AL IBTIDA: JURNAL PENDIDIKAN GURU MI (2023) VOL 10 (2): 241 - 252
DOI: http://dx.doi.org/10.24235/al.ibtida.snj.v10i2.15056

Al Ibtida: Jurnal Pendidikan Guru MI
ISSN: 2442-5133, e-ISSN: 2527-7227
Journal homepage: http://syekhnurjati.ac.id/jurnal/index.php/ibtida
Journal email: alibtida@syekhnurjati.ac.id

Integrating PhET Interactive Simulations to Enhance Students' Mathematical Understanding and Engagement in Learning Mixed Fractions

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Received: September 01st, 2023. Accepted: October 28th, 2023. Published: October 31st, 2023.

Abstract

This study aims to document how the integration of PhET interactive simulations into mathematics learning enhances students' conceptual understanding of mixed fractions. This collaborative action research project adhered to the action research cycle proposed by Kemmis and McTaggart. In total 17 4th-grade students from one of the public elementary schools in Malang City, Indonesia participated in this investigation. The data was collected through tests, interviews, and classroom observation. The test of students' mathematical understanding (TSMU) was administered to the students at the pre-cycle, post-cycle I, and post-cycle II stages. The number of questions given in each test was 10 mathematical problems, and they were designed to assess students' mathematical understanding of mixed fractions. The quantitative data was analyzed by using descriptive statistics using SPSS 25, and the qualitative data was analyzed simultaneously using a qualitative data analysis cycle. The research findings unveiled the following key insights. First, we found a notable enhancement in students' mathematical understanding of mixed fractions emerged throughout the study. Specifically, the pre-cycle average score for students' mathematical understanding stood at M=51.59, which saw substantial improvement in the post-cycle I phase (M=61.53) and further growth in the post-cycle II phase (M=76.94). Moreover, the utilization of PhET simulations was found to significantly enhance students' engagement in the realm of mathematics learning. Therefore, the integration of PhET interactive simulations in mathematics learning has been shown to have a significant effect on improving students' mathematical understanding and engagement in learning fraction.

Keywords**:** *PhET interactive simulation, conceptual understanding, mixed fractions, students' engagement.*

Abstrak

Penelitian ini bertujuan untuk mendokumentasikan bagaimana integrasi PhET *interactive simulation* ke dalam pembelajaran matematika meningkatkan pemahaman konseptual siswa pada materi pecahan campuran. Desain penelitian tindakan kelas kolaboratif (PTK) dilaksanakan mengikuti siklus penelitian tindakan Kemmis dan McTaggart. Sebanyak 17 siswa kelas 4 di salah satu sekolah dasar negeri di Kota Malang, Indonesia dilibatkan dalam penelitian ini. Pengumpulan data dilakukan melalui tes, wawancara, dan observasi kelas. Tes pemahaman matematis siswa (TPMS) diberikan kepada siswa pada tahap pra siklus, pasca siklus I, dan pasca siklus II. Jumlah soal yang diberikan dalam setiap tes adalah 10 soal matematika, dan dirancang untuk menilai pemahaman matematis siswa tentang pecahan campuran. Data kuantitatif dianalisis dengan menggunakan statistik deskriptif menggunakan SPSS 25, dan data kualitatif dianalisis secara simultan mengacu pada siklus analisis data kualitatif. Hasil penelitian mengungkapkan bahwa: (1) terdapat peningkatan kemampuan pemahaman matematis siswa pada materi pecahan campuran. Hasl ini ditunjukan dengan rata-rata hasil TPMS pada pra-siklus *M=51,59*, pasca siklus I *M=61,53*, dan pasca siklus II *M=76,94*; (2) penggunaan PhET *interactive simulation* terbukti berkontribusi dalam meningkatkan keterlibatan siswa dalam pembelajaran matematika. Oleh karena itu, integrasi simulasi interaktif PhET dalam pembelajaran matematika terbukti memberikan pengaruh yang signifikan terhadap peningkatan pemahaman konsep matematis pecahan campuran siswa.

Keywords: *PhET interactive simulation, pemahaman matematis, pecahan campuran, keterlibatan siswa.*

INTRODUCTION

Mathematical understanding, comprising conceptual comprehension and procedural fluency, is a fundamental component of mathematical proficiency that students must acquire during their mathematical education (NCTM, 2000; Ivars et al., 2020). Mathematical understanding, as a crucial facet of mathematical proficiency, assumes a pivotal role in enabling students to delve deeply into mathematical concepts and apply them in practical scenarios (Boaler, 2022; Cai & Ding, 2017; Yang & Sianturi, 2019). This is also in line with the perspective that explains how mathematical understanding enables students to apply mathematical principles in solving real-world problems (Verschaffel et al., 2001; Kazak et al., 2015). Highlighting the primacy of this notion, Hiebert and Grouws (2007) underscore that effective mathematics education should prioritize the development of students' conceptual understanding as the initial step toward achieving a solid grasp of mathematics. Consequently, mathematics educators bear the responsibility of fostering robust mathematical understanding, including proficiency in fractions, among their students.

Research in mathematics education underscores the pivotal role of understanding fraction concepts in students' progression toward more advanced mathematical learning (Leng et al., 2020; Pedersen et al., 2022). A proficient grasp of fractions profoundly influences students' overall mathematical achievements and equips them with essential skills for mastering more advanced mathematical concepts (Copur-Gencturk, 2021; Hunt et al., 2016). However, fractions continue to pose challenges, both in terms of learning and teaching (Chen et al., 2022; Koopman et al., 2019). Teaching fraction in elementary school remain to be challenging (Harvey, 2012). Previous research has cast a spotlight on the obstacles students encounter while learning fractions, as exemplified by the work of Fauzi and Suryadi (2020). Furthermore, the acquisition of mixed fractions presents specific challenges due to its

incorporation of fundamental mathematical concepts, including fractions, whole numbers, and arithmetic operations (NCTM, 2014). This complexity arises from the presence of a whole number bias, rendering the concept of fractions more intricate than that of natural numbers (Bouck et al., 2020). Therefore, educators are tasked with addressing and surmounting these challenges in fraction education.

Teachers possess a multitude of tools and methods to facilitate students' understanding of fraction concepts. Research in mathematics education has demonstrated the efficacy of interactive and adaptive simulations, particularly for students with lower levels of achievement (Reinhold et al., 2020; Bedada & Machaba, 2022). Additionally, research has established that interactive simulations can significantly enhance student academic performance (Banda & Nzabahimana, 2023; Yohannes & Chen, 2021). For instance, the research conducted by Birgin and Acar (2020) highlights the substantial impact of interactive simulations on students' achievement in exponential and logarithmic functions. In line with this, Chotimah and Festiyed (2020), in their meta-analysis, discovered that the utilization of PhET simulations substantially enhances student learning in both mathematics and science. Furthermore, Zulnaidi et al. (2020) found that the integration of Interactive Simulations positively influences students' conceptual understanding of mathematics. Hence, the integration of interactive simulations like PhET in mathematics education represents a promising approach to addressing the challenges students face in learning fractions.

While numerous studies have emphasized the integration of interactive simulations into mathematics education (e.g., Birgin & Acar, 2020; Chen et al., 2022; Viberg et al., 2023), there remains a paucity of research that specifically explores the use of interactive simulations in the context of fraction learning, particularly at the primary school level. To address the aforementioned challenges and urgent needs, this research takes a distinct approach by investigating the impact of integrating PhET Interactive Simulations into mathematics education on students' mathematical achievements. The research questions addressed in this study are as follows:

1) Does the integration of PhET Interactive Simulations enhance students' understanding of mixed fractions?
2) How does student engagement manifest during mathematics instruction when integrating PhET interactive simulations?

METHODS

Research Design

In this study, a classroom action research (CAR) methodology was utilized to assess how the integration of PhET Interactive Simulation into mathematics instruction influences students' mathematical understanding, specifically within the realm of mixed fractions. This research framework allows educators and researchers to systematically observe and assess the outcomes of incorporating PhET Interactive Simulation into the teaching and learning process. The research design employed in this study adheres to the CAR model, as illustrated in Figure 1.

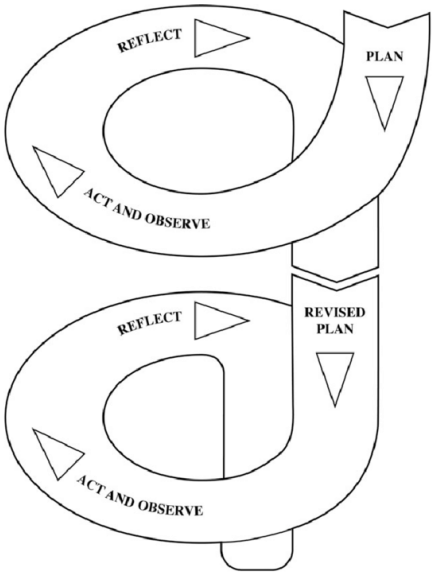

Figure 1. Classroom Action Research Design
Source: Kemmis and McTaggart (2008)

Planning

The planning activities for integrating PhET Interactive Simulations into fraction material learning are carried out in the following stages. First, determine the learning objectives related to mixed fraction material. Next, select a PhET simulation that is relevant to the subject of mixed fractions. The interactive simulation of selected mixed fraction material is shown in Figure 2.

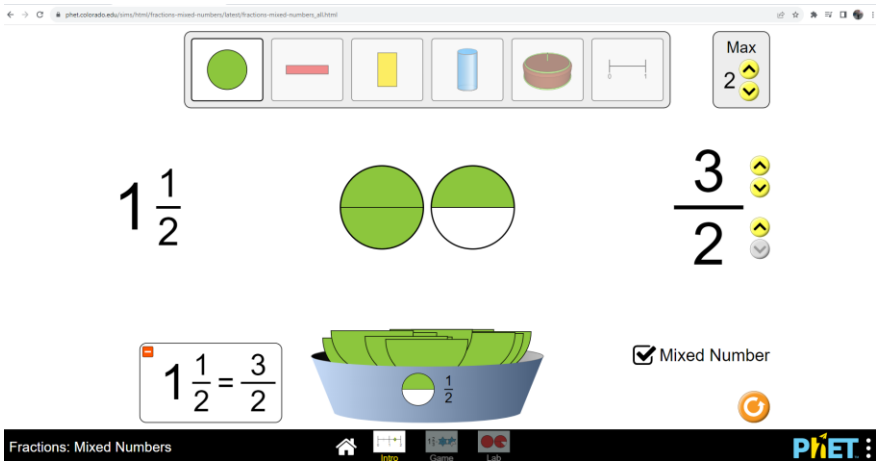

Figure 2. Example of the PhET Interactive Simulation display for Mixed Fraction Materials
Source: https://phet.colorado.edu/

Learning design that integrates PhET simulation is accomplished through developing a series of activities that combine learning theory about fractions with the use of interactive PhET simulations, such as visual exploration of mixed fractions through simulations, followed by group discussions about the results of students' observations and understanding. Formative evaluations, such as brief quizzes or discussion questions, were also used to assess the level of students' understanding during the learning process. The developed learning design enables students to actively engage in their learning, utilize interactive technology resources, and gain a better understanding of the concept of mixed fractions.

Treatment Design

This research used a classroom action research (CAR) design consisting of two cycles. Each cycle consisted of four main stages, namely planning, implementation, observation, and reflection.

Mathematical Understanding Ability Test

The mathematical understanding ability test (TSMU) is given to students to measure their mathematical understanding ability in mixed fraction material. This test was given at the pre-cycle, post-cycle I, and post-cycle 2 stages.

Treatment

Following the pre-cycle test, students were provided with mathematics learning developed by integrating PhET Interactive Simulation with mixed fraction material. This integration was carried out using interactive PhET simulations that are relevant material concepts. Through these simulations, students were given learning experiences that included hands-on exploration with a focus on deep conceptual understanding.

Figure 3. Implementation of Learning Using PhET Interactive Simulation Mixed Fraction Material

After the completion of the learning treatment involving PhET Simulation integration, all students in both the control and experimental groups underwent a post-test to assess the improvement in their conceptual understanding of mixed fraction material. This post-test maintained the same format as the pre-test, enabling a direct comparison between the initial level of understanding and the level following the treatment.

Participants

This research focuses on the effect of using PhET Interactive Simulations in mathematics learning on IV grade elementary school students' mathematical conceptual understanding abilities. The research population consisted of two groups, 28 students in the control group and 28 students in the experimental group, all of whom were between the ages of 9 and 10.

Data Collection Instrument

The data collection instrument used was a test of students' mathematical understanding abilities in mixed fraction material. The pre-test and post-test contain a total of 10 questions. The test instrument for students' mathematical understanding of mixed fraction material was developed using the mathematical understanding criteria presented in Table 1.

Table 1. Indicators of Mathematical Understanding Aspects

Aspect	Indicator	Question Number
Conceptual Understanding	The ability to connect the Mathematical idea and concept	1, 2, 3
	The ability to present Mathematical situation with different way	4, 5, 6, 7
	The ability to use Mathematical representation to solve certain Mathematical problem	8, 9, 10

Adapted from: (Arifin et al., 2020)

Data Analysis

This research adopted a classroom action research design to analyze the effect of integrating PhET Interactive Simulations in mathematics learning on increasing students' mathematical conceptual understanding abilities in mixed fraction material. The employed data analysis technique comprises comprehensive stages that integrate both quantitative and qualitative data analysis methods.

Descriptive Statistical Analysis

Descriptive statistical analysis was applied to summarize data on students' mathematical conceptual understanding abilities in mixed fraction material at the pre-cycle, post-cycle I, and post-cycle II stages. Descriptive statistical test analysis was carried out using SPSS 25.

Qualitative Data Analysis

Qualitative data analysis was performed simultaneously on data collected through observation, interviews, and documentation studies during the research. Qualitative data analysis was carried out to explore the extent of student engagement in learning mathematics which had been designed by integrating PhET Interactive Simulation with mixed fraction material.

RESULTS AND DISCUSSION

Pre-Cycle

Before starting treatment in cycle I, students completed a 10-question mathematical understanding test. The results of the pre-cycle tests obtained are presented in Table 2.

Table 2. Pre-Cycle Mathematical Understanding Test Results

Descriptives	Statistic
Mean	57.59
Minimum	46.00
Maximum	85.00
Std. Deviation	13.84

According to the results of the mathematical understanding tests in the pre-cycle, as shown in Table 2, it is clear that the average attained by students in the pre-cycle

mathematical understanding test is M = 57.59. Meanwhile, the minimum and maximum scores obtained are Min = 46.00 and Max = 85.00.

Cycle I

Descriptive Analysis Results of the Mathematical Understanding Ability Test

Students' post-cycle mathematical understanding tests on mixed fraction material I was assigned to assess students' mathematical understanding abilities after they had completed mathematics learning according to the planned learning design. The results of students' mathematical understanding tests after cycle I are shown in Table 3.

Table 3. Mathematical Understanding Test Results in Post-Cycle I

Descriptives	**Statistic**
Mean	61.53
Minimum	46.00
Maximum	100.00
Std. Deviation	18.72

According to the results of the post-cycle I mathematical understanding tests, as shown in Table 3, the average score earned by students is M = 61.53. Meanwhile, the minimum and maximum scores achieved in post-cycle I are Min = 46.00 and Max = 100.00.

Cycle II

Table 4. Mathematical Understanding Test Results in Post-Cycle II

Descriptives	**Statistic**
Mean	76.94
Minimum	46.00
Maximum	100.00
Std. Deviation	14.09

According to the results of the post-cycle II mathematical understanding tests, as shown in Table 4, the average score earned by students is M = 76.94. Meanwhile, the minimum and maximum scores achieved are Min = 46.00 and Max = 100.00.

Analysis of Mathematical Understanding Improvement

Based on the results of the analysis using descriptive statistics carried out on students' TSMU results in pre-cycle, post-cycle I, and post-cycle II, the improvement in students' mathematical understanding ability in mixed fraction material is presented in Figure 4.

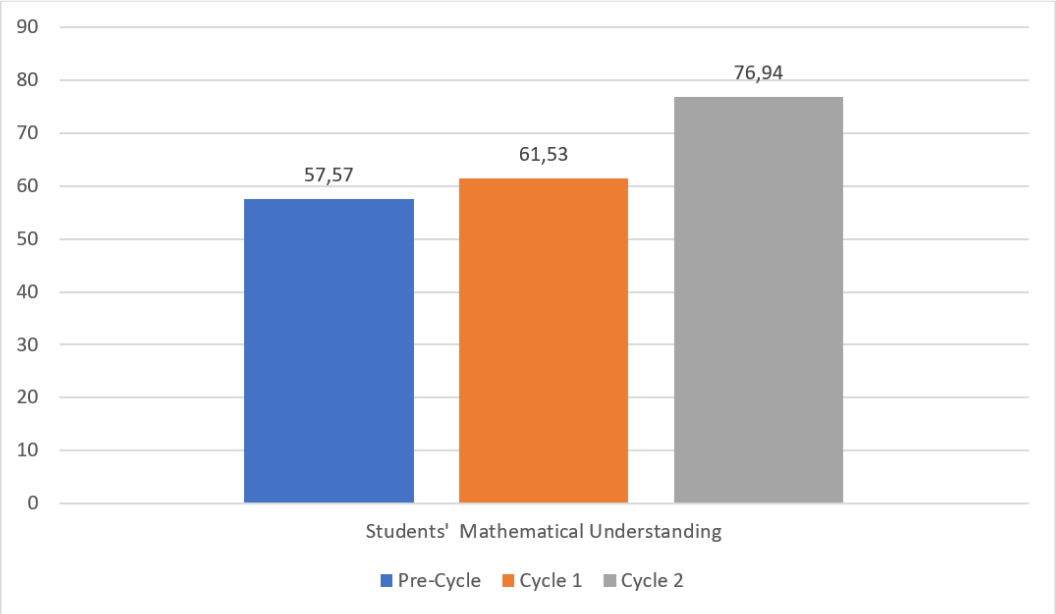

Figure 4. Average results of mathematical understanding tests

Student Engagement Analysis Results

Findings from observations made during the initial cycle of learning activities revealed an improvement in student engagement with the study of mathematics, particularly fractions, throughout the learning process. This was evident in students actively exploring PhET interactive simulation media integrated into the learning of mixed fraction material.

Figure 3. The students actively learn mixed fraction material through PhET Interactive Simulation

In line with the findings of observations performed during learning activities, interviews with teachers suggested that student engagement increased while learning mixed fraction material utilizing PhET interactive simulation. The following is given by the teacher's statement (Mrs. WR=teacher's initials).

Researcher: Based on your experience carrying out learning using PhET simulation, how did you monitor student engagement during the lesson?

Mrs. WR: Based on my observations during the PhET simulation implementation phase, students appeared to be more enthusiastic. Besides, students engage actively in exporting and modifying the objects they utilize as representations of the mixed fraction material they are studying.

This demonstrates that integrating PhET interactive simulations into mathematics learning not only enhances students' mathematical understanding of mixed fraction material but also significantly boosts student engagement. Students exhibit increased engagement in exploratory task involving the manipulation of simulated objects within the PhET simulation. Additionally, they actively participate in discussions with their peers while engaging in object exploration activities within the PhET simulation.

The outcomes of this study indicate that the utilization of PhET interactive simulations holds promise for enhancing students' mathematical understanding of mixed fractions. This assertion is substantiated by the demonstrable improvement evident in the results of students' mathematical understanding tests, which were administered sequentially at the pre-cycle, cycle I, and cycle II stages. These findings resonate with the research who have underscored the capacity of interactive simulations to bolster students' conceptual understanding (Nzabahimana, 2021; Hernández et al., 2020). Additionally, Yeh et al. (2019) have empirically demonstrated that the incorporation of interactive simulation media can enhance students' competencies, particularly in the domains of mathematical problem-solving and word problems. Furthermore, Adams (2010) has affirmed, through his research, that PhET Simulations can serve as an efficacious pedagogical tool for nurturing students' conceptual grasp, provided they are thoughtfully integrated with appropriate guidance from the teacher, who assumes the role of a learning facilitator. Meanwhile, according to the findings elucidated by Uwamahoro et al. (2021), PhET Interactive Simulation exhibits the potential to significantly enhance students' mathematical understanding, specifically within the area of mixed fractions.

Consequently, the integration of PhET interactive simulations in the instructional framework may prove advantageous for educators seeking to bolster students' mathematical understanding. Furthermore, the research findings underscore that the incorporation of PhET Interactive Simulation in mathematics learning can engender increased student engagement in the learning process. In alignment with these findings, Buteau et al. (2016) have emphasized the efficacy of interactive simulations in enhancing student engagement through active, exploratory activities designed to cultivate a deeper understanding of mathematical concepts. These explorations, facilitated by interactive simulations and guided through well-crafted conceptual questions, empower students to actively investigate and indirectly participate in enhancing their understanding of the mathematical principles under study (Adams, 2010). Integrating a PhET interactive simulation for mathematics education requires a thoughtful approach that focuses on both pedagogical effectiveness and user experience. Regularly solicit feedback from educators and students to refine and enhance the simulation's educational impact. As educators, we are encouraged to consider the integration of PhET interactive simulations into our instructional practices, acknowledging its potential to enhance students' mathematical understanding and engagement.

CONCLUSION

Based on the analysis of the data and the elucidation provided in the preceding section, this research concludes that the integration of PhET Interactive Simulations in the context of mathematics instruction has the potential to enhance students' mathematical understanding, particularly in the realm of mixed fractions. The notable enhancement in students' performance on mathematical understanding assessments across the pre-cycle, cycle I, and cycle II phases underscores the efficacy of PhET Interactive Simulations in facilitating the understanding of intricate mathematical concepts. These findings align with earlier research, which has consistently demonstrated the capacity of interactive simulations to significantly enhance students' grasp of conceptual material. Therefore, it is advisable for pedagogical approaches in mathematics education to continue advocating for the development and integration of educational technologies, such as interactive simulations, aiming to enrich students' learning experiences and enhance their understanding of pivotal mathematical concepts. Furthermore, there is room for further investigation to delve into the enduring impact of PhET Interactive Simulations on students' conceptual understanding over an extended period, as well as its influence on student engagement and motivation in the pursuit of mathematical knowledge. In conclusion, PhET Interactive Simulations have the potential to significantly enhance students' mathematical understanding, particularly in the context of mixed fractions. Through the effective integration of these simulations into mathematics instruction and by following the recommended strategies, educators can empower students to develop a strong comprehension of mixed fractions and related mathematical concepts.

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