quantitative approach using a true experimental pretest-posttest control group design. The participants were 30 Grade 9 students enrolled during the summer term of 2023, selected through total population sampling and randomly assigned into control and experimental groups with 15 students each. An adapted and validated diagnostic test aligned with the Thai Basic Education Core Curriculum was used as the pretest and posttest instrument. The control group received traditional lecture-based instruction, while the experimental group was taught using PhET-Math Simulation integrated into Mathematics lessons for four weeks. Data were analyzed using frequency count, mean, standard deviation, paired samples t-test, and independent samples t-test at the 0.05 level of significance. Findings revealed that both groups began with low mastery levels in the pretest. After the intervention, the control group improved from a mean score of 21.67 to 27.93, while the experimental group increased from 19.67 to 31.13. Both groups showed statistically significant improvement from pretest to posttest, but the experimental group obtained significantly higher mean gain scores than the control group ($t = -3.044$, $p = 0.009$). The study concluded that PhET-Math Simulation was more effective than traditional instruction in improving students' mastery level in Mathematics. A training program for teachers and students was proposed to support the effective integration of simulation-based learning.

Keywords: *PhET-Math Simulation, Mathematics achievement, simulation-based learning*

INTRODUCTION

The rapid advancement of educational technology has created new opportunities for improving teaching and learning in Mathematics. Digital tools such as simulations, virtual manipulatives, and interactive applications have been increasingly integrated into classrooms to support conceptual understanding, learner engagement, and academic achievement. Among these innovations, Physics Education Technology (PhET) Interactive Simulations developed by the University of Colorado Boulder have gained recognition as effective instructional tools that promote inquiry-based and visual learning through dynamic models and immediate feedback.

Although originally designed for science education, PhET simulations have expanded to include Mathematics content that enables students to explore abstract concepts, manipulate variables, and observe relationships in real time. These features are particularly relevant in Mathematics, where many learners struggle with symbolic representations, procedural tasks, and problem-solving. Boaler (2016) emphasized that students develop deeper understanding when mathematical ideas are presented through multiple representations rather than through memorization and routine procedures alone. Thus, simulation-based learning may provide an effective alternative to traditional lecture-centered instruction.

Previous studies have reported positive effects of PhET simulations on student learning outcomes. Widyasari et al. (2025) found that PhET digital media significantly improved Grade 3 pupils' performance in fractions. Arifin et al. (2023) likewise reported increased engagement and stronger understanding of mixed fractions among Grade 4 learners exposed to simulation-based instruction. At the secondary level, Lopez and Gurat (2024) revealed that Grade 8 students who used PhET simulations achieved significantly higher mastery in graphing linear equations than those taught using conventional methods. Despite these promising results, limited studies have examined the effectiveness of PhET-Math Simulation among Grade 9 students in private secondary schools, particularly in multilingual educational settings. This gap is important because Grade 9 represents a transition stage where students encounter more advanced topics such as functions, variations, and algebraic reasoning. Weak mastery at this level may negatively affect performance in later Mathematics subjects.

Mathematics is often regarded as a difficult subject because many concepts are abstract and symbolic in nature. Learners commonly struggle when they are unable to connect formulas, equations, and procedures with meaningful visual representations. For this reason, visualization has been widely recognized as an essential component of mathematics instruction. Carbonaro et al. (2019) reported that interactive geometric simulations improved students' spatial reasoning and understanding of shapes, rotations, reflections, and translations. Because learners could manipulate figures directly, they developed stronger intuition about geometric properties.

In algebra instruction, visual models are equally beneficial. Students who use graphing technologies and dynamic function tools often gain clearer understanding of slope, intercepts, rates of change, and functional relationships (Pierce & Stacey, 2010). These tools allow learners to immediately observe how changes in one variable affect another.

Mikeska et al. (2022) synthesized findings from a working conference focused on the use of simulations in K–12 mathematics and science teacher education. The study found that although simulations vary in format and purpose, they share a common feature of providing interactive learning environments where teachers can rehearse important teaching practices. These include questioning techniques, classroom facilitation, lesson pacing, and responding to student misconceptions. The researchers also emphasized the importance of structured learning cycles that include preparation, practice, feedback, and reflection. They recommended the use of experimental and quasi-experimental designs to determine under what conditions simulations are most effective in teacher preparation.

Chini et al. (2019) found that preservice teachers who used interactive simulations such as PhET developed greater confidence in designing inquiry-based lessons. Simulations helped them connect abstract theories to practical classroom application and anticipate possible student misconceptions. Teachers became more likely to use student-centered approaches that emphasized exploration rather than rote memorization. The study also noted that repeated use of simulations encouraged reflective practice, allowing teachers to improve instructional strategies based on feedback and observation.

Lancaster et al. (2021) reported that simulations helped preservice teachers connect content knowledge with pedagogical content knowledge. In mathematics education, simulations encouraged future teachers to think critically about how students interpret graphs, equations, and visual representations. Collaborative simulation tasks also improved communication skills and problem-solving among teacher trainees. The researchers concluded that simulations are valuable because they develop both subject mastery and teaching competence.

Gravett et al. (2023) emphasized the use of mixed-reality simulations in preservice teacher training, particularly when school practicum placements were limited. Their study found that simulations created authentic but low-risk teaching environments where preservice teachers could practice questioning, pacing, and adaptive dialogue. Participants reported improved confidence and metacognitive awareness. However, the authors stressed that coaching and feedback were necessary to maximize learning benefits.

Edward (2020) investigated Australian high school students' perceptions of PhET simulations and found that students considered them highly useful for visualizing difficult concepts. Learners reported that simulations helped them understand relationships among variables, interpret graphs, and connect mathematics to real-world phenomena. The study concluded that simulations are especially effective when they make invisible processes visible.

Findley (2017) explored how middle school mathematics teachers used PhET simulations in classroom instruction. Results showed that simulations supported inquiry-based teaching, increased student participation, and encouraged conceptual discussion. Teachers viewed simulations as valuable tools for helping students achieve diverse learning goals.

Similarly, Keller et al. (2019) noted that students using simulation tools in algebra and geometry demonstrated improved understanding of relationships between equations and graphs. Because students could manipulate variables directly, they developed stronger intuition about mathematical behavior. Lin et al. (2017) also reported that simulations supported mathematical modeling skills among elementary learners. Students explored patterns, tested hypotheses, and refined solutions through repeated interaction with simulation environments.

Parish et al. (2024) explored virtual reality simulations in teacher education and found that such tools improved self-efficacy, communication skills, and confidence in handling parent-teacher consultations. The study demonstrated that simulations can also develop interpersonal competencies, not only academic skills. McGarr (2020) examined virtual simulations for classroom management training and found that preservice teachers benefited from practicing responses to common classroom challenges in low-stakes settings. However, the study warned that simulations must be paired with guided reflection to avoid reinforcing inaccurate assumptions about student behavior.

Chernikova et al. (2020), in a meta-analysis of simulation-based learning in higher education, found that simulations significantly improved complex skill development, professional identity, and learner confidence. Their review highlighted that scaffolding, peer collaboration, and reflective debriefing were major factors influencing effectiveness. Haynes (2025) proposed the "Graduated Realism" framework for AI-powered simulations in teacher training. The study argued that overly complex or hyper-realistic simulations may overwhelm beginners. Instead, simpler simulations should be introduced first, with realism gradually increased as learners gain competence. This design reduces cognitive overload while maintaining engagement.

Madden et al. (2019) compared immersive virtual reality, desktop simulations, and hands-on activities in teaching the phases of the moon. Although no significant differences were found in achievement, most students preferred the virtual reality simulation because it was more immersive and engaging. This suggests that simulations can positively influence learner attitudes even when achievement gains are similar. Jung and Park (2019) found that immersive simulations increased nursing students' intrinsic and extrinsic motivation. Learners reported stronger attention and perceived relevance because simulated tasks resembled authentic professional experiences. Motivation is especially important because interested students are more likely to persist in difficult learning tasks.

Smetana and Bell (2019) found that simulations act as cognitive tools that make invisible processes visible and allow learners to manipulate variables that would be impossible to control in real life. This interaction helps students build both procedural and conceptual knowledge. The study also reported that collaborative simulation tasks enhanced long-term retention and critical thinking.

Fallon (2019) found that young learners using simulations were better able to explain scientific concepts in their own words. Students demonstrated autonomy by testing variables, drawing conclusions, and reflecting on outcomes. These behaviors indicate growth in reasoning and metacognitive awareness. Sandi et al. (2017), in a review across higher education disciplines, found that simulations positively affected cognitive, behavioral, and affective domains of learning. Their analysis showed benefits in content mastery, skill acquisition, and learner motivation.

Edward (2020) found that students perceived PhET simulations as enjoyable and helpful. Learners appreciated the ability to manipulate variables, explore scenarios, and receive immediate responses. This interactive nature sustained attention and reduced boredom. Kaphesi and Jere (2020) similarly observed that students exposed to simulation-based lessons were more motivated and more willing to participate in classroom discussions. The game-like features of simulations contributed to positive attitudes toward learning. Boaler (2016) argued that when mathematics instruction becomes exploratory and visual, students develop confidence and persistence. Technology-supported learning environments may therefore reduce fear and resistance often associated with mathematics.

This study was anchored in Constructivist Learning Theory, which proposes that learners actively construct knowledge through exploration and experience (Piaget, 1972). It was also supported by Social Constructivist Theory, which emphasizes the importance of guided learning and interaction in knowledge development (Vygotsky, 1978). PhET simulations align with these theories because they allow students to manipulate mathematical models, test ideas, and receive immediate feedback in an interactive environment.

At Sunflower Trilingual School, school assessment records over the previous three academic years showed that many Grade 9 students performed below the expected mastery level in Mathematics. Students frequently obtained scores classified under developing or approaching mastery, especially in competencies involving equations, functions, and problem-solving. Teachers also observed low learner engagement and difficulty in connecting symbolic expressions with practical applications. These concerns indicate the need for an instructional intervention that can improve understanding and performance.

Hence, this study determined the effect of utilizing PhET-Math Simulation on the mastery level of Grade 9 students in Mathematics at Sunflower Trilingual School. Specifically, it compared the performance of students taught through traditional methods and those taught using PhET-Math Simulation. The findings may provide empirical support for integrating simulation-based instruction to improve Mathematics learning outcomes.

Research Questions

This study determined whether the utilization of PhET-Math Simulation has a significant effect on increasing the mastery level of Grade 9 students in Mathematics at Sunflower Trilingual School.

Specifically, it sought to answer the following research questions:

1. What is the mastery level of students in the control and experimental groups before and after the intervention based on their pre-test and post-test scores?
2. Is there a significant difference in the mastery level of the control group based on their pre-test and post-test scores?
3. Is there a significant difference in the mastery level of the experimental group based on their pre-test and post-test scores after the use of PhET-Math Simulation?
4. Is there a significant difference in the mastery levels of students when comparing the mean gain scores of the control group and the experimental group?
5. What training program for teachers and students may be proposed to enhance the mastery level of students in Mathematics?

Hypotheses

Based on the research questions, the following null hypotheses were formulated and tested at a 0.05 level of significance.

1. There is no significant difference in the mastery level of the control group based on their pre-test and post-test scores.
2. There is no significant difference in the mastery level of the experimental group based on their pre-test and post-test scores following the use of the PhET-Math Simulation.
3. There is no significant difference in the mastery levels of students when comparing the mean gain scores of the control group and the experimental group.

METHODOLOGY

This study employed a quantitative research approach using a true experimental pretest–posttest control group design to determine the effect of PhET-Math Simulation on the mastery level of Grade 9 students in Mathematics. The study was conducted in a private secondary school in Samut Sakhon, Thailand, which offers a trilingual academic program and integrates technology-enhanced instruction in selected subjects. The setting was considered appropriate for the study due to the availability of Grade 9 learners and access to digital learning resources necessary for the implementation of PhET-Math Simulation.

The participants of the study were 30 Grade 9 students enrolled during the Summer Term of 2023. Total population sampling was utilized since all available Grade 9 students during the term were included in the study. The participants were randomly assigned into two equal groups: 15 students in the control group and 15 students in the experimental group. Random assignment was used to minimize selection bias and ensure comparability between groups in terms of prior knowledge and ability.

The primary instrument used in the study was an adapted diagnostic test used as both pretest and posttest. The instrument was aligned with the Grade 9 Mathematics competencies based on the national curriculum and covered topics such as algebraic expressions, linear equations, functions, variations, and problem-solving. The test consisted of multiple-choice and problem-solving items designed to measure both conceptual understanding and procedural skills. The instrument was adapted from existing Mathematics assessment materials and validated by experts in Mathematics education to ensure content validity. A pilot test was conducted on a similar group of students not included in the actual study to establish reliability before its administration in the main study.

Data collection began with the administration of the pretest to both groups under standardized conditions. This was followed by a four-week instructional period. The control group was taught using traditional lecture-based instruction, while the experimental group was taught using PhET-Math Simulation integrated into classroom instruction. Both groups were exposed to the same learning competencies, instructional time, and subject teacher to ensure consistency. After the intervention, a posttest using the same instrument was administered to both groups under similar testing conditions.

The collected data were analyzed using descriptive and inferential statistics. Mean and standard deviation were used to describe the mastery level of students. Paired sample t-test was used to determine significant differences within each group between pretest and posttest scores. Independent sample t-test was used to compare the mean gain scores between the control and experimental groups to determine the effectiveness of the intervention. All statistical tests were interpreted at a 0.05 level of significance.

The scope of the study was limited to Grade 9 students in one private secondary school during a single academic term and focused only on selected Mathematics competencies covered in the intervention. Variables such as long-term retention, motivation, and engagement were not included. The study was also limited by its small sample size and short duration, which may affect generalizability to other contexts.

RESULTS

This section presents the results of the study based on the data gathered, focusing on the mastery level of Grade 9 students in Mathematics, as well as the comparison of pretest, posttest, and mean gain scores of the control and experimental groups.

Mastery Level of Grade 9 Students in Mathematics

The mastery levels of the students in both groups were determined using frequency and percentage distributions based on their pretest and posttest scores.

Table 1.
Frequency Distribution Table for Pretest and Posttest Scores of Control Group

	Pretest		Posttest	
	Frequency	Percentage	Frequency	Percentage
0-14	0	0%	0	0%
15-26	15	100%	4	27%
27-34	0	0%	11	73%
35-38	0	0%	0	0%
39-40	0	0%	0	0%

Scale: 0-14 (Very Low Mastery); 15-26 (Low Mastery); 27-34 (Average Mastery); 35-38 (High Mastery); 39-40 (Very High Mastery)

Table 1 shows that all students in the control group initially belonged to the low mastery level, indicating limited prior understanding of the mathematics competencies assessed. After instruction using traditional methods, most students shifted to the average mastery level, although a portion remained in the low mastery category. No students reached high mastery levels, suggesting moderate improvement only.

Table 2.
Frequency Distribution Table for Pretest and Posttest Scores of Experimental Group

	Pretest		Posttest	
	Frequency	Percentage	Frequency	Percentage
0-14	2	13%	0	0
15-26	13	87%	0	0
27-34	0	0	14	93%
35-38	0	0	1	7%
39-40	0	0	0	0

Scale: 0-14 (Very Low Mastery); 15-26 (Low Mastery); 27-34 (Average Mastery); 35-38 (High Mastery); 39-40 (Very High Mastery)

In the experimental group, Table 2 shows that most students also began at low mastery levels, with a small percentage classified as very low. After the use of PhET-Math Simulation, nearly all students moved to the average mastery level, while a small proportion reached high mastery. No students remained in the low or very low categories, indicating substantial improvement across all learners.

Pretest, Posttest, and Mean Gain Scores

The descriptive statistics for both groups are presented to show changes in performance before and after the intervention.

Table 3
Pretest and Posttest Scores of the Control Group

Control Group	Mean	SD
Pretest	21.67	3.011
Post-test	27.93	3.845
Mean gain score	6.87	3.815

For the control group, Table 3 shows an increase in mean scores from pretest to posttest, with a mean gain score indicating moderate improvement following traditional instruction.

Table 4
Pretest, Posttest, and Mean Gain Scores of the Experimental Group

Experimental Group	Mean	SD
Pretest	19.67	3.716
Posttest	31.13	2.356
Mean gain score	11.47	4.422

For the experimental group, Table 4 shows a larger increase in mean scores from pretest to posttest, with a higher mean gain score compared to the control group. This indicates greater improvement in the group exposed to PhET-Math Simulation.

Significant Difference in Pretest and Posttest Scores

Inferential statistics were used to determine whether the observed differences were significant.

Table 5
Significant Difference in the Pretest and Posttest Scores of the Control Group

	Control Group		df	t	p-value
	Mean	SD			
Pretest	21.67	3.011	14	-6.97	<.001
Posttest	27.93	3.845			

Table 5 shows that the control group obtained a statistically significant difference between pretest and posttest scores ($p < .001$), indicating that traditional instruction led to significant but moderate improvement in mathematics performance.

Table 6

Significant Difference in the Mean Gain Scores of the Control and Experimental Group

	Experimental Group		df	t	p-value
	Mean	SD			
Pretest	19.67	3.716	14	-10.04	<0.001

Posttest	31.13	2.356

Table 6 shows that the experimental group also obtained a statistically significant difference between pretest and posttest scores ($p < .001$). The higher mean gain and lower variability suggest that PhET-Math Simulation produced a stronger and more consistent improvement in student performance.

Significant Difference in Mean Gain Scores Between Groups

Table 7

Significant Difference in the Mean Gain Scores of the Control and Experimental Group

	Control Group		Experimental Group		df	t	p-value
	Mean	SD	Mean	SD			
Pretest	21.67	3.011	19.67	3.716	14	-3.044	0.009
Posttest	27.93	3.845	31.13	2.356			
Mean gain score	6.87	3.815	11.47	4.422			

Table 7 presents the comparison of mean gain scores between the control and experimental groups. The results show a statistically significant difference ($p = 0.009$), indicating that the experimental group outperformed the control group in terms of learning gains. This confirms that students who were taught using PhET-Math Simulation achieved significantly higher improvement in mastery level compared to those taught using traditional methods.

DISCUSSION

The findings of this study provide evidence on the effectiveness of PhET-Math Simulation in improving the mastery level of Grade 9 students in Mathematics. Overall, the results indicate that both traditional instruction and simulation-based instruction led to improvements in student performance; however, the experimental group demonstrated a substantially higher level of gain, suggesting the stronger impact of PhET integration on learning outcomes.

The results of the pretest and posttest frequency distributions (Tables 1 and 2) show that both groups initially started at low mastery levels, indicating that students had limited prior knowledge of the targeted competencies. This aligns with the observation that learners often struggle with abstract mathematical concepts when instruction is primarily symbolic and procedural in nature. As noted by Boaler (2016), mathematics taught without meaningful representations often results in shallow understanding. After instruction, the control group improved to the average mastery level, while the experimental group advanced further, with most students reaching average mastery and a portion achieving high mastery. This suggests that while traditional instruction can support foundational learning, it may not be sufficient for developing higher-level conceptual understanding.

The results in Tables 3 and 4 further support this pattern of improvement. Both groups showed increases in mean scores from pretest to posttest; however, the experimental group demonstrated a considerably larger mean gain. The control group’s moderate improvement is consistent with direct instruction approaches that emphasize procedural fluency and guided practice (Cheung & Slavin, 2013). In contrast, the experimental group’s stronger performance is consistent with constructivist learning theory, which emphasizes active engagement and knowledge construction through exploration. The larger gain in the experimental group suggests that PhET simulations provided richer learning experiences that enhanced both conceptual and procedural understanding.

The significant differences within groups (Tables 5 and 6) confirm that both instructional methods produced statistically meaningful improvements in student performance. However, the magnitude of improvement in the experimental group was greater. The reduction in standard deviation in the experimental group also indicates more consistent learning outcomes, suggesting that PhET simulations may help bridge performance gaps among learners. This finding is consistent with Wieman et al. (2010), who emphasized that interactive simulations promote inquiry-based learning by allowing students to visualize and manipulate abstract concepts.

The comparison of mean gain scores between groups (Table 7) provides the strongest evidence of the effectiveness of PhET-Math Simulation. The statistically significant difference in favor of the experimental group indicates that students exposed to simulation-based instruction achieved higher learning gains than those taught using traditional methods. This supports previous studies by Arifin, Razali, and Rahayu (2023), Lestari and Mansyur (2021), Lopez and Gurat (2024), and Widyasari et al. (2025), which similarly found that PhET simulations improve students’ conceptual understanding and engagement in mathematics learning.

From a theoretical perspective, these findings are supported by constructivist learning theory and the cognitive theory of multimedia learning. Constructivism explains that learners develop deeper understanding when they actively engage with content, while multimedia learning theory suggests that combining visual, symbolic, and interactive representations enhances cognitive processing. PhET simulations embody both principles by allowing students to explore mathematical relationships dynamically, receive immediate feedback, and visualize abstract concepts in real time.

Overall, the results suggest that while traditional instruction remains effective in improving basic mathematical performance, the integration of PhET-Math Simulation provides a more powerful approach for enhancing mastery levels. The consistent superiority of the experimental group across all statistical measures indicates that simulation-based instruction is a more effective strategy for developing deeper conceptual understanding and improving overall student achievement in Mathematics.

Conclusions

Based on the results of the study, the following conclusions were drawn:

1. Both traditional instruction and PhET-Math Simulation improved students' mathematics mastery; however, students exposed to PhET achieved a higher posttest mean score compared to those in the control group (27.93), indicating stronger learning gains.
2. There is a significant difference between the pretest and posttest scores of the control group. Traditional instruction significantly improved student performance, but the improvement was limited to average mastery, suggesting that conventional methods are effective for foundational learning but less effective for higher-level conceptual development.
3. There is a significant difference between the pretest and posttest scores of the experimental group. PhET-Math Simulation produced a significantly greater improvement in student mastery, supporting the effectiveness of interactive, visualization-based instruction in mathematics learning.
4. There is a significant difference in the mean gain scores of the control and experimental groups. This confirms that PhET-based instruction is more effective than traditional teaching in improving mathematics mastery.
5. The results justify the implementation of a structured training program for teachers and students, as effective integration of educational technology requires pedagogical and technical readiness.

Recommendations

The following are recommended based on the results of this study.

1. Teachers may use PhET-Math Simulation in teaching Mathematics to improve student understanding and engagement.
2. Schools may provide computers, internet access, and training for teachers to support simulation-based learning.
3. Curriculum planners may include PhET simulations as part of Mathematics instruction to support conceptual learning.
4. Students may actively use PhET simulations during lessons to better understand mathematical concepts.
5. A simple training program may be implemented for teachers and students that includes orientation, hands-on practice, classroom use, and evaluation.
6. Future researchers may conduct further studies on the long-term effects of PhET Simulation and its use in other subjects and grade levels

Compliance with Ethical Standards

This study adhered to strict ethical standards to ensure the protection and fair treatment of all participants. Ethical clearance was obtained from the FEU Roosevelt Institutional Research Ethics Board prior to data collection. Informed consent was also secured from the school administration and stakeholders, and participation was voluntary with full disclosure of the study's purpose and procedures.

Confidentiality and anonymity were maintained by assigning codes to participants, and all data were securely stored and used solely for research purposes. Only relevant data necessary to answer the research questions were collected and analyzed.

Fairness and equal treatment were ensured, as both groups received the same instructional time, competencies, and assessments, differing only in the mode of instruction. This minimized bias and ensured valid comparison of results.

The study further upheld data integrity, with all findings honestly reported and properly cited where applicable. AI tools were used only for language refinement and formatting support, and all outputs were carefully reviewed and validated by the researcher.

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