Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 3. September 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

THE EFFECT OF USING PHET SIMULATIONS ON STUDENTS' MATHEMATICAL UNDERSTANDING OF FRACTIONS IN FOURTH GRADE ELEMENTARY SCHOOL

Safira Zahra[1]*, Kowiyah[2]

[1] Prof. Dr. Hamka Muhammadiyah University

[a]*E-mail:* safirazahra342@gmail.com

(*) Corresponding Author
safirazahra342@gmail.com

ARTICLE HISTORY
Received : 20-06-2026
Revised : 26-07-2026
Accepted : 30-07-2026

KEYWORDS
PhET Simulation, Mathematical Understanding, Fractions, Elementary School, Pretest-Posttest Design.

ABSTRACT
Mastering foundational concepts in primary mathematics is crucial, yet the inherent abstraction of fractions frequently creates substantial learning barriers for young pupils. This investigation evaluated the empirical impact of integrating PhET Interactive Simulations on fourth-graders' comprehension of fraction topics. Using a quantitative single-group pretest-posttest design, the study involved 28 fourth-grade students at SDN Pekayon 03 Pagi as the total sample. Data were gathered through a validated 10-item written instrument measuring core mathematical understanding indicators and analyzed via descriptive and inferential statistics—specifically the paired-samples t-test, normalized gain (N-Gain), and Cohen's d effect size. Findings showed an increase in mean comprehension performance from 64.07 to 87.32. Hypothesis testing confirmed a statistically significant difference ($t = -16.262$, $p = 0.000 < 0.05$). Additionally, the average N-Gain reached 0.67 (66.7%), reflecting moderate effectiveness, while the effect size was 3.07, indicating a large effect category. In conclusion, embedding PhET Simulations into instruction aids in visualizing abstract fraction concepts and improving students' mathematical comprehension in elementary education

INTRODUCTION

Mathematics education at the elementary school level plays a pivotal role in fostering logical, analytical, and systematic reasoning. Mathematics serves rather merely as a computational tool, mathematics cultivates higher-order problem-solving and decision-making capacities essential for future academic success (Agustin et al., 2025). Within the primary curriculum, fractions represent a critical yet challenging topic, requiring pupils to comprehend part-whole relationships and translate fractional values across diverse representations. However, the abstract nature of the fraction concept often makes it difficult for students to construct their understanding. Mathematical understanding itself entails the ability to link interconnected concepts and apply them flexibly across problem-solving contexts (Ulfa et al., 2021).

Extensive literature has explored the causes of low mathematical comprehension. Safitri et al., (2025)reported that elementary students' understanding of fractions remains moderate (66.11%), largely constrained by teacher-centered instruction, passive one-way learning, and repetitive mechanical drills. To address these pedagogical limitations, the *Merdeka Curriculum* advocates integrating interactive digital technologies to create dynamic, student-centered environments tailored to 21st-century learners (Nordiana et al., 2024). Among available digital tools, PhET Interactive Simulations effectively visualize abstract concepts into manipulative representations, enabling learners to discover conceptual interconnections and significantly elevate their mathematical understanding (Ansori, 2024).

While existing research on PhET simulations predominantly focuses on secondary, higher education, or science domains, empirical inquiries targeting foundational fraction topics (specifically comparing and representing values) in fourth-grade elementary settings remain sparse. This study fills this empirical gap by evaluating PhET Simulations as a pedagogical bridge to reduce abstraction in a primary classroom context previously reliant on conventional methods (Zulfah & Turmudi, 2023).

Based on the results of a preliminary study through an interview with Ms. Devi Oktafiani, S.Pd., the fourth-grade homeroom teacher at SDN Pekayon 03 Pagi, the main problem identified was students' low mathematical understanding of fractions, where students routinely memorize algorithms without conceptual clarity and struggle when comparing or representing fractional values**.** Diagnostic data from the 2025/2026 Odd-Semester Final Assessment (PAS) confirmed this deficit: out of 28 enrolled students, 11 (39.29%) failed to reach the Minimum Proficiency Criteria (KKM 70), while only 17 students (60.71%) achieved mastery.

Grounded in this theoretical framework and field problem, this study hypothesizes that utilizing PhET Interactive Simulations significantly improves fourth-graders' mathematical understanding of fractions. Accordingly, this article aims to empirically analyze and verify the impact of PhET integration at SDN Pekayon 03 Pagi, offering scientific novelty regarding virtual simulation media in primary mathematics education

METHOD

This study adopted a quantitative approach using a single-group pretest-posttest experimental design. Although a quasi-experimental design with a control group provides stronger causal inference, the single-group framework was selected due to administrative constraints and class availability at the school site. To mitigate internal validity threats inherent in non-control designs, the intervention was tightly structured and monitored (Sugiyono, 2020). The operational flow followed the standard $O1 \times O2$ scheme, where $O1$ represents the pretest score measuring baseline mathematical understanding, X denotes the pedagogical intervention using PhET Interactive Simulations, and $O2$ refers to the posttest score administered following the intervention.

The target population and analytical sample comprised the entire cohort of 28 fourth-grade students enrolled at SDN Pekayon 03 Pagi during the 2025/2026 even academic term. Employing a total sampling (saturated sampling) technique, all 28 students served as both the sample and experimental group, ensuring total consistency across diagnostic and post-intervention data. The instructional content was fully aligned with the *Merdeka Curriculum*, focusing on foundational fraction concepts, comparison, ordering, and visual representation.

The research procedure spanned three main phases over four instructional sessions (2 × 35 minutes per session): preparation, implementation, and evaluation (Sugiyono, 2023). In the preparation phase, the researcher conducted preliminary field observations, developed lesson plans, and obtained institutional permits. During the implementation phase, students first completed the pretest ($O1$). Over three subsequent sessions, the treatment (XX) was delivered, where students actively explored fraction concepts using the PhET Simulation (*Fractions: Intro* and *Fractions: Equality* modules). Finally, the evaluation phase involved administering the posttest ($O2$) to measure learning gains.

Data were gathered using a validated written test consisting of 10 open-ended essay items. The test was operationalized based on four indicators of mathematical understanding: (1) representing mathematical concepts in visual or symbolic forms (items 2, 3, 5, 6); (2) applying mathematical concepts to solve problems (items 1, 4, 7, 9);

Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 3. September 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

(3) explaining problem-solving steps logically (items 8, 10); and (4) connecting fraction concepts to real-world contexts (items 8, 10). Content and construct validity were confirmed through expert judgment and Pearson Product-Moment correlation (*r count* > *r table*), while internal consistency reliability was verified via Cronbach's Alpha (α>0.70).

Data analysis involved both descriptive and inferential statistical techniques. Prior to hypothesis testing, data normality was evaluated using the Shapiro-Wilk test given the sample size (N=28<50) at a significance level of α=0.05. Data were considered normally distributed if p>0.05.
Upon satisfying the normality assumption, hypothesis testing was conducted using the Paired-Sample t-test.
The test statistic was computed using the following formula:

$$t = \frac{\bar{d}}{\frac{S_d}{\sqrt{n}}} \quad (1)$$

where n is the sample size (n=28), Sd is the standard deviation of the score differences, and $\bar{d}$ is the mean difference between the pre-test and post-test scores. H0: $\mu1 \leq \mu2$ against H1: $\mu_1 > \mu_2$ is the statistical hypothesis being tested. A significance level (two-tailed) < 0.05 or t_(calculated) > t_(table) is the condition for rejecting H_0.

Additionally, the Normalized Gain (N-Gain) was computed using the following formula to assess the efficacy and enhancement of students' mathematical comprehension after PhET Simulation-based learning was implemented

$$N\text{-Gain} = \frac{\text{Skor Posttest} - \text{Skor Pretest}}{\text{Skor Maksimum} - \text{Skor Pretest}}$$

where Smax is the optimal maximum score, $\bar{x}$post is the mean post-test score, and $\bar{x}$pre is the mean pre-test score. The N-Gain criteria were then used to classify the resulting g-index values, namely:

Table 1 N-Gain Test Criteria

N-Gain (g) Value	Criteria
$g \geq 0{,}70$	High
$0{,}30 \leq g < 0{,}70$	Moderate
$g < 0{,}30$	Low

Source: (Arikunto, 2021)

RESULT AND DISCUSSION

PhET (Physics Education Technology) Simulation is a virtual laboratory-based learning platform designed to support the learning process through interactive, visual, and manipulative features. For fourth-grade elementary school mathematics, this platform provides a hands-on simulation that comprehensively presents the concept of fractions, ranging from the introduction of visual representations of fractions and equivalent fractions to addition operations. The integration of interactive visualizations and quiz-based challenges within this simulation not only makes it easier for students to grasp the abstract concept of fractions but also stimulates critical thinking and mathematical problem-solving skills in a more intuitive way.

Use of PhET Simulation

The implementation of *PhET (Physics Education Technology) Simulations* as a learning tool for teaching fractions in fourth grade involves the following stages:

1) Preparation Stage

The learning process begins with a preparation stage, during which the educator selects and sorts the types of

Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 3. September 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

simulations on the PhET platform that precisely support the indicators of mathematical understanding for fourth-grade fractions, namely the "Fractions: Intro" and "Fractions: Equality" modules. To optimize the students' exploration process and anticipate technical obstacles such as unstable internet connectivity at school, the educator downloads the simulation files in advance so they can be run offline on the prepared devices.

Figure 1 *PhET Simulations* (source: Primary Research Data, 2026)

Educators formulate learning objectives that are broken down into indicators of students' mathematical understanding of the fractions material. These objectives are then incorporated into lesson plans that specifically integrates the use of *PhET Simulations* interactive media to support the achievement of these learning indicators.

2) **Introductory Phase**
Apperception & Media Introduction: The educator presents the *PhET Simulations* interactive game to review the concept of common fractions, demonstrates how the media navigation works (setting parameters and observing simulations), and involves student representatives to try using the media directly.
Operational Simulation Instructions: The educator introduces the *Equality Lab* feature in the *"Fractions: Equality"* module, which is used to visually explore and compare equivalence relationships between fractions.
3) **Problem Orientation Phase**
Presentation of a Contextual Problem: The educator sparks an initial discussion by presenting a contextual problem regarding the fair division of a cake, followed by encouraging students to ask critical questions related to the problem.
4) **Learning Organization Phase**
Formation of Work Groups: Students are grouped into small teams to discuss and complete tasks on the Student Worksheet (LKPD).
5) **Individual and Group Investigation Stage**
After selecting the Equality Lab menu, students can observe two forms of fractions displayed through images and mathematical symbols. Students can change the number of parts and the shaded portions using the available features. Next, students observe the changes in the images and symbols of the fractions to compare the two fractions and determine whether they have the same value or are equivalent fractions.

SJP Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 3. September 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

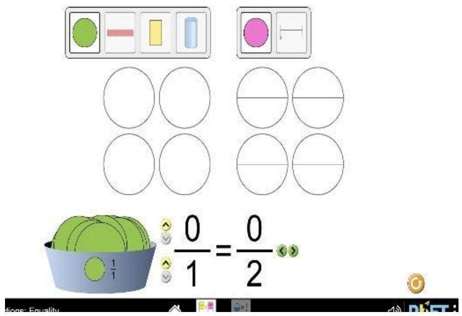

Figure 2: Students Using *PhET Simulations* (Source: Primary Research Data, 2026)

6) Development and Presentation of Results Stage

Formulation of Group Solutions: Each group discusses and formulates a final solution to the fraction problem based on the results of their exploration in the worksheet.

Communication Presentation: Group representatives present their findings to the class, including a step-by-step explanation of how they used *PhET Simulations* to solve fraction problems.

7) Discussion, Evaluation, and Reflection Phase

Concept Confirmation & Reinforcement: The teacher leads a plenary discussion to correct any misunderstandings and provide theoretical reinforcement of the fraction material.

Self-Assessment: Students complete assessment questions individually to measure their level of mathematical understanding after using *PhET Simulations*.

Learning Reflection: Educators and students engage in a joint reflection to evaluate the learning experience and the benefits they gained while using the simulation software.

Data Description

a. Validity Test

The validity test of the research instrument was conducted using 10 mathematical comprehension test items administered to 30 fourth-grade students (N = 30) at SDN Cijantung 03 Pagi. Statistical test results using SPSS 20 showed that all test items were deemed valid. This is shown in Table 2, where the calculated R value obtained for each item was greater than the table R value (0.361) (Septi et al., 2024).

Table 2 Uji Validity Test

Question No.	R count	R table	Information
1	0.839	0.361	VALID
2	0.838	0.361	VALID
3	0.839	0.361	VALID
4	0.798	0.361	VALID
5	0.744	0.361	VALID
6	0.810	0.361	VALID
7	0.775	0.361	VALID

SJIP Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 3. September 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

8	0.826	0.361	VALID
9	0.782	0.361	VALID
10	0.787	0.361	VALID

Source: Primary Data Processed with SPSS 20, 2026

b. Reliability Test

The instrument's reliability was tested on 30 fourth-grade students at SDN Cijantung 03 Pagi. Statistical analysis using SPSS 20 showed that the instrument is reliable, with a *Cronbach's Alpha* value of 0.939 for the 10 test items. This value indicates very high internal consistency of the instrument (Very High) (Yuliyanto et al., 2021).

Results of Descriptive Statistics Test of Pretest and Posttest

This study used *pretest* data as baseline data prior to the *treatment*. Descriptive data on student learning outcomes were analyzed using SPSS 20 and are presented in Table 3 below.

Table 3 Descriptive Statistics Test

Class	Minimum	Maximum	Mean	Standard Deviation
Pretest	35.00	80.00	64.07	11.85
Posttest	75.00	100.00	87.32	7.503

Source: Primary Data Processed with SPSS 20, 2026

Based on Table 3, there was an increase in students' average mathematical comprehension scores after receiving *the PhET Simulation*-assisted *treatment*. The average *posttest* score reached 87.32 with a standard deviation of 7.503, indicating a significant increase from the average *pretest* score of 64.07. The range of students' *posttest* scores was also higher, ranging from 75 to 100. These data indicate that the treatment delivered through the *PhET Simulation* interactive medium had a significant positive impact on students' mathematical understanding.

Data Analysis Requirements Test

a. Normality Test

The researcher performed a normality test following the collection of pretest and posttest data from the primary sample of 28 students (N=28). The purpose of this normality test was to determine whether the distribution of students' mathematics comprehension scores before and after the intervention was normal. Before the researcher may use parametric statistical analysis, particularly the t-test, it is imperative to confirm that the data are normal. The Shapiro-Wilk test was the most suitable normality test method to utilize in this study because the sample size was less than 50 students (N=28). If the obtained significance value (Sig.) is larger than 0.05, the criteria for drawing inferences state that the data are regularly distributed.

Table 4 Normality Test

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pre_test	.156	28	.080	.938	28	.100
Post_test	.093	28	.200*	.954	28	.250

*. This is a lower bound of the true significance.

SJP Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 3. September 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

a. Lilliefors Significance Correction
Source: Primary Data Processed with SPSS 20, 2026
The distribution of student results is proven to be NORMAL because the Sig. values for the pre-test (0.100 > 0.05) and post-test (0.250 > 0.05) on the Shapiro-Wilk test are more than 0.05. The criteria for parametric analysis have been satisfactorily fulfilled.

b. Paired Samples T-Test

The primary analysis used by the researcher to assess the research hypothesis is the a Paired Samples T-Test. In order to empirically show whether using the PhET Simulation medium has a significant impact on fourth-grade students' mathematical understanding of fractions, the main goal of this test is to compare the mean scores of students before the treatment (Pre-test) and after the treatment (Post-test) (Wardani et al., 2024). In this hypothesis test, the null hypothesis (H0) is rejected and the alternative hypothesis (Ha) is accepted if the computed T-value is greater than the critical T-value at a two-tailed significance level (Sig. 2-tailed); that is, if the Sig. (2-tailed) value is less than 0.05.

Table 5 Paired Samples T-Test **Paired Samples Test**

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	d. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pre_test - Post_test	-23.250	7.565	1.430	-26.183	-20.317	-16.262	27	.000

Source: Primary Data Processed with SPSS 20, 2026
The computed t-value, with degrees of freedom (df) = 27 and a significance level (Sig., 2-tailed) of 0.000, is −16.262 based on the Paired Samples Test table. According to the t-test decision criteria, the statistical choice is to reject H_0 and accept H_1 if the computed t-value is higher than the critical t-value (16.262 > 2.052) and the achieved significance value is 0.000, which is mathematically considerably smaller than 0.05 (0.000 < 0.05). The hypothesis test's final result demonstrates that using the PhET Simulation medium significantly improves fourth-grade elementary school pupils' mathematical comprehension of fractions. The negative sign of *the t-value* confirms a positive direction of change, meaning that students' understanding performance after the learning process was proven to be significantly superior compared to before the treatment was administered.

c. N-Gain Test

After confirming the significant effect of the instructional medium, the researcher proceeded to conduct an N-Gain (Normalized Gain) test. This test aims to measure the level of effectiveness in improving fourth-grade students' mathematical understanding after they participated in the fractions learning process aided by the PhET Simulation medium (Wahab et al., 2021). The results of the N-Gain score analysis will be interpreted based on Hake's classification to determine the improvement category (High, Moderate, Low) and the percentage of effectiveness (High/Effective, Moderately Effective, Less Effective).

Table 6 N-gain Test

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
NGain_Score	28	.35	1.00	.6670	.16992
Valid N (listwise)	28				

Source: Primary Data Processed with SPSS 20, 2026

Based on descriptive calculations in SPSS, the mean value of the students' overall N-Gain Score was found to be 0.6670. Referring to Hake's normalized gain index criteria, the value of 0.6670 falls within the interval $0.30 \leq g \leq 0.70$, indicating that the group's improvement in mathematical understanding is classified as "Moderate" (very close to the threshold for the "High" category at 0.70). Meanwhile, when viewed based on the percentage of

SJIP Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 3. September 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

effectiveness, the N-Gain value is equivalent to 66.7%, which means that the use of the PhET Simulation medium is considered "Moderately Effective" for boosting and stimulating elementary school students' understanding of fraction concepts.

Table 7 Categories of Improvement and Effectiveness

Normalized Gain (N-Gain) Value Thresholds	**Categories**
$g \geq 0,70$	Tinggi
$0,30 \leq g < 0,70$	Sedang
$g < 0,30$	Rendah
N-Gain Percentage (%)	**Effectiveness Interpretation**
> 76%	Efektif
56% - 75%	Cukup Efektif
40% - 55%	Kurang Efektif
< 40%	Tidak Efektif

Source: (Hake, 1999)

d. Effect Size Test (Cohen's D)

The researcher used Cohen's d standardization to perform an Effect Size test as a last step to bolster the discussion. This test's objective is to quantify the degree to which the independent variable (PhET Simulation) actually influences the dependent variable (students' mathematical comprehension). This test is crucial since the t-test findings only show the existence of an impact; they do not specify its strength.

Calculation Data: Taken from the Paired Differences table, namely the mean difference (Mean Paired = 23.250) and the standard deviation of the difference (Std. Deviation Paired = 7.565).

Paired Samples Test

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference	
					Lower	Upper
Pair 1	Pre_test - Post_test	-23.250	7.565	1.430	-26.183	-20.317

Source: Primary Data Processed with SPSS 20, 2026

Calculation Formula:

$$d = \frac{\text{Mean Paired}}{\text{Std. Deviation Paired}} = \frac{23,250}{7,565} = 3,07$$

According to Cohen's standard, if *the d-value* is greater than 0.80, the effect is classified as very large. The calculation yielded an *Effect Size* of 3.07. This figure is well above the threshold for *a* large effect (0.80), so it is

SJIP Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 3. September 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

concluded to fall *into the "Large* Effect" category. The implemented learning model has been proven to exert a highly dominant and strong influence on students' understanding.

Discussion

Based on the results of inferential statistical data analysis, this study empirically demonstrates that the integration *of PhET Simulation* as an interactive learning medium has a very positive and significant impact on elementary school student' understanding of mathematical concepts related to fractions. The significant increase in students' mean scores from 64.07 on the *pretest* to 87.32 on the *posttest* indicates a tangible transformation in conceptual understanding following the implementation of *PhET Simulation* .

Correlation tests and testing of the difference in means using a Paired Samples T-Test, which produced a computed t-value of 16.262 ($p = 0.000 < 0.05$), confirm the significance of this improvement. The PhET Simulation's interactive and visual aspects have a direct (causal) impact on students' mathematics comprehension, as evidenced by the rejection of the null hypothesis (H_0). Additionally, this medium's efficacy is supported by an N-Gain score of 0.6670 (66.7%), which falls into the "moderately effective to high" category, and an Effect Size (Cohen's d) of 3.07, which fits inside the "Large Effect" threshold ($d > 0.80$).

The ability of *the PhET Simulation* to transform elementary school students' mathematical understanding is closely tied to the medium's characteristics, which are based on interactive, manipulative, and dynamic visualization. When learning about fractions, elementary school students often experience *cognitive load* in understanding abstract concepts such as numerators and denominators. Through *PhET Simulation*, students can manipulate variables in *real time* and observe their visual representations, such as fractions depicted as proportionally divided circles or rectangles.

his finding aligns with the research by Rindiani et al. (2025) which suggests that the use of the *PhET Simulation* digital learning tool significantly enhances students' mathematical representation skills. Interactive simulations help facilitate the transition of mathematical concepts from concrete-visual representations to abstract symbolic forms.

From a pedagogical perspective, the effectiveness of *PhET Simulation* at the elementary school level also confirms the results of a study by Zulviani et al. (2024), which found a significant impact of using *PhET Simulation* on the mathematics learning outcomes of elementary school students. Simulation-based mathematics learning sparks students' interest and active engagement in the classroom, allowing concepts that were previously difficult to understand to be absorbed more intuitively and enjoyably. The rich visualizations in *PhET Simulations* have been shown to have an impact not only on mathematics but have also been consistently proven effective in science contexts to clarify abstract and contextual concepts(Lubis et al., 2024).

Optimizing the deployment of PhET Simulations in fraction instruction involves leveraging interactive modules tailored to specific learning goals. Specifically, the 'Fractions: Intro' module serves to introduce foundational fractional forms, whereas 'Fractions: Equality' instills core concepts surrounding equivalent values, comparisons, and ordering(Wieman et al., 2008). Throughout these sessions, pupils actively manipulate numerator and denominator parameters, observing real-time visual adaptations. Engaging in group tasks supported by Student Worksheets (LKPD) alongside PhET tools enables learners to construct their own conceptual framework through hands-on inquiry, effectively transitioning the environment toward a student-centered model. This substantial gain in comprehension underscores how hands-on engagement with simulation media enhances long-term knowledge retention (Norlaila et al., 2024).

In addition to improving conceptual understanding and basic learning outcomes, *the PhET Simulation-based* learning environment also contributes to the development *of high-order thinking skills* (HOTS) (Santoso & Herlia Putri, 2023). Through challenges in the form of quizzes and game features integrated into *PhET*, students are encouraged to analyze problems, test simple hypotheses, and evaluate their answers independently. These positive impacts align with Shidik, (2020) analysis, which confirms that the use of *PhET simulations* has strong potential to train and enhance students' critical thinking *skills* compared to conventional static learning media.

Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 3. September 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

The implications of this study suggest that *PhET simulations* can serve as a leading alternative digital learning medium at the elementary school level to address the limitations of physical concrete materials. The integration of these interactive virtual simulations has been proven, both empirically and theoretically, to foster a *student-centered learning* environment in mathematics, enhance the effectiveness of teaching fractions, and significantly optimize students' understanding of mathematical concepts**.**

CONCLUSION

This study demonstrates that integrating PhET Interactive Simulations positively enhances fourth-grade students' conceptual understanding of fractions. Empirical findings confirmed a statistically significant improvement in post-intervention scores ($t = -16.262$, $p < 0.001$), accompanied by a moderate learning gain (N-Gain = 0.67) and a large effect size ($d = 3.07$). The utilization of interactive modules specifically 'Fractions: Intro' and 'Fractions: Equality'—supports learners in translating abstract fractional concepts into visual representations. Overall, the virtual simulation serves as an effective pedagogical tool to facilitate student-centered learning and elevate mathematical comprehension in primary education.

Recommendations

Based on the empirical findings and study scope, the following recommendations are provided:

1. For Educators: Primary school teachers are encouraged to incorporate interactive virtual manipulatives into abstract mathematics topics, ensuring that digital exploration is supported by structured worksheets (LKPD) to guide conceptual discovery.
2. For School Administrators: Schools should provide basic ICT infrastructure and encourage offline module downloads to overcome connectivity constraints during classroom integration.
3. For Future Researchers: Given the internal validity limitations of the single-group pretest-posttest design, future studies should employ quasi-experimental designs with control groups, extend the intervention duration, and evaluate the long-term retention of mathematical comprehension across diverse primary school contexts.

REFERENCES

Agustin, M., Nordiana, N., & Ulfa, M. (2025). Digital learning innovations in primary mathematics: Enhancing higher-order thinking skills through virtual labs. *Journal of Primary Education*, *14*(1), 45–58. https://doi.org/10.15294/jpe.v14i1.78201

Ansori, H. (2024). Visualizing abstract mathematical concepts: The role of interactive technology in primary classrooms. *International Journal of STEM Education*, *11*(2), 112–125. https://doi.org/10.1186/s40594-024-00465-x

Arikunto, S. (2021). *Prosedur penelitian: Suatu pendekatan praktik*. Rineka Cipta.

Hake, R. R. (1999). Analyzing change/gain scores. In *Unpublished Software Report* (Vol. 16, Issue 7).

Lubis, M. S., Br Ginting, S. S., & Wahyuni, F. (2024). Mathematical Understanding Concept Ability of Junior High School Students on Algebra. *Al-Khwarizmi: Jurnal Pendidikan Matematika Dan Ilmu Pengetahuan Alam*, *12*(1), 1–14. https://doi.org/10.24256/jpmipa.v12i1.4824

Nordiana, A., Agustin, M., & Safitri, R. (2024). Integrating Merdeka Curriculum with digital media in primary schools. *Jurnal Pendidikan Sekolah Dasar*, *10*(2), 189–201. https://doi.org/10.30870/jpsd.v10i2.23104

Norlaila, Ansori, H., & Juhairiah. (2024). Pengaruh Penggunaan Media Pembelajaran Interaktif Phet Simulation Terhadap Hasil. *Jurmadikta (Jurnal Mahasiswa Pendidikan Matematika)*, *4*, 54–66. https://doi.org/10.37985/jer.v5i4.1204

Rindiani, R., Yusmin, E., & Fitriawan, D. (2025). Pengaruh Penggunaan Media Pembelajaran Digital Phet Simulation Terhadap Kemampuan Representasi Matematis Siswa. *Jurnal AlphaEuclidEdu*. https://doi.org/10.26418/ja.v6i1.100544

Safitri, N., Hodsay, Z., & Lestari Ningsih, Y. (2025). *Kemampuan Pemahaman Konsep Matematika Siswa pada*

Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 3. September 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

Materi Pecahan Kelas III SD Negeri 06 Palembang.https://doi.org/10.26418/alphaeuclidedu.v6i1.100544

Santoso, G., & Herlia Putri, A. (2023). *Efektivitas Metode Pembelajaran Berbasis Game dalam Meningkatkan Keterampilan Pecahan Pada Siswa Kelas 5 Sekolah Dasar*. https://doi.org/10.20527/jurmadikta.v4i1.2104

Septi, I., Susongko, P., & Nafiati, D. A. (2024). Desain Instrumen Tes Capaian Pembelajaran Matematika Dengan Uji Validitas Pearson Correlation. *Journal of Education Research*, *5*(4). https://doi.org/10.23887/ijee.v9i1.65432

Shidik, A. W. (2020). *Perbandingan penggunaan media pembelajaran Macromedia Flash dan Phet Simulation dalam meningkatkan keterampilan berpikir kritis*. digilib.uinsgd.ac.id. https://digilib.uinsgd.ac.id/31348/

Sugiyono. (2020). *Metode Penelitian Kuantitatif, Kualitatif, dan R&D* (Edisi 2, Cetakan 2). Alfabeta.

Sugiyono. (2023). *Metode Penelitian Kuantitatif, Kualitatif, Dan R&D*. Alfabeta.

Ulfa, N., Jupri, A., & Turmudi, T. (2021). Analisis Hambatan Belajar Pada Materi Pecahan. *Research and Development Journal of Education*, *7*(2), 226. https://doi.org/10.30998/rdje.v7i2.8509

Wahab, A., Zulviani, N., & Rochmah, E. (2021). Normalized gain analysis in assessing ICT-based instructional efficacy. *Asian Journal of University Education*, *17*(3), 201–212. https://doi.org/10.24191/ajue.v17i3.14512

Wardani, K., Septi, I., & Rindiani, R. (2024). Assessing parametric statistical applications in elementary educational research. *Jurnal Elemen*, *10*(2), 341–355. https://doi.org/10.29408/jel.v10i2.19820

Wieman, C. E., Adams, W. K., & Perkins, K. K. (2008). PhET: Simulations that enhance learning. *Science*, *322*(5902), 682–683. https://doi.org/10.1126/science.1161948

Yuliyanto, A., Turmudi, T., Syaodih, E., Saputra, D. R., Dharmawan, A., & Pertiwi, C. K. (2021). The Validity and Reliability of Instruments for Measuring Elementary School Students' Early Mathematical Ability. *Kalamatika: Jurnal Pendidikan Matematika*, *6*(2), 127–142. https://doi.org/10.22236/kalamatika.vol6no2.2021pp127-142

Zulfah, Z., & Turmudi, T. (2023). Virtual manipulatives in primary mathematics classrooms: A systematic literature review. *Educational Technology Research and Development*, *71*(4), 1621–1645. https://doi.org/10.1007/s11423-023-10211-1

Zulviani, N., Rochmah, E., & Sati, S. (2024). Pengaruh Penggunaan Media PhET Simulation Terhadap Hasil Belajar Peserta Didik Pada Pembelajaran Matematika Di Kelas III SD Negeri 1 Dukuhjati. In *J-CEKI: Jurnal Cendekia Ilmiah* https://doi.org/10.56799/jceki.v3i5.3412.