Journal of Educational Sciences
Journal homepage: https://jes.ejournal.unri.ac.id/index.php/JES

P-ISSN 2581-1657
E-ISSN 2581-2203

Integration of Concrete Media and PhET Simulation in Fraction Learning Through Realistic Mathematics Approach in Elementary School

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ARTICLE INFO

Article history:

Received: 07 June 2025
Revised: 13 June 2025
Accepted: 15 June 2025
Published online: 15 July 2025

Keywords:

Fractions,
PhET Simulation,
Concrete Media,
Realistic Mathematics Approach,
Learning Outcomes

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Article Doi:

https://doi.org/10.31258/jes.9.4.p.2740-2752

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A B S T R A C T

This study investigated the effectiveness of integrating concrete media and PhET simulation in fraction learning using a realistic mathematics approach in elementary schools. This study responded to students' difficulties in understanding abstract mathematical concepts, especially in adding and subtracting fractions with the same denominator. The method used was a quasi-experimental design with a non-equivalent control group design, involving 60 fourth-grade students divided into experimental and control groups. Pretest and posttest were given to both groups. Data were analyzed using paired and independent sample t-tests. The results showed a statistically significant increase in the learning outcomes of the experimental group. After the intervention, the experimental group achieved an average posttest score of 77.47 while the control group scored 40.30. The average difference between the two groups was 37.17 points, with a t value of 15.690 and a p value of 0.000 ($p < 0.05$). These findings confirm that the integration of concrete and digital media in fraction learning through a realistic mathematics approach significantly improves students' learning outcomes. This multimodal learning strategy effectively addresses common difficulties in fraction learning and offers a promising model for enhancing mathematics instruction at the elementary level.

1. Introduction

Education in the 21st century demands an adaptive and innovative learning approach, particularly in mastering mathematics. This fundamental subject fosters logical, systematic, and critical thinking skills. However, the reality in the field shows that the learning process in elementary schools is still dominated by conventional one-way methods, where teachers are the center of information and students play a passive role. The lack of student involvement in the learning process results in low learning outcomes, especially in mathematics subjects that require strong conceptual understanding and problem-solving skills, as emphasized by Isma et al. (2023).

In a global context, the report UNESCO (2021) emphasizes that the main challenge in education today is to ensure that students not only master academic content but also have 21st-century skills such as critical thinking, communication, collaboration, and creativity. All of these skills are closely related to mathematics learning. Unfortunately, most elementary school students have difficulty understanding mathematical material, especially the topic of fractions. Barbosa & Vale (2021) stated that fractions are often considered abstract concepts and are difficult to understand if presented procedurally without the help of concrete visualization.

The use of teaching aids can help students build deeper and more meaningful conceptual understanding. Mbagho & Tupen (2020) emphasized that concrete media such as fraction circles can provide direct learning experiences that strengthen the connection between mathematical concepts and the real world. To overcome these difficulties, the realistic mathematics approach is present as a solution that emphasizes the importance of real context in the development of mathematical concepts. Inci et al. (2023) state that the realistic mathematics approach is rooted in the principle that mathematics is a human activity that must be taught through the context of everyday life. Concrete media, such as fraction circles, are very suitable to support a realistic mathematics approach because they allow students to understand fractions as part of a whole in a visual context. However, concrete media have limitations in terms of flexibility and explorability. Many elementary schools still lack manipulative teaching aids, while this media is also unable to show dynamic changes in value or present a large number of variations of questions quickly. This is where the role of digital media becomes important.

Along with the development of technology, interactive digital media has become an alternative that can overcome these limitations. One relevant platform is PhET simulation, developed by the University of Colorado Boulder. This platform provides various interactive, concept-based simulations for science and mathematics topics, including fractions. PhET allows students to directly manipulate fraction representations, connect visual displays with mathematical symbols, and observe the consequences of changes in real time. This interaction encourages students' cognitive engagement and strengthens their overall understanding of concepts as emphasized by Umiliya et al. (2023).

Previous studies support the effectiveness of PhET in learning. Fitria et al. (2023) found that the use of interactive simulations such as PhET significantly improved students' understanding of the concept of fractions and encouraged learning motivation. Similar findings were also conveyed by Zhang et al. (2020), who showed that PhET plays a role in bridging the gap between concrete experiences and symbolic representations, so that students can build conceptual understanding. The integration of concrete media and PhET simulations within the framework of a realistic mathematics approach is an innovative approach that is worth studying. This integration has the potential to create a holistic learning experience, combining physical activity with digital interaction and connecting students' real experiences with abstract mathematical concepts more effectively.

This study aims to analyze the effect of integrating concrete media, such as fraction circles and PhET Simulation media, in fraction learning, especially addition and subtraction of fractions with the same denominator, through a realistic mathematics approach in elementary schools. The main focus is directed at improving learning outcomes, then active student involvement, and conceptual understanding of fraction material, with the hope of contributing to the development of more innovative and relevant mathematics learning strategies to the needs of the 21st century.

2. Methodology

Research Design

This study applies a quasi-experimental method with a design known as the non-equivalent control group design. In this design, researchers compare two groups of students, namely the experimental group given special treatment and the control group not given the treatment, to determine the extent of the differences in learning outcomes that occur due to the intervention given. This research design involves an experimental quantitative approach that utilizes two types of measurements, namely pretest and posttest. The pretest is given to both groups before learning takes place, to determine the initial abilities or initial conditions of students before being given treatment. While the posttest is given after the learning activities are completed, to measures the extent of the increase in learning outcomes obtained by students after following the learning process. By comparing the pretest and posttest results from each group, researchers can evaluate the effectiveness of the learning approach used in the study. The research design is presented as shown in Table 1.

Table 1. Non-Equivalent Control Group Design

Group	Pretest	Treatment	Posttest
E	Q_1	X	Q_2
K	Q_3	-	Q_4

The population in this study was all fourth-grade students in one of the public elementary schools, consisting of two classes with a total of 60 students. The sample was determined using a purposive sampling technique, namely selection based on certain considerations that are relevant to the objectives of the study. Class IV A was designated as the experimental group and Class IV B as the control group, each consisting of 30 students. The experimental group received fraction learning using concrete media and PhET simulations, while the control group received learning using the lecture method. The group division was carried out to compare the effectiveness of the realistic mathematics approach that integrates concrete media and PhET simulations, compared to the lecture approach without the assistance of learning media applied to the control group in the addition and subtraction of fractions with the same denominator material.

Instrument

The research instruments in this study consisted of initial knowledge tests and learning outcome tests in mathematics subjects prepared by the researcher. This instrument was designed to measure the extent of students' understanding and abilities before and after following the learning process with a certain approach. In order for the data obtained through the instrument to be accurate, reliable, and truly reflect the students' actual abilities, it is very important for the instrument to have an adequate level of validity and reliability.

To ensure the quality of the instrument, a series of tests were conducted before the instrument was used in collecting research data. This test aims to determine the extent to which the instrument can be said to be valid and reliable. The validity used in this study is content validity, which is a type of validity that assesses the suitability and completeness of the contents of the test items to the material to be measured. The process of assessing content validity is carried out through assessment techniques by experts, or what is known as expert judgment.

In this stage, mathematics education experts who understand the content of the material and the rules for compiling questions are asked to provide input, evaluation, and assessment of the instruments that have been prepared. The assessment is focused on the extent to which the questions reflect the learning indicators that have been set, as well as the suitability with the basic competencies that are used as references. Thus, the assessment of experts provides a theoretical and practical basis that this instrument can be used to measure students' learning abilities to the objectives of the study.

After the assessment by the validators, the results are then analyzed quantitatively by calculating the percentage of the validity level. This percentage is used to determine the extent to which all the questions in the instrument meet the criteria as a valid measuring instrument. An instrument that gets a high percentage of validity means that it has met the aspects of material, language clarity, and suitability of indicators, and therefore is suitable for use in data collection. With this validation process, the instrument can be considered to have good quality and can be used effectively in conducting research. Then, the results of the assessment by the validator are analyzed by calculating the percentage of validity. This percentage serves to determine how well the instrument meets the standards set as a measuring instrument. The following is the validation formula according to Krisnanti et al. (2020), which is used to calculate the value of the validity percentage.

The assessment of the validity of the instrument in this study was carried out by considering two main aspects, namely the suitability of the instrument's content with the learning indicators and the clarity of the questions in language and concepts. This validity is reviewed from the statistical and theoretical side so that the instrument truly represents the ability to be measured. The criteria for grouping the level of validity refer to the opinion of Arikunto (2013), who divides it into

several categories based on the distance of the percentage of scores obtained, as seen in Table 2.

Table 2. Criteria Validity Test

Percentage	Criteria
81- 100	Very high
61-80	Tall
41- 60	Neutral
21- 40	Low
0-20	Very low

The results of the research instrument validation process show that the validity quality of the initial knowledge test and the student learning outcome test has each reached a value of 83%. This percentage indicates that the questions compiled are by the learning indicators and the materials being tested, so it can be concluded that both instruments have a very high level of content validity. High content validity indicates that the instrument actually measures what should be measured and can be used to obtain relevant and representative data on student abilities.

In addition, to ensure that the instrument is not only valid but also consistent in its measurement, a reliability test was conducted using the Cronbach's Alpha method. The results of this reliability test indicate that both the initial knowledge test and the student learning outcome test have a very good level of reliability. The use of Cronbach's Alpha values allows researchers to assess the extent to which the instrument provides stable and consistent results when used on similar subjects. Based on Creswell & Creswell (2018) criteria, both instruments meet the required standards of validity and reliability for use in this quantitative study, as shown in Table 3.

Table 3. Category Reliability Instruments

Cronbach's Alpha Coefficient Percentage	Category Reliability Instrument Test
0,86–100	Very High
0,66–0,85	Tall
0,36–0,65	Low
0,20–0,35	Very Low
0,00–0,19	Not reliable

The results of the reliability analysis showed that the initial knowledge test and the student learning outcome test showed a very high level of reliability, indicated by the Cronbach's Alpha value of 0.883. This figure shows that both instruments are in the high reliability category according to the measurement standards commonly used in educational research. This means that the instruments used in this study have strong internal consistency and can be trusted to measure initial abilities and student learning outcomes accurately and stably. Thus, both instruments are declared feasible and valid for use in conducting experimental research, because they are able to produce data that can be scientifically accounted for and support the achievement of research objectives optimally.

Data collection

The data collection technique in this study was carried out through a written test in the form of an essay consisting of 10 questions, consisting of a pretest and a posttest. The pretest was given to the experimental group and the control group before the treatment to measure students' initial abilities in the fraction material. After the treatment was given, both groups were given a posttest again to determine the improvement in learning outcomes. The test instrument was in the form of descriptive questions that had been validated by experts and tested for reliability using Cronbach's Alpha. Data were obtained directly from the results of student answer sheets, then classified and analyzed quantitatively to assess the effectiveness of the treatment given to the experimental group compared to the control group.

Data analysis

This study utilized the SPSS version 25 application to analyze the data. The analysis procedure included descriptive and inferential statistical analysis adjusted to the research design and characteristics of the data obtained. Descriptive statistics were used to describe the data in general, such as the average value, standard deviation, maximum and minimum values, while inferential statistical analysis was used to test the formulated hypothesis. The analysis stage began with the process of inputting data into SPSS, followed by identifying the variables being analyzed. In this study, the dependent variable was the learning outcomes on the material of fractions with the same denominator, while the independent variable was the integration of concrete media and phet simulation in fraction learning based on a realistic mathematical approach applied to fraction material, especially addition and subtraction of fractions with the same denominator in grade IV of elementary school.

Before testing the hypothesis, a prerequisite analysis test was first carried out, including a normality test and a homogeneity test. The normality test was carried out using Shapiro-Wilk. This test aims to determine whether the data is normally distributed or not. Furthermore, a homogeneity test was carried out to ensure that the data variance between groups was comparable conditions. These two tests are important to determine the type of statistical test that is appropriate in the hypothesis testing process. If the assumptions of normality and homogeneity are met, then the analysis can be continued using the appropriate parametric test according to the research objectives.

3. Results and Discussion

Researchers use concrete media in the form of fraction circles to help students understand the basic concept of fractions visually and directly. Through this activity, students are introduced to real representations of parts and wholes, thus building an initial understanding of the relationship between fractional parts. After the basic concept is understood, learning continues with concept reinforcement through digital media. At this stage, researchers ask students to explore the Build a

Fraction digital simulation from the PhET platform. This simulation allows students to build their fraction representations by dragging and arranging parts of the circle, according to the questions or problems presented in the learning. Then, students match them with symbolic forms in the form of fractional numbers. Through this interaction, students can understand the relationship between visual and numerical representations of fractions in more depth. In addition, the interactive features in this simulation help increase student' active involvement and strengthen their conceptual thinking skills. The appearance of the PhET simulation used in the learning process can be seen as shown in Figure 1.

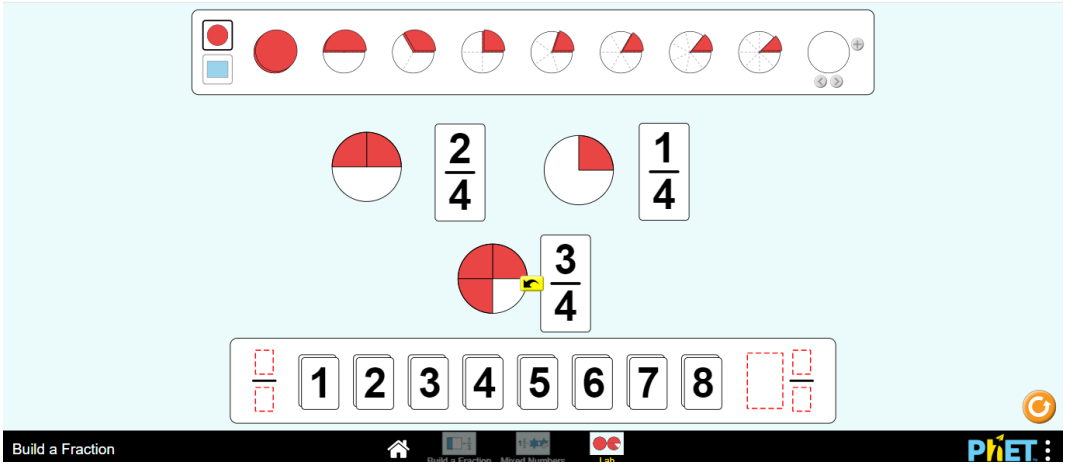

Figure 1. Build a Fraction Simulation view from PhET used in fraction learning activities.

After all stages of learning were completed, students were given a posttest to measure changes in fraction calculation skills, both in the experimental group and the control group. Then, after giving the posttest, the next step was to analyze the data that had been collected. Based on the summary of the pretest and posttest data recapitulation from the trial class and the control class, it was revealed that each class consisted of 30 students. In the trial class, the pretest score showed the lowest score of 24 and the highest score of 57. After the treatment was given, the posttest score in the trial class increased, with the lowest score being 56 and the highest score being 92.

This indicates a significant development in learning outcomes in the trial class. On the other hand, the control class had pretest scores ranging from 6 to 43. After the usual learning process through the lecture method, the posttest score for the control class showed an increase, with the lowest score of 26 and the highest score of 61. Although both classes showed progress in learning outcomes, the trial class was more prominent in its improvement compared to the control class. This shows that the treatment applied in the trial class was more effective in improving students' learning processes. The average pretest and posttest results of the experimental and control classes are presented as shown in Table 4.

Table 4. Average Results of Pretest and Posttest

Descriptive Statistics					
Data type	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Experiment Pretest	30	24	57	36.67	8.810
Experiment Posttest	30	56	92	77.47	9.468
Control Pretest	30	6	43	22.90	8.531
Control Posttest	30	26	61	40.30	8.871

From the descriptive statistical results of the pretest and posttest scores in both classes, further analysis was carried out through normality and homogeneity tests to determine whether the data met the assumptions needed for parametric analysis. The normality test is used to assess whether the distribution of data in each group is within acceptable normal limits. The results of the normality test for the experimental and control groups can be seen in Table 5.

Table 5. Normality Test Results

	Shapiro-Wilk		
Data type	**Statistic**	**df**	**Sig.**
Experiment Pretest	.950	30	.172
Exsperimen Posttest	.957	30	.263
Control Pretest	.970	30	.527
Control Posttest	.963	30	.372

The results obtained from the normality test on the pretest of the experimental class were 0.172 > 0.05, and the pretest of the control class was 0.572 > 0.05, meaning that both data sets were normally distributed. While for the posttest results, both were normally distributed, for the posttest of the experimental class, it was 0.263 > 0.05, and the posttest of the control class was 0.372 > 0.05. Then, to find out that both classes have homogeneous variations, it can be seen in Table 6.

Table 6. Homogeneity Test Results

	Levene Statistic	**df1**	**df2**	**Sig.**
Based on Mean	.120	1	58	.730
Based on Median	.047	1	58	.830
Based on Median and with adjusted df	.047	1	56.777	.830
Based on trimmed mean	.162	1	58	.689

The results of the homogeneity test based on the average value (mean) show that the significance value is 0.730 > 0.05, which means that both groups, namely the experimental class and the control class, have the same or homogeneous variance. This condition indicates that before the treatment was given, both classes had relatively equal initial abilities in understanding the concept of fractions, especially in terms of arithmetic skills. After the normality and homogeneity tests were met, the next step was to analyze to find out if there was a difference between the pretest and posttest results, the researcher applied a paired sample t-test because both measurements were carried out on the same group of students, so they were included in the paired sample category (dependent). The decision to accept or reject the null hypothesis (H_0) is based on a comparison of the t-statistic (also called the

calculated t-value) with the critical value of the t-distribution table (table value). If the absolute value of the calculated t exceeds the t-table value, or if the p-value is less than 0.05, then the difference is declared statistically significant. The analysis of the test results data is presented in Table 7.

Table 7. Results of Paired Sample T Test

Paired Samples Test								
				95% Confidence Interval of the Difference				
Data Type	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Exsperiment Pretes – Exsperiment Posttest	-40.800	10.902	1.990	-44.871	-36.729	-20.498	29	.000
Control Pretest – Control Posttest	-17.400	9.427	1.721	-20.920	-13.880	-10.110	29	.000

The results of the analysis show that for the experimental group, the t-statistic value is -20.498 with a p-value of 0.000. With a degree of freedom (df) of 29 and a significance level of 5% ($\alpha = 0.05$), the critical t-value of the t-distribution is ±2.045. Since the absolute value of the t-statistic (|–20.498| = 20.498) far exceeds the critical t-value and the p-value is less than 0.05, the null hypothesis (H_0) is rejected. This shows that there is a statistically significant increase in students' mathematics learning outcomes after the implementation of a realistic mathematics approach-based learning supported by the integration of concrete media and PhET simulations.

Similarly, in the control group, the t-statistic value was obtained at -10.110 with a p-value also of 0.000. With the same critical t-value (±2.045), the null hypothesis was again rejected. This shows that there is a significant difference between the pretest and posttest results in the control group, although the increase is not as large as the experimental group. This can be seen from the smaller mean difference in the control group (-17.400) compared to the experimental group (-40.800), which indicates that the use of a lecture approach without the aid of learning media results in a more limited increase in understanding the concept of fractions. To strengthen the findings of the analysis, it was continued with an independent sample t-test to compare the final posttest results of the two groups, as can be seen in Table 8.

Table 8. Independent test results: Test Control and Experiment

	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	.120	.730	15.690	58	.000	37.167	2.369	32.425	41.908
Equal variances not assumed			15.690	57.756	.000	37.167	2.369	32.425	41.909

The test results show that the t-value is 15.690 with degrees of freedom (df) = 58 and a significance value (p) of 0.000. Because the t-value (15.690) is much greater than the critical t-value at a significance level of 5% (around ±2.001) and the p-value <0.05, the null hypothesis (H_0) is rejected. This indicates that there is a statistically significant difference between the experimental group and the control group in mathematics learning outcomes.

The average difference in learning outcomes between the two groups was 37.167 points, with the experimental group showing a higher score. The range of confidence intervals at the 95% confidence level was between 32.425 and 41.908, further strengthening that this difference was not caused by chance alone. Thus, it can be concluded that the realistic mathematics learning approach that integrates concrete media and PhET simulations has a more positive impact on students' understanding of the addition and subtraction of fractions with the same denominator compared to the lecture approach without the assistance of learning media applied to the control group.

Discussion

This study shows that the integration of concrete media and digital simulation PhET, based on a realistic mathematics approach, significantly improves students' learning outcomes in the addition and subtraction of fractions with the same denominator. This is indicated by an increase in the average posttest score in the experimental class of 77.4, compared to the control class, which only reached 40.3. With an independent t-test, a significance value of 0.000 (p <0.05) was obtained, indicating that there was a significant difference between the two groups. This finding confirms the importance of a contextual and multimodal approach (physical and digital) in teaching abstract concepts such as fractions. Fraction circle media helps concrete understanding, while PhET simulations strengthen understanding through visualization and interactivity. Thus, this learning model is effective in overcoming common challenges in teaching fractions in elementary schools, such as simplifying, comparing, and understanding fractions with the same denominator as emphasized by Fidayanti & Shodiqin (2020)**.**

The results of this study are in line with initial expectations and strengthen the findings of previous studies. Wilkie & Roche (2023) emphasized that the use of concrete models such as fraction circles is effective in helping students understand the concept of the relationship between parts and the whole more realistically. Furthermore, research conducted by Ngu & Phan (2024) found that visual media presented in a structured manner can reduce cognitive load and improve students' conceptual skills. Research by Pedersen et al. (2023) shows that students with low academic achievement can achieve a better understanding when given interactive visualizations that are concrete. Furthermore, Viberg et al. (2023) stated that the use of digital manipulatives not only improves understanding but also has a positive impact on students' active participation and learning motivation. Thus, the findings in this study support and strengthen the current literature that recommends a multimodal approach as an effective strategy in mathematics learning.

The findings of this study also have a close relationship with a number of similar studies. The research conducted by Fitria et al. (2023) shows that a realistic approach is able to improve mathematics learning outcomes through a learning context that is close to students' real experiences. Furthermore, Norlaila et al. (2024) experimentally proved that the application of interactive simulation based on PhET in fraction learning effectively improves students' understanding in elementary schools. This is also reinforced by the findings of Rahmawati et al. (2024), which concluded that the integration of digital simulation can optimize student learning outcomes in just one learning cycle.

Other studies Mindiari (2023), also support the use of a realistic approach based on concrete media as an effective strategy in achieving learning completion more quickly, while making the learning process more interesting and meaningful. Although the results obtained show the effectiveness of the applied learning model, there are likely other contributing factors, such as students' intrinsic motivation, teachers' experience in using media, and support for the learning environment. Therefore, the success achieved is likely also influenced by the comfort of the learning atmosphere and students' emotional involvement in the media used. A study by Rahadian (2021) also strengthens this by stating that the use of physical media not only improves learning outcomes but also the enthusiasm and motivation of students to continue to actively participate in the learning process.

The results of this study have several important implications. First, elementary school teachers can begin to integrate realistic mathematics approaches with physical and digital media, especially for abstract materials such as fractions. Second, teacher training in the use of digital media such as PhET needs to be improved so that technology-based learning is more optimal. Third, schools and policymakers can use these findings as a basis for developing a curriculum that is adaptive to technology and contextual learning needs. However, this study has limitations. The subjects only involved one school, so the results cannot be generalized. The short duration of the intervention is also not enough to measure the sustainability of student understanding. In addition, affective and metacognitive aspects have not been studied, even though they have an effect on learning outcomes. Further research is recommended to include more schools, longer durations, and indicators of student motivation, interest, and learning strategies for more comprehensive results..

4. Conclusion

This study shows that the integration of concrete media in the form of fraction circles and PhET digital simulations in a realistic mathematics learning approach significantly improves students' learning outcomes on the topic of addition and subtraction of fractions with the same denominator in elementary schools. This learning approach helps students understand concepts concretely and visually and encourages active involvement in the learning process. Compared to the lecture approach without the assistance of learning media, this multimodal approach is proven to be more effective, as seen from the difference in final scores between the

experimental and control groups. These results emphasize the importance of real-context-based learning that combines visual, kinesthetic, and interactive elements. These findings are relevant to the challenges of 21st-century learning and can be a reference for teachers and policymakers in designing innovative and technology-adaptive mathematics learning strategies. However, to ensure the sustainability of its positive impact, further research is needed that includes aspects of motivation, metacognition, and a broader learning context. Therefore, this study not only provides theoretical contributions but also practical benefits in improving the quality of mathematics learning in elementary schools.

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How to cite this article:

Ressa., & Latifah, N. (2025). Integration of Concrete Media and PhET Simulation in Fraction Learning Through Realistic Mathematics Approach in Elementary School. *Journal of Educational Sciences*, *9(4)*, 2740-2752.