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Improving Students Multiplication Operation Learning Outcomes Through the Use of PhET Interactive Simulation Media

Kharisma Aulia Putri
Pendidikan Dasar, Sekolah Pascasarjana, Universitas Negeri Semarang
kharismaaulia@students.unnes.ac.id

Wiwi Isnaeni
Pendidikan Dasar, Sekolah Pascasarjana, Universitas Negeri Semarang
sri.sumartiningsih@mail.unnes.ac.id

Sri Sumartiningsih
Pendidikan Dasar, Sekolah Pascasarjana, Universitas Negeri Semarang
wiwiisna@mail.unnes.ac.id

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ABSTRACT

This research employs a quasi-experimental design to examine how effective PhET Interactive Simulations are in improving third-grade elementary students' learning outcomes in multiplication operations. The research design used is a pretest-posttest control group design. The research subjects consisted of 64 third-grade students of State Elementary School x Bandung Regency, which were divided into two groups, namely the experimental group (using PhET Interactive Simulations media) and the control group (using conventional methods). Data were collected through learning outcome tests. The hypothesis in this study is H0, namely there is no difference in the average between the learning outcomes of the pretest and posttest, which means there is no effect of the use of Phet Interactive Simulation in improving student learning outcomes and Ha, namely there is a difference in the average between the learning outcomes of the pretest and posttest, which means there is an effect of the use of Phet Interactive Simulation in improving student learning outcomes. Data analysis was carried out quantitatively using descriptive analysis, normality tests, paired sample t-tests. The research findings showed that there was a significant difference between the learning outcomes of the experimental group and the control group. After calculations using SPSS, the Sig. (2-tailed) value was obtained at 0.00 <0.05. The results of the paired sample t-test and the known hypothesis indicate that H0 is rejected and Ha is accepted. Based on these results, it can be concluded that there is a significant effect of the PhET Interactive Simulation media before and after the implementation (posttest) in improving students' mathematics learning outcomes.

Keywords: *Learning outcomes, Interactive media, elementary mathematics, multiplication, PhET Interactive Simulation*

ABSTRAK

Penelitian ini dilatarbelakangi oleh rendahnya hasil belajar operasi hitung perkalian siswa sekolah dasar yang masih didominasi metode konvensional dan minim pemanfaatan media interaktif berbasis simulasi. Padahal, media PhET Interactive Simulations berpotensi membantu siswa memahami konsep matematika secara visual dan konseptual, namun pemanfaatannya pada materi perkalian di kelas rendah sekolah dasar masih terbatas. Oleh karena itu, penelitian ini bertujuan untuk menguji efektivitas penggunaan media PhET Interactive Simulations terhadap hasil belajar operasi hitung perkalian siswa kelas III sekolah dasar. Penelitian ini menggunakan pendekatan kuantitatif dengan desain quasi eksperimen berupa pretest–posttest control group design. Subjek penelitian terdiri atas 60 siswa kelas III Sekolah Dasar Negeri X di Kabupaten Bandung yang dibagi ke dalam kelompok eksperimen dan kelompok kontrol. Kelompok eksperimen memperoleh pembelajaran menggunakan media PhET Interactive Simulations, sedangkan kelompok kontrol menggunakan metode pembelajaran konvensional. Data dikumpulkan melalui tes hasil belajar dan dianalisis menggunakan statistik deskriptif, uji normalitas, serta uji *paired sample t-test*. Hasil analisis menunjukkan adanya perbedaan signifikan antara nilai pretest dan posttest pada kelompok eksperimen dibandingkan kelompok kontrol (Sig. (2-tailed) < 0,05). Nilai uji *t* menunjukkan peningkatan hasil belajar yang bermakna dengan ukuran efek kategori sedang hingga tinggi (Cohen's d > 0,5). Temuan ini mengindikasikan bahwa penggunaan media PhET Interactive Simulations secara signifikan meningkatkan hasil belajar operasi hitung perkalian siswa. Penelitian ini memberikan kontribusi teoretis dalam pembelajaran matematika berbasis konstruktivistik serta menegaskan kebaruan penggunaan simulasi interaktif PhET pada pembelajaran perkalian di kelas rendah sekolah dasar.

Kata Kunci: Hasil belajar, Media interaktif, matematika SD, Perkalian, *PhET Interactive Simulation*

INTRODUCTION

Mathematics is a fundamental subject that plays a crucial role in the development of science and technology and in developing students' logical and systematic thinking skills. At the elementary school level, particularly in third grade, mastery of basic concepts such as multiplication forms an essential foundation for understanding subsequent mathematics material. However, in practical learning, many students still struggle to conceptually grasp multiplication concepts because learning tends to emphasize memorizing results without understanding the process (Rezeki et al., 2025). This condition makes it difficult for students to relate multiplication to repeated addition and explain the steps for solving problems logically. This poor understanding of multiplication concepts is inextricably linked to the limited use of learning media capable of concretizing abstract mathematical concepts. Learning media serves as a bridge between abstract concepts and students' concrete experiences, facilitating multiplication comprehension (Fatimah et al., 2021). This suggests that interactive media has the potential to enhance student understanding through concrete visualizations and manipulatives of multiplication concepts.

Learning that is too teacher-centered, lacking media, and lacking active student involvement leads to low student engagement and motivation. This aligns with Laimeheriwa's (2025) findings, which show that the use of interactive learning media can improve understanding of basic mathematical concepts in elementary schools. The need for using visual

and interactive media is also supported by a theoretical basis. Based on Piaget's cognitive development theory, elementary school students are at the concrete operational stage and therefore require visual and manipulative representations to understand mathematical concepts (Arsiah, 2022). Furthermore, Mayer's Multimedia Learning Theory, Dual Coding Theory, and Cognitive Load Theory emphasize that learning is more effective when information is presented through a well-structured combination of visual and verbal content to avoid overloading students' cognitive capacities (Haddad et al., 2025). A harmonious presentation of material between text, images, and interactive activities can help students construct more meaningful mental representations, enhance conceptual understanding, and strengthen information retention in long-term memory.

Mayer's Multimedia Learning Theory, Dual Coding Theory, and Cognitive Load Theory conceptually emphasize that learning is more effective when information is presented through a well-structured combination of visual and verbal content. Mayer's Multimedia Learning Theory explains that students learn more optimally from words and images than from words alone, because humans have two information processing channels, namely visual and verbal, with limited capacity and requiring an active learning process in the form of selection, organization, and integration of information (Hukom et al., 2025). Presenting learning materials that combine text, images, animations, or simulations in a harmonious manner can help students build a deeper conceptual understanding and reduce the risk of cognitive overload. In line with this, the Dual Coding Theory proposed by Paivio states that presenting information in verbal and visual forms simultaneously will produce two mental representations that reinforce each other, thereby improving understanding and retention of information in long-term memory (Nursolehah et al., 2024). Thus, the use of learning media that combines oral or text explanations with relevant visualizations can help students connect concepts more meaningfully and retain them longer in memory. Meanwhile, the Cognitive Load Theory developed by Sweller emphasizes the importance of managing cognitive load so that students' working memory is not burdened by irrelevant information, allowing cognitive resources to be focused on processing core learning concepts (Permana et al., 2025). The integration of these three theories provides a strong theoretical foundation for the use of visual and interactive learning media to support effective and meaningful learning processes.

Empirically, the use of interactive simulations has been shown to increase engagement and learning quality. Students demonstrate higher motivation and perceived learning benefits when interactive simulations are applied to mathematics (Alvarez & Webb, 2025). Technology-based media also integrate images, animations, and direct interaction, facilitating the understanding of abstract concepts. However, most research on PhET Interactive Simulations still focuses on science, particularly physics, resulting in limited empirical evidence regarding the application of PhET to basic arithmetic in elementary schools (Simbolon et al., 2025). This research gap highlights the need for further study on the effectiveness of PhET on multiplication. Along with the rapid development of digital technology in education, various technology-based learning media innovations have been developed to improve the quality of student learning processes and outcomes. One learning medium that has been widely researched and implemented is the PhET Interactive Simulation, which is designed to visualize

abstract concepts dynamically and interactively. Research on PhET Interactive Simulation shows a growing trend in science and mathematics education, highlighting its effectiveness in improving students' conceptual understanding and academic achievement (Suryani et al., 2025) . The analysis identified improved conceptual learning, integration with problem-based learning models, and enhanced critical thinking as the main impacts of PhET simulations in STEM education. Thus, the use of PhET simulations serves not only as a visual aid, but also as a pedagogical tool that encourages active, exploratory, and student-centered learning, making it relevant for implementation at various levels of education.

Learning conditions in the field indicate that third-grade students still experience difficulty solving simple multiplication problems, connecting multiplication with repeated addition, and using multiplication tables correctly. These difficulties are influenced by internal factors, such as low interest and conceptual understanding, as well as external factors such as the use of insufficiently varied learning media (Yulia et al., 2024). Monotonous conventional learning makes students less enthusiastic and tends to be passive in the learning process. The use of interactive simulations (PhET) is considered a solution because it can visualize multiplication concepts through easy-to-understand animations and object manipulation. Interactive media based on educational games has been shown to increase student motivation and conceptual mastery (Hartanto et al., 2023). Furthermore, other studies have shown an increase in elementary school students' participation and learning interest (Lathifah & Damayanti, 2024). Various previous studies have shown that the use of technology-based learning media has a positive contribution to improving the quality of elementary school students' learning processes and outcomes. Research at SDN Lambheu, Aceh Besar, also showed that the use of PhET can improve students' critical thinking skills in integers (Ningsih et al., 2025). These findings indicate that interactive simulation media such as PhET not only help students understand abstract mathematical concepts but also encourage active student involvement in the learning process, thereby improving higher-order thinking skills. In an effort to improve the effectiveness of learning through the use of technology-based media, various empirical studies have been conducted to compare conventional learning with learning that utilizes interactive simulations. The results of the study showed a significant increase in the learning outcomes of students exposed to PhET simulations compared to traditional teaching, which indicates that interactive simulations can improve not only conceptual understanding but also student performance in assessed tasks (Subhashani, 2022). These findings confirm that PhET simulations are able to create more meaningful learning experiences through active student engagement, thus contributing positively to improving overall learning outcomes.

To address these various causes, several alternative problem-solving methods can be implemented. Technology in mathematics learning has been shown to help students understand abstract concepts more concretely. Technology-based learning media provides learning content with a combination of images, slides, video, audio, and animation to make learning more engaging (Yulia et al., 2024). The necessary solution is to present similar presentations through animation and object manipulation, making it easier for students to understand the multiplication process. One solution considered effective is the use of

interactive learning applications, such as the PhET Interactive Simulation, which can present multiplication concepts visually and dynamically. Improved learning quality can be achieved when technology is used appropriately in learning activities. The importance of using technology in learning is crucial to improving the quality of learning (Nuraeni et al., 2023). This aligns with the purpose of using the PhET Interactive Simulation, which is to provide a more effective and visual learning experience for understanding multiplication operations.

The use of this interactive media is expected to attract student interest and facilitate a more concrete understanding of the concept. The use of interactive learning media aligns with the demands of 21st-century learning, Education 4.0, and the implementation of the Independent Curriculum, which encourages the use of digital technology in learning (Jeranah et al., 2023). From a national education policy and regulation perspective, implementing learning that takes into account the characteristics and needs of students is a must. Normatively, the use of learning methods and media appropriate to student characteristics is also in line with Law Number 20 of 2003 concerning the National Education System (Tyson et al., 2021). This emphasizes that teachers have a professional responsibility to design innovative, contextual, and student-centered learning to optimally support the achievement of national education goals. This is in line with Minister of Education and Culture Regulation Number 22 of 2016, which emphasizes interactive, inspiring, and challenging learning (Masluchah et al., 2022). Therefore, this study aims to examine the effectiveness of the use of PhET Interactive Simulation in improving student learning outcomes in multiplication operations in grade III of elementary school.

METHODS

Type and Design

This study employed a quasi-experimental research method using a Pretest–Posttest Control Group Design. This design was used to compare students' learning outcomes between the experimental group, which received instruction using PhET Interactive Simulations, and the control group, which learned through conventional teaching methods.

Table 1. Research Design Description

Group	Pretest	Treatment	Posttest
Experimental	O_1	X	O_2
Control	O_3	–	O_4

Description:

- X = Treatment in the form of learning using *PhET Interactive Simulations*.
- O_1 and O_3 = Pretests administered to measure students' prior knowledge before treatment.
- O_2 and O_4 = Posttests administered to measure learning outcomes after treatment.

The study involved all grade III students of SDN X in Bandung Regency, totaling 60 students as the population. The research sample was determined using purposive sampling, resulting in two groups: the experimental group consisting of 30 students from class IIIA who

were taught using PhET Interactive Simulations, and the control group consisting of 30 students from class IIIB who were taught using conventional methods. The research procedure consisted of three systematic stages. The first stage, preparation, included developing lesson plans, validating research instruments by experts, and assigning students to experimental and control groups. The second stage, implementation, began with administering the pretest to all participants, followed by the learning process, during which the experimental group used PhET Interactive Simulations, while the control group continued with traditional instruction. The third stage, evaluation, involved administering the posttest to both groups to assess the improvement in learning outcomes after the intervention.

The purposive sampling technique was used in this study with certain considerations relevant to the research objectives. The sample inclusion criteria included: (1) third-grade students who had acquired the prerequisite material for basic arithmetic operations, (2) students who had participated in the entire series of learning and tests, and (3) classes that had relatively balanced academic conditions based on previous grade data. Meanwhile, the exclusion criteria included students who did not participate in the complete pretest or posttest and students with incomplete attendance during the learning process. The selection of class IIIA as the experimental group and class IIIB as the control group was based on the equality of class characteristics and school administrative considerations.

The study was conducted at SDN X in Bandung Regency, which provides essential technological facilities such as projectors, laptops, and stable internet access to support the use of interactive learning media like PhET. With these resources, this research aimed to provide a comprehensive understanding of the effectiveness of technology-based learning media in improving elementary students' mathematics achievement.

Data and Data Sources

The data for this research were obtained from students' test scores, which consisted of pretest and posttest scores obtained from both the experimental and control groups. These quantitative data were used to measure students' understanding of basic multiplication concepts before and after the implementation of PhET Interactive Simulations. The primary data source comprised all 60 third-grade students of SDN X in Bandung Regency during the 2024/2025 academic year. The research instrument used was a validated learning achievement test consisting of multiple-choice and short-answer items designed to assess students' mastery of multiplication concepts.

In addition to expert judgment, the learning outcome test instrument used in this study was also empirically tested for reliability. Reliability testing was conducted using the Cronbach's Alpha coefficient to determine the level of internal consistency of the test items. The instrument was declared reliable if the Cronbach's Alpha value was ≥ 0.70, indicating that the test items had a good level of consistency in measuring students' mastery of multiplication concepts. The results of the reliability test indicated that the test instrument met the reliability criteria and was suitable for use in research.

Data collection technique

Data were collected using achievement tests administered twice — a *pretest* and a *posttest*. The pretest was given prior to the intervention to assess the students' baseline understanding, while the posttest was administered after the learning process to evaluate the impact of the treatment. The same set of questions was used for both groups to maintain consistency and ensure comparability of results. Additionally, classroom observations were conducted to document student engagement, participation, and interaction during the lessons. Supporting documents such as lesson plans, learning materials, and teacher reflections were also collected to strengthen the validity of the data and provide a more comprehensive picture of the learning process.

Data analysis

The data analysis process consisted of several stages. First, descriptive statistical analysis was performed to determine the mean, standard deviation, range, and overall distribution of students' scores in both the experimental and control groups. This analysis provided an initial overview of students' learning outcomes before and after the intervention. Second, a normality test (Kolmogorov–Smirnov and Shapiro–Wilk) was conducted to examine whether the data were normally distributed. As the results showed $p > 0.05$, the data were considered normally distributed, allowing the use of parametric tests. Third, a Paired Sample t-Test was conducted to assess whether the pretest and posttest scores in each group differed significantly. The significance level was set at 0.05 ($\alpha = 0.05$). If the Sig. (2-tailed) value was less than 0.05, it indicated that the intervention had a significant effect on students' learning outcomes. To ensure that the sample size used was adequate, a power analysis was conducted using G*Power software. This analysis aimed to determine the study's ability to statistically detect treatment effects at a significance level of $\alpha = 0.05$ and a minimum power of 0.80. The analysis results showed that the sample size of 60 students met the requirements for adequate power to detect differences in learning outcomes between the experimental and control groups.

All statistical procedures were carried out using IBM SPSS Statistics version 25, following proper data analysis procedures such as data cleaning, transformation, and interpretation. This process ensured the accuracy, validity, and reliability of the findings derived from the collected data. The data analysis process consisted of several stages. First, descriptive statistical analysis was performed to determine the mean, standard deviation, range, and overall distribution of students' scores in both the experimental and control groups. This analysis provided an initial overview of students' learning outcomes before and after the intervention. Second, a normality test (Kolmogorov–Smirnov and Shapiro–Wilk) was conducted to examine whether the data were normally distributed. As the results showed $p > 0.05$, the data were considered normally distributed, allowing the use of parametric tests. Third, a Paired Sample t-Test was applied to evaluate whether the difference between pretest and posttest scores in each group was statistically meaningful. The significance level was set at 0.05 ($\alpha = 0.05$). If the Sig. (2-tailed) value was less than 0.05, it indicated that the intervention had a significant effect on students learning outcomes.

All statistical analyses were performed using IBM SPSS Statistics version 25, following proper data analysis procedures such as data cleaning, transformation, and interpretation. This process ensured the accuracy, validity, and reliability of the findings derived from the collected data. This study also considered the ethical aspects of educational research. Prior to conducting the study, the researcher obtained official permission from the school. Furthermore, the class teacher and parents were provided with an explanation of the study's purpose, procedures, and benefits. Student participation was voluntary, and all data collected was kept confidential and used solely for academic purposes. This study posed no physical or psychological risks to students and was conducted in accordance with ethical principles of educational research.

RESULTS AND DISCUSSION

This study took a sample of 30 students in the experimental group and 30 students in the control group, from a population of 60 third-grade students at SD Negeri X, Bandung Regency. The instrument was a learning outcome test (pretest and posttest) given before and after the treatment. Data analysis began with descriptive analysis, then normality test, and continued with a paired t-test to determine changes in each group. Before conducting statistical tests, a descriptive analysis was first conducted to describe the data on student learning outcomes in general, both at the pretest and posttest stages. This analysis aims to see the distribution of scores, averages, standard deviations, and trends in improving learning outcomes in both groups. With descriptive analysis, researchers can obtain an initial picture of the differences in learning outcomes between the experimental group using PhET Interactive Simulations media and the control group using conventional learning methods.

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Pre - Test Eksperimen	30	14	50	64	56.87	3.972
Post - Test Eksperimen	30	13	75	88	79.67	3.198
Pre - Test Kontrol	30	15	50	65	58.40	4.248
Post - Test Kontrol	30	20	55	75	67.53	5.164
Valid N (listwise)	30					

Figure 1. Descriptive Statistics

The figure above shows that the average score for the experimental group increased from 56.87 in the pretest to 75.20 in the posttest. This indicates that the learning treatment using the PhET Interactive Simulations interactive, the use of media contributes to the enhancement of students' learning outcomes. The control group also saw an increase, from 57.10 to 65.45, but the posttest score for the experimental group was higher than the control group. The greater increase in the experimental group indicates that interactive media provides advantages over conventional learning. Research by Raehang & Karim (2024) found that interactive learning media significantly increased student engagement and motivation, as well as improving their understanding of the subject matter. Thus, these descriptive results support the hypothesis that the use of interactive media has the potential to improve learning outcomes.

The improvements in both groups indicate that the learning process, using both conventional methods and interactive media, can have an impact on student learning outcomes. However, the significantly greater improvement in the experimental group demonstrates the effectiveness of using interactive media in helping students understand the material visually and contextually. These results align with the findings of who stated that interactive media can facilitate students' visualization of abstract concepts and foster a higher interest in learning compared to traditional learning (Laimeheriwa, 2025). Therefore, descriptively, it can be concluded that PhET Interactive Simulations media plays an important role in significantly improving student conceptual understanding and learning outcomes. After descriptive analysis was conducted, it was observed that learning outcomes improved in both groups. The next step was to conduct a normality test. This test was used to ensure that the pretest and posttest scores from both groups were normally distributed, thus determining the feasibility of using parametric statistical tests in subsequent analyses.

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Kelas	Statistic	df	Sig.	Statistic	df	Sig.
Hasil Belajar Perkalian	1	.135	30	.172	.955	30	.232
	2	.132	30	.192	.956	30	.250
	3	.138	30	.153	.954	30	.210
	4	.112	30	.200*	.956	30	.245

Figure 2. Tests of Normality

The results of the normality test show that the pretest and posttest scores in both groups have $p > 0.05$, so it can be concluded that the data from all four stages meet the assumption of normality. This is important because the next analysis uses a parametric test, namely the paired t-test. With normality met, the use of the t-test is statistically appropriate. This is in line with the experimental research who examined the effect of the Teams Games Tournament learning model on the learning outcomes of second grade students at SDN Bendungan Semarang with data analysis using the normality test, the Paired Sample T-Test (Wati et al., 2024). The results of the study also showed that the data were normally distributed so that researchers could conduct a valid parametric analysis, so that the conclusions obtained were more accurate and reliable.

The normality test plays a crucial role in ensuring that the data variations are solely due to the treatment provided, not to deviations in the data distribution. Therefore, the fulfillment of the normality assumption strengthens the validity of the difference test results conducted in this study. Based on the data known once the data are confirmed to follow a normal distribution, the subsequent step is to run a Paired Sample t-Test to identify whether a significant difference exists between the pretest and posttest scores in each group. This test is used to measure the extent to which the treatment provided, namely the use of PhET Interactive Simulations media, influences the improvement of student learning outcomes compared to before the treatment was given.

Paired Samples Statistics

	Mean	N	Std. Deviation	Std. Error Mean

Pair 1	Preeksperimen	56.87	30	3.972	.725
	Posteksperimen	79.67	30	3.198	.584
Pair 2	Prekontrol	58.40	30	4.248	.775
	Postkontrol	67.53	30	5.164	.943

Figure 3. Paired Samples Statistics

In output pair 1, a summary of the descriptive statistical results of the two samples studied is shown, namely the pretest and posttest scores in the experimental class. For the pretest score, the average learning outcome was 56.87, while for the posttest score, the average learning outcome was 79.67. The number of respondents used as the research sample was 30 students. For the std. Deviation score in the pretest was 3,972 and the posttest was 3,198. This means that, because the average learning outcome score in the pretest was 56.87 < Posttest 79.67 in the experimental class, descriptively there is a difference in the average learning outcomes of students in the experimental class.

In the output pair 2, a summary of the descriptive statistics for the two samples examined is presented, namely the pretest and posttest scores in the control class. For the posttest score, the average learning outcome was 58.40, while for the posttest score, the average learning outcome was 67.53. The number of respondents used as the research sample was 30 students. For the std. Deviation value in the pretest was 4,248 and the posttest was 5,164. This means that, because the average learning outcome in the pretest was 58.40 < Posttest 67.53 in the control class, there is a descriptive difference in the average learning outcomes of students in the control class. Moreover, to determine whether the difference is genuinely significant, the results of the paired sample t-test presented in the output table must be interpreted in Paired Sample Correlations.

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Preeksperimen & Posteksperimen	30	.439	.015
Pair 2	Prekontrol & Postkontrol	30	.699	.000

Figure 4. Paired Samples Correlations

The displayed output presents the results of the correlation test, illustrating the relationship between the two datasets or the association between the pretest and posttest variables. In output pair 1, the correlation coefficient is known to be 0.439 with a significance value of 0.015. Because the Sig. value of 0.439 > 0.05, it can be said that there is a relationship between the pretest and posttest variables in the experimental class. In output pair 2, the correlation coefficient is known to be 0.699 with a significance value of 0.00. Because the Sig. value of 0.00 > 0.05, it can be said that there is no relationship between the pretest and posttest variables in the control class. Furthermore, it should be emphasized that the significance values in the Paired Samples Correlations table are not intended to interpret the meaningfulness of learning outcomes, but rather to indicate the degree of relationship between pretest and posttest scores. Therefore, interpretation of treatment effectiveness is not based on these correlation values, but rather on the results of the Paired Sample t-Test and the effect size, which describes the difference in scores before and after treatment.

The results of this correlation indicate that there is a relationship between the initial and final scores of students in both groups, which means that the improvement in student learning outcomes can be attributed to the learning treatment received. In the experimental group, the improvement is strongly suspected to be due to the influence of the use of PhET Interactive Simulations media, which is able to help students understand concepts more deeply and interactively. This is supported by research by Widiastari and Puspita (2024) which states that the integration of digital media has been shown to create a more interactive.

Figure 5. Paired Samples Test

In addition to statistical significance, this study also considered practical significance by calculating the effect size using Cohen's d. The results showed that the improvement in learning outcomes in the experimental group was in the large effect category, while in the control group it was in the medium effect category. These findings indicate that the use of

Paired Samples Test

		Paired Differences					t	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper		
Pair 1	Preeksperimen - Posteksperimen	-22.800	3.854	.704	-24.239	-21.361	-32.401	.000
Pair 2	Prekontrol - Postkontrol	-9.133	3.748	.684	-10.533	-7.734	-13.346	.000

PhET Interactive Simulations is not only statistically significant but also has a strong practical impact in improving elementary school students' understanding of multiplication concepts. The 95% confidence interval for the t-test results indicates that the difference between the average pretest and posttest scores is consistent and does not cross zero. This indicates that the improvement in learning outcomes is stable and reliable, thus strengthening the conclusion that the learning treatment using PhET Interactive Simulations has a significant impact on student learning outcomes.

Based on the Paired Sample t-Test results table, a significance value (Sig. 2-tailed) of 0.000 was obtained, which is smaller than the 0.05 limit. This indicates that there is a significant difference between the pretest and posttest scores in the experimental class using PhET Interactive Simulations media. Thus, the null hypothesis (H_0) which states that there is no difference in the average learning outcomes before and after treatment is rejected, while the alternative hypothesis (H_a) is accepted. This means that learning using PhET interactive media has a significant effect on improving student learning outcomes. Theoretically, the findings of this study can be explained through Mayer's Multimedia Learning Theory, Dual Coding Theory, and Cognitive Load Theory. PhET Interactive Simulations present information

visually and interactively, helping students process multiplication concepts through visual and verbal channels simultaneously. This allows students to build stronger mental representations and reduce irrelevant cognitive load, thus positively impacting learning outcomes.

Statistically, these results confirm that there is an increase in student learning abilities after receiving treatment through interactive simulation-based learning. PhET Interactive Simulations media helps students understand concepts through visual and exploratory experiences, so that the concepts learned become more concrete and easier to remember. This increase in learning outcomes can also be associated with increased student engagement during the learning process, because interactive media allows students to interact directly with the subject matter. These significant results indicate that learning utilizing technology is not only visually appealing but also impacts the quality of students' cognitive processes. In the context of mathematics learning, interactive simulations are able to bridge students' difficulties in understanding the abstract relationship between symbols and number concepts. Based on this, it can be concluded that the PhET Interactive Simulations media plays a significant role in improving the mathematics learning outcomes of third-grade students at SD Negeri X, Bandung Regency. The results of this study align with findings in reputable international journals, such as Computers & Education, Learning and Instruction, and Educational Technology Research and Development, which report that interactive simulation and visualization-based learning media can significantly improve conceptual understanding and student learning outcomes. This similarity of findings strengthens the research's position within the international literature and demonstrates that the use of digital simulation is a relevant approach in mathematics learning.

Based on the descriptive and inferential analysis above, it can be concluded that learning using interactive PhET Interactive Simulations media in the experimental group showed a higher increase in learning outcomes compared to the control group using conventional methods. The significant increase in the experimental group indicates that technology-based interventions provide benefits in terms of conceptual understanding, learning motivation, and student learning activities. The integration of various digital learning media has been shown to improve student learning outcomes. Research found that the integration of PhET Interactive Simulations and YouTube videos contributed to better learning outcomes among Grade 12 students (Delubom & Tatira, 2025). If digital media integration alone can improve learning outcomes, then the use of PhET Interactive Simulations specifically for multiplication material can have a positive impact on student learning outcomes.

The mechanism for the success of this interactive learning is related to the characteristics of the media, including concept visualization, opportunities for exploration, and two-way interaction between students and the material. Good learning should enable students to construct knowledge through meaningful experiences. Learning is a process to help students learn well to achieve behavioral changes in the form of knowledge, skills, and attitudes (Agustin & Adi Winanto, 2023). PhET Interactive Simulations provide opportunities for students to experience direct learning experiences, thus encouraging them to build new

understandings of multiplication. Selecting the right learning media is crucial to help students understand abstract concepts in multiplication operations. The use of PhET Interactive Simulations as a visual-interactive medium can provide a concrete representation of the mathematical thinking process. This is in line with the findings who stated that, students in the experimental group who utilized the PhET Interactive Simulations demonstrated better academic achievement compared to those in the control group. (Alvarez & Webb, 2025). Thus, the use of PhET Interactive Simulations in mathematics learning can be an effective alternative to improve student learning outcomes because it allows students to explore concepts independently and in a directed manner."

Good learning media is designed to facilitate the delivery of material to students. Using proper learning media will facilitate the delivery of the materials to be well-received by the recipients (Audia et al., 2021). PhET Interactive Simulations provide dynamic visualizations that help students understand multiplication concepts more deeply and intuitively. Learning media plays a crucial role as a means of conveying information that can enhance the effectiveness of the learning process. In the context of mathematics learning, this is important because students can directly experience the process of manipulating numbers or variables through simulations, rather than just passively receiving them. Research by Taroreh (2024) shows that the use of technology-based interactive learning media significantly improves students' understanding of science concepts compared to conventional learning methods. These findings indicate that integrating technology into learning can be an effective strategy to overcome students' difficulties in understanding abstract concepts. Mathematical concepts are often abstract, requiring media that can help visualize them. Interactive media helps students visualize mathematical problems and understand concepts more easily (Enhance et al., 2024). PhET Interactive Simulations provide dynamic visualizations that can strengthen students' understanding of multiplication concepts.

The existence of learning media is not just an aid, but an important element in the effectiveness of learning. PhET Interactive Simulations as an interactive digital media can create a more efficient learning process because students can directly observe the relationship between concepts in multiplication operations. Media that allows students to see, touch, or manipulate learning objects directly has been shown to increase retention and learning outcomes. The application of the STAD cooperative learning model has been proven to affect students' learning outcomes and make students more active and enthusiastic in learning activities (Inas Fauziah Farda & Nurrohmatul Amaliyah, 2023). This strengthens the fact that interactive learning, including through PhET Interactive Simulations, can help students master multiplication material through more meaningful learning experiences.

CONCLUSION

This study investigated the effectiveness of PhET Interactive Simulations in improving mathematics learning outcomes of third-grade students at SD Negeri X, Bandung Regency. The findings demonstrate that the use of PhET Interactive Simulations had a statistically significant effect on students' learning outcomes, as evidenced by the Paired Sample t-Test results showing a Sig. (2-tailed) value of 0.000 (< 0.05). Although students in the control group

also showed improvement, the magnitude of improvement in the experimental group was substantially greater, indicating that interactive simulation-based learning is more effective than conventional instructional methods for teaching multiplication concepts.

From a theoretical perspective, these findings contribute to the growing body of research supporting constructivist and multimedia learning theories, which emphasize the role of visualization, interactivity, and active learner engagement in facilitating conceptual understanding. The results suggest that PhET Interactive Simulations help students process abstract mathematical concepts more effectively by providing concrete visual representations and opportunities for exploration, thereby strengthening conceptual construction. From a practical perspective, this study provides empirical evidence for teachers and schools that technology-based interactive media can be an effective instructional tool in elementary mathematics learning. The use of PhET Interactive Simulations can support teachers in creating more student-centered learning environments and in addressing students' difficulties in understanding abstract concepts such as multiplication. Therefore, integrating interactive simulations into classroom instruction may serve as a viable alternative to enhance learning outcomes in primary education.

Despite these positive findings, several limitations should be acknowledged. First, the study involved a relatively small sample size and was conducted in a single school, which limits the generalizability of the results. Second, the duration of the intervention was relatively short and focused on a single mathematical topic. Third, this study primarily examined cognitive learning outcomes, without directly measuring other relevant variables such as cognitive load, learning motivation, or long-term retention. Based on these limitations, future research is recommended to employ stronger experimental designs, such as randomized controlled trials, to enhance internal validity. Longitudinal studies are also needed to examine students' retention of mathematical concepts learned through PhET Interactive Simulations. In addition, future studies should consider incorporating measurements of cognitive load, motivation, and higher-order thinking skills to provide a more comprehensive understanding of how interactive simulations influence the learning process. Overall, this study highlights the potential of PhET Interactive Simulations as an effective and theoretically grounded approach to improving mathematics learning outcomes in elementary education.

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