

Understanding Simple Fractions Through STEAM-Integrated Game-Based Learning Supported by PhET Simulations in Primary School

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ABSTRACT

This study aims to evaluate the effect of STEAM-integrated game-based learning supported by PhET simulations on fourth graders' conceptual understanding of simple fractions. This study employed a pre-experimental design with a pre- and post-test design involving 27 fourth-grade students from a public elementary school in Pekanbaru, Indonesia. Data were collected using a simple fractional conceptual comprehension test and analyzed using paired sample t-tests and N-Gain scores to measure the significance and effectiveness of treatment. Findings showed a significant improvement in students' conceptual understanding after the implementation of STEAM-integrated game-based learning supported by PhET simulations. The N-Gain indicates a moderate level of effectiveness. These findings suggest that the use of STEAM-integrated game-based learning supported by PhET simulations can create an engaging and interactive learning environment, thereby improving students' conceptual understanding of simple fractions.

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INTRODUCTION

Mathematics is made up of abstract and hierarchical concepts, so understanding concepts at the lower levels of education is necessary to understand the concepts on them (Yang et al., 2021). Students are expected to be able to use mathematical knowledge to solve a variety of real-world problems (Arthur, Owusu, Asiedu-Addo, et al., 2018; Jacint & Carreira, 2023). However, numerous students face challenges in mastering mathematical concepts if the material is not represented (Mangarin & Caballes, 2024). To represent it, an intermediary is needed a media that can interpret abstract concepts to students. One topic that requires media is simple fractions, because a solid understanding of fractions will result in a firm grasp of the subject. (Chn et al., 2024; Dalimunthe et al., 2025; Reinhold et al., 2020).

Students face a number of problems when learning mathematics due to the abstract material and curriculum demands. These problems lead to unmotivated students to learn (Bimenyimana & Uworwabaye, 2022; Hossein-Mohand & Hossein-Mohand, 2023; Q. Li et al., 2021; Obut et al., 2023). Moreover, the classroom atmosphere tends to be boring because teachers only present the material in the book conventionally and do not pay attention to the expected learning outcomes. The results of the 2022 International Student Assessment Program (PISA) illustrate a significant decline in the academic achievement of Indonesian 2 children, which ranks 64th out of 81 countries with an average score of 366, far below the OECD (Organisation for Economic Cooperation and Development) average score of 500 (OECD, 2023).

One of the crucial topic in mathematics for elementary school students is fractions since a good understanding of fractions will help them in learning further concepts at a higher level (Abidovich et al., 2024; Arthur, Owusu, & Asiedu-addo, 2018). In addition, the concept of fractions is highly beneficial in solving various problems in daily life. Therefore, it is essential for elementary school students to comprehend this material. Some examples of common misconceptions among students are as follows 1) properties of whole numbers can be applied to fractions, 2) the longer is larger (the larger numerators and denominators) is the larger fractions, 3) numerator and denominator are separate values, two separate whole numbers, 4) the numbers in numerator and denominator should be compared separately rather than considering the whole fraction, 5) operation rules for natural numbers can be applied to operations with fractions, 6) the value of the fraction increases when either the numerator or the denominator increase, 7) the unit is the smallest fraction, 8) multiplication always makes the number bigger and division always makes the number smaller, 9) fractions have unique successors (does not understand infinity and density) (Hea-Jin & Irina, 2015; Lee & Boyadzhiev, 2020; Vamvakoussi & Vosniadou, 2010).

In light of this, a learning method or strategy is required to make learning more enjoyable which is game-based learning. Therefore, this game-based learning method is used for mathematical concepts such as fractions (L. Zhang et al., 2020). The goal is to improve students' skills in understanding, manipulating, and applying fractional concepts in the real world. By using this method, students have the opportunity to learn actively and interact directly with the material. This learning method can improve understanding of fractions and create a fun learning environment by incorporating interesting elements. This method can help students understand mathematical material such as fractions in a more interesting and effective way. Game-based learning emphasizes that learning processes involving active interaction, direct participation, and elements of enjoyment can improve student comprehension (Adipat et al., 2021a). This method not only improves students' mastery of the material, but also enhance teamwork, problem-solving, and critical thinking skills (Mao et al., 2021).

In the context of STEAM education (Science, Technology, Engineering, Arts, and Mathematics), game-based learning becomes even more relevant because it supports interdisciplinary learning experiences that connect mathematics to real-world problem solving. Fractions, for example, are not only mathematical concepts but are also widely applied in science experiments, engineering design, measurements, and even artistic activities such as patterns and proportions. STEAM-integrated learning encourages students to view fractions as practical tools rather than abstract numbers, allowing them to connect mathematical understanding with technological applications and creative exploration. Thus, integrating STEAM principles into game-based learning can provide students with richer learning experiences that develop both conceptual understanding and broader competencies such as creativity and innovation

To effectively implement game-based learning within a STEAM-oriented classroom, interactive and innovative learning media are needed. One potential medium is the PhET

Simulation virtual laboratory, which provides an engaging digital environment for students to explore mathematical ideas through interactive simulations. Although PhET Simulation is a simulation medium, it has strong gamification elements, such as high interactivity, free exploration, instant feedback, and implicit goals that are highly supportive and can be integrated into game-based learning strategies. Therefore, PhET is not being used as a 'game' in the literal sense, but rather as an essential supporting medium in game-based learning strategies designed to improve conceptual understanding of simple fractions. The game elements of PhET Simulation will be utilized in learning scenarios.

The popular game elements of gamification used in gamification include 4 important parts namely points, badges, leaderboards, and challenges (Rodrigues et al., 2019; Wang et al., 2022). Gamification is closely related to the concept of game-based learning. Game-based learning refers to the achievement of learning outcomes through game and game content. Game-based learning also enhances learning through problem-solving and challenge spaces that give learners and players a sense of accomplishment (Krath et al., 2021). The application of STEAM in digital-based learning also has a positive impact on the learning outcomes of elementary school students (Hidayanthi et al., 2024). In line with this, this study aims to examine the effect of the application of STEAM integrated game-based learning supported by PhET simulations on the understanding of elementary school grade IV students about simple fractions.

LITERATURE REVIEW/ THEORETICAL FRAMEWORK

The literature review discusses the theoretical foundations underlying students' understanding of simple fractions and the use of STEAM-integrated Game-Based Learning supported by PhET simulations. The discussion covers students' understanding of fractions, cognitive development in learning fractions, Game-Based Learning, STEAM in learning, PhET Simulation as an interactive learning medium, and the integration of these approaches for learning fractions.

Simple Fraction Understanding: Theoretical Foundations

Among the math materials studied in elementary school, fractions are one of the most important for students to understand in order to understand further theory at higher grade levels. In addition, the concept of fractions is very useful for solving daily issues (Baiduri, 2020). Therefore, as elementary school students, it is very important for them to be able to understand and master this fractional material. A fraction can be defined as a part of something whole (Sastry, 2023). In the illustration of the image, the part in question is the part that is usually marked with a scar. This part is called the numerator. The intact part is the part that is considered a unit and is called the denominator (Dewi et al., 2017; Moyo & Machaba, 2021). Fractions basically show multiple parts of the same number of parts. The whole number of equal parts is also considered a unit. Fractional learning requires professional skills, perseverance, attention, and seriousness considering that a dominant level of thinking can naturally reduce students' challenges (Abuasad et al., 2019; Dewi et al., 2017; Nurlela et al., 2025; Sukowati & Masduki, 2024; Wulandari & Alyani, 2022).

Teaching fractions not only transfers mathematical ideas, methods and concepts, but defines fractions as a process of origin, occurrence and development (Obersteiner et al., 2018). It starts by connecting a math topic to real life, known as a contextual approach. Students build their own mathematical concepts. Based on this explanation, understanding the concept of fractions is critical for elementary school students as it is the foundation for various mathematical materials and a skill required in daily life (Fitriani, 2022; Ruqoyyah et al., 2025). Students are considered to have understood the concept of fractions if they can use them in various situations, such as stating, distinguishing, providing examples, and solving real-world problems. This understanding is built

by making connections between new information and existing knowledge. Therefore, methods are needed that convey mathematical concepts and describe fractions as a process of formation and development in order to gain a deep understanding. Thus, mastery of fractional material becomes an important foundation for students' success in mathematics and its application in daily life (Ruqoyyah et al., 2025; Yuniara et al., 2020).

Teaching the concept of fractions to elementary school students requires a simple and fun approach. Fractional learning can begin with concrete activities that allow students to see the relationship between parts and wholes (Abidovich et al., 2024; Moyo & Machaba, 2021; Putra et al., 2021). For example, a round tart can be used as a tool to introduce fractions. "If there is a round tart (if possible, an actual tart). We cut this tart into four equal pieces (exactly equal). Then we eat one piece of the tart. We call the size of one piece of the tart a quarter, or a quarter written as $\frac{1}{4}$."

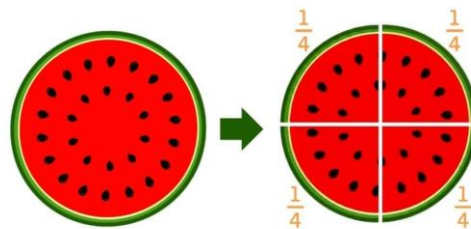


Figure 1 Fraction Concept

Then, if a watermelon is cut into six equal parts, then the piece of tart is called one-sixth, and one-tenth if it is cut into ten equal sized pieces. Comparing simple fractions is also important in strengthening the understanding of fractional concepts. Comparisons can be made through the representation of images with shaded areas.



Figure 2 (a) Visual Shade and $\frac{1}{2}$ (b) Visual Shade $\frac{1}{4}$

As figure 2 (a) the shaded area is 1 of 2 parts, then the shaded area shows the fraction $\frac{1}{2}$. The fraction symbol $\frac{1}{2}$ is read one-half. Then, for figure 2 (b) the shaded area is 1 of 4 parts, then the shaded area shows the fraction $\frac{1}{4}$. Fractional symbols $\frac{1}{4}$ read a quarter. This proves that $\frac{1}{2}$ greater than $\frac{1}{4}$. The fraction comparison can be written $\frac{1}{2} > \frac{1}{4}$.

Cognitive development in understanding fractions

Cognitive development can be interpreted as changes and growth in a person's thinking ability to understand, process, remember, and use information (Babakr et al., 2019; Oktaviani et al., 2023). According to the theory of cognitive development put forward by Piaget, elementary school-age students, especially the lower to middle grades, are at a concrete operational stage (Yanti et al., 2024; J. Zhang, 2022). At this stage, the students' way of thinking is still highly dependent on real objects, visuals, and activities that involve students directly. They are not yet fully able to think abstractly, so understanding complex mathematical concepts such as fractions will be a challenge for students. Fractions involve not only numbers but also the relationship

between parts and wholes, which for children is abstract if they are only presented in the form of number symbols.

Students who are 7-11 years old are in a concrete operational period (Faqih et al., 2024; Yanti et al., 2024). Because of this, students at this stage need visual and manipulative media that can help them observe, touch, move, or manipulate representations of fractions. Manipulative media such as folding paper, splinter blocks, splinter circles, or whole section models allow children to build understanding through hands-on experience. Meanwhile, interactive digital media such as PhET Simulation provide dynamic visualizations such as zooming in and out of parts, changing the shape of representations, and showing directly how a whole can be divided into specific parts. In addition to the need for concrete media, fractional learning also requires the use of various forms of representation. Children need to connect various forms of representation in order to build a comprehensive understanding of concepts ranging from direct experience, visualization, to mathematical symbols (Jäder & Johansson, 2025; Tiwari et al., 2021).

One approach that emphasizes this is concreteness fading. This approach uses representations arranged from the most concrete to the most abstract, as Bruner's theory puts forward, in concreteness fading, the concept is introduced through three stages: (1) Enactive, i.e. using physical or concrete models; (2) Iconic, i.e. using images or visual models; and (3) Symbolic, namely using mathematical notation. This gradual approach helps elementary school students connect real experiences with abstract symbols more easily (Chatain et al., 2025; Wildaniati, 2024). Presenting these three types of representation is very important because the concept of fractions cannot be understood through numbers alone. The child needs to see how the "half" looks visually, how it can be divided or changed, and then relate it to mathematical symbols. Multiple representations help students internalize the concept of fractions more strongly, especially in understanding equivalence, fraction comparison, and relationships between parts. Thus, visual, manipulative, and multiple representation media are not only complementary, but are the main needs for elementary school students (Zuhri et al., 2023). Interactive media such as PhET play an important role as a bridge between concrete experiences and abstract understanding, thus allowing students to build the cognitive structure necessary to understand fractional concepts.

Game-Based Learning in Mathematics

Game-based learning is a learning approach that integrates elements of play into the learning process to increase student motivation, engagement, and understanding of the material (Adipat et al., 2021b; Tiwari et al., 2021). In game-based learning, students learn through play activities designed with specific learning objectives in mind. The games used can be in the form of digital or non-digital games, with scenarios and rules that encourage students to think critically, solve problems, and actively interact with learning materials (Anastasiadis et al., 2018; Hui & Mahmud, 2023; Zheng et al., 2024). Game-based learning allows teachers to use games as an engaging, fun, challenging, and interactive means of learning. Through play activities, students gain meaningful learning experiences as well as opportunities to experiment, find solutions, and understand scientific concepts in depth (Adipat et al., 2021b; X. Li & Kangas, 2024). Game-based learning is a term that refers to a learning environment in which game content or games are used to improve learners' knowledge and skills (Banihashem et al., 2023; Hu, 2024; Hwang & Chen, 2022). In-game activities give players a sense of accomplishment through the process of problem-solving and challenge solving (Anunpattana et al., 2021).

Game-based learning allows students to learn through experiential learning by providing opportunities to try different ways of making decisions and achieving game goals (Hermita et al., 2021; Hu, 2024; Yeh et al., 2019). In addition, game-based learning also helps students to learn

applying theoretical knowledge in a simulated environment. Through emotional expression, active engagement, and immersion in the context of the game, students can more easily understand and remember learning topics and contexts (Jääskä et al., 2021). In-game play activities that involve movement, exploration, and problem-solving can help students learn as well as develop critical thinking skills. In the modern learning era, educational games are considered an interesting and fun way to help students understand lesson concepts (Cheung & Ng, 2021; Suritno et al., 2021; Usman et al., 2024). The purpose and benefits of the application of game-based learning are to provide opportunities for students to acquire a wide range of knowledge and skills, such as understanding dynamic principles, processes, and structures; ability to solve problems, make decisions, work together, and build discipline (Sun et al., 2023).

In addition, game-based learning also develops communication skills, collaboration, and adherence to game rules that naturally shape students' disciplined attitudes (Christopoulos & Mystakidis, 2023). Thus, game-based learning not only serves as a media of entertainment, but also as a learning approach that fosters intrinsic motivation and high-level thinking skills. The concept of game-based learning emphasizes the idea that learning involving active engagement, direct involvement, and enjoyment during the learning process can help students grasp the material effectively. Game-based learning can help students learn to make important conclusions, especially considering the knowledge that requires conclusions and establishing processes that are important for decision-making (Kusumawardani et al., 2018; Wardoyo et al., 2021). Game-based learning is also used to convey material through various game activities in a way that makes students enjoy the learning process.

It can be concluded that game-based learning is a learning strategy or model that utilizes games. Effective to improve students' knowledge and skills through a fun gaming experience. Game-based learning facilitates active learning, improving problem-solving and decision-making skills. The six main principles that Karl M. Kapp always emphasizes in designing game-based learning include: (1) focus of learning objectives, (2) meaningful game mechanics, (3) story or narrative, (4) providing immediate feedback, (5) safe environment for failure, and (6) learner-centre design. These principles help ensure that games are entertaining and effective as the means of learning (Kapp, 2012). These principles were later expanded by several later researchers, such as Qian and Clark (2016) and Hamari (2014) into eight main principles by adding aspects of active learning, collaboration, reflection, and motivation as reinforcement of Kapp's initial ideas. In the implementation of game-based learning, systematic stages are needed so that the learning process through games can take place effectively. Kapp (2012) emphasizes the importance of context, narrative, and reflection as key components in game-based learning. Three main phases in the game-based learning process, namely preparation (pre-game), gameplay, and debrief (Kiili, 2005). The 12 stages are then adjusted to the principles of game based learning according to Kapp (2012) to ensure that each phase not only focuses on playing activities, but also on achieving learning objectives and strengthening student understanding.

STEAM in Learning

STEAM (Science, Technology, Engineering, Arts, and Mathematics) is an interdisciplinary learning approach that integrates different fields of science to create meaningful and contextual learning experiences (Hidayanthi et al., 2024; Sasmita et al., 2025). STEAM-based learning, students are directed to actively explore real-world problems; students will connect concepts across disciplines and build understanding through hands-on activities. This approach is closely related to constructivist learning theory, where knowledge is built through interaction, inquiry, and reflection rather than passive memorization. This is what makes the implementation of STEAM-based

learning effective for elementary school-age students, because it will support students for active learning, critical thinking, creativity, and training students to improve their problem-solving skills.

Through STEAM learning, it is possible to make abstract material concepts that can be learned more concrete because they are linked and relevant students' daily lives (Anugraheni et al., 2025; Muntazah et al., 2025). Then, the integration of technology and engineering will support students to explore through activities such as simulation and designing according to assignments, while for art students will create and visualize mathematical ideas. For example, in learning simple fractions, students can develop understanding through contextual activities such as measurement, object division, and visual modeling, supported by interactive digital media. Thus, STEAM learning not only strengthens students' conceptual understanding but also enhances their ability to apply mathematical knowledge in practical situations.

In the context of the studies studied in this chapter, simple fractional material will be studied through a PhET simulation which is an interactive simulation. Through this simulation of PhET associated with STEAM, students will learn the concepts of fractions in a more concrete way, as there will be hands-on visualization and exploration. The use of this simulation allows students to observe the relationship between parts and wholes, compare fractional values, and conduct experiments directly in an interactive digital environment. Thus, the integration of technology in learning is expected to help students understand the concept of fractions more deeply and increase their involvement in the mathematics learning process.

PhET Simulation as an interactive learning media

PhET Simulation is a research-based interactive simulation software that is available for free and can be accessed through the <https://phet.colorado.edu> page founded by Carl Wieman under the University of Colorado's institution of higher education. PhET Simulation is an interactive learning tool that enables students to visualize abstract mathematical and scientific concepts through dynamic, real-time simulations. Interactive digital media like PhET can enhance students' conceptual understanding by linking symbolic representations with visual models (Ajayan et al., 2025; Samitra et al., 2023). Simulation-based learning environments foster deeper conceptual comprehension and inquiry skills because students can manipulate variables freely and observe the effects immediately (Banihashem et al., 2023). In addition, it aims to ensure continuity and effective education. PhET Simulation is designed to support the learning process; students can use the PhET Simulation application in a virtual lab to demonstrate their ideas by emphasizing the relationship between some sciences and the real world. PhET Simulation offers interactive simulations that aid teaching and learning in a variety of subjects, including mathematics using visual and interactive experiences that make abstract concepts more accessible (Kumar, 2024; Perkins et al., 2006).

PhET Simulation allows students to explore fun simulations and gain an understanding of science. In addition, because it has elements of images and animations, students can respond or use media as a virtual experiment helper. The learning process using PhET Simulation is to study certain materials directly independently using a computer that is already equipped with the PhET program. The use of PhET Simulation media will certainly be able to invite and support students to be more interested in learning simulations on their respective computers, students will feel like they are playing games when in fact they are building their knowledge when using the PhET Simulation media application that has been programmed on the computer they are using in learning (Hasbullah et al., 2025; Ismalia et al., 2022; Pranata, 2024). By using PhET Simulation as a mediator, student learning outcomes can be improved. Students will be more active while learning and more motivated to learn because PhET Simulation offers a unique and engaging learning

process. The improvement of student learning processes and outcomes with this simulation can be seen from the learning process and increased learning outcomes (Kaysi, 2025).

PhET Simulation allows students to connect real-world phenomena with basic science, improve their understanding of fractions, and increase their interest in mathematics (Assawaphum et al., 2023; Dwiyantri & Nurafni, 2023). PhET Simulation is an interactive learning media designed to help students understand abstract concepts through hands-on visualization and manipulation (Haryadi & Pujiastuti, 2020; Jamali et al., 2025). Through dynamic simulations, students can change variables, move objects, or see changes in real time, making the learning process more interesting and easier to understand. The PhET simulation on fraction learning allows students to visually see the relationship between parts and wholes, try various forms of representation, and learn through exploration. In the context of this study, through the PhET simulation, students can directly see, change, and modify fraction material. In this manner, PhET not only increases student engagement but also assists in building a stronger conceptual understanding.

STEAM Integrated Game-Based Supported by PhET Simulation for Learning Fractions

Integrating STEAM in 21st-century learning is quite important. Through the application of STEAM in the learning process, this will help students to improve their critical thinking, creativity, and problem-solving skills (ElSayary, 2025; Ichsan et al., 2024; Sasmita et al., 2025). Through this approach, learning does not only focus on remembering but also on how concepts can be applied in daily life. Through STEAM, students will carry out learning by exploring, experimenting, and interacting directly with the material taught. One strategy that can support the implementation of STEAM is the integration of interactive technology and engaging learning models, such as game-based learning and simulation-based environments (Hu, 2024; Qian & Clark, 2016; Yeh et al., 2019).

Game-based learning and PhET simulations are believed to be an approach that is able to create a much more dynamic, interactive, and meaningful learning environment for students (Byusa et al., 2022; Diab et al., 2024). This merger does not only present games as a means of entertainment but also makes games a forum to apply academic concepts through direct experience. In this study, PhET Simulation does not only serve as a visual aid or complementary medium but rather becomes an important part of game design. Simulations can be incorporated into a variety of challenges, levels, or missions, so students must utilize natural science or math concepts to solve problems, make decisions, or achieve specific goals (Haryadi & Pujiastuti, 2020; Kumar, 2024). This approach makes learning activities feel more natural because students not only receive the material but also actively use it in the context of the game.

PhET also provides fast and clear feedback through motion visualization, variable changes, and numerical data displayed in real-time. This hands-on feedback helps students understand cause-and-effect relationships, see patterns, and build a stronger conceptual understanding of concepts that are initially abstract (Drastisianti et al., 2024; Umiliya et al., 2023). In addition, the variable manipulation feature in the simulation allows students to conduct safe and flexible virtual experiments, allowing them to explore, explore various possibilities, and discover concepts through an *inquiry-based* learning experience (Bahtiar et al., 2024; Lamina, 2019). Thus, the combination of *game-based learning* and PhET Simulation not only increases motivation through game elements, but also deepens students' understanding of the subject matter. Direct interaction with simulations makes the learning process more active, contextual, and meaningful and supports the development of better scientific thinking and problem-solving skills.

PhET Simulation can be integrated into a challenge or mission game, where students must use their scientific knowledge and skills to solve problems to achieve a specific goal (Jamali et al.,

2025; Perkins et al., 2006; Sari et al., 2024). The feedback provided by PhET Simulation, both in the form of visualizations and numerical data, helps students understand abstract concepts concretely and build a deep conceptual understanding. In addition, these simulations facilitate the exploration and discovery of scientific concepts through virtual experiments, where students can manipulate variables and observe results firsthand. Thus, this combination not only increases students' motivation through the game elements, but also enhances their understanding of the subject matter through direct interaction with the PhET simulation.

PhET simulations, when combined with game-based learning principles, offer visualization, hands-on feedback, and exploration opportunities not found in conventional learning. These features help bridge the transition from concrete to abstract representations, reduce misconceptions, and increase student engagement and confidence in understanding fractions (Latifah & Ressa, 2025; Samitra et al., 2023; Sari et al., 2024). Nonetheless, the effectiveness of these media is highly dependent on proper pedagogical design and how teachers' direct exploration, assign meaningful assignments, and create space for students to reason from what they observe. Then, to make learning more meaningful, it will be integrated with STEAM. The approach associated with STEAM will make learning more meaningful, especially in fractional materials (Muntazah et al., 2025; Sasmita et al., 2025; Ulya et al., 2025).

This simple fractional learning will be taught through a blend of STEAM-based and game-based learning supported through PhET simulations. Through this application, students will not only know fractions as mathematical symbols, but they will also understand them as something real and close to their daily lives. This interdisciplinary interconnectedness will make students' understanding more complete, because they will see how the concept of fractions is real. Then, this STEAM approach encourages students to be active during the learning process; students are invited to experiment, explore, and face problems directly so that knowledge is really built from their own experiences. In the end, this combination is expected to be able to improve students' conceptual understanding of fractions while honing critical thinking, creativity, and reasoning skills that are the main demands in mathematics learning in the 21st century (Aryani et al., 2025; Qudwatullathifah et al., 2021; Susanti et al., 2025).

To create a richer and more meaningful learning environment in fractional learning, all aspects of learning need to be considered comprehensively. The digital tools used should not only convey material, but also stimulate curiosity, support the problem-solving process, and help students see mathematics as a field that can be explored, not just memorized. With planned and targeted implementation, STEAM Integrated Game-Based Learning Supported by PhET Simulations has great potential to strengthen conceptual understanding and encourage students to become more proficient in numeracy, confident, and motivated to explore mathematical ideas in depth.

METHOD

This section describes the research design, participants, data collection procedures, research instrument, and data analysis used to examine the effect of STEAM-integrated Game-Based Learning supported by PhET Simulations on fourth-grade students' conceptual understanding of simple fractions.

Research Design

This study employed a pre-experimental design using a one-group pretest-posttest design. The study was conducted to examine changes in fourth-grade students' conceptual understanding of simple fractions before and after the implementation of STEAM-integrated Game-Based Learning supported by PhET Simulations.

Participants

This study was conducted in one public elementary school in Pekanbaru, Riau, Indonesia, during the odd semester of the 2025/2026 academic year. The participants consisted of 27 fourth-grade students. One class was selected purposively based on the school's readiness and the availability of equipment required to implement PhET Simulation. All students in the selected class participated in the study; therefore, total sampling was applied within the selected class.

Data Collection and Research Instrument

Data were collected using a test of students' conceptual understanding of simple fractions. The test consisted of multiple-choice questions. Before being administered to the fourth-grade students, the test items were tried out on fifth-grade students to examine the quality of the instrument. The final test consisted of 23 valid items. The difficulty level of the test items was analyzed before the test was administered to the research participants. The results showed that 8 items were categorized as difficult, 19 items as moderate, and 3 items as easy. The distribution of the difficulty level is presented in Table 1.

Table 1. The difficulty level of each question item

Value (p)	Category	Question Number	Total
0,00 – 0,30	Difficult	3, 5, 10, 14, 22, 26, 29, 30	8
0,31 – 0,70	Moderate	2, 4, 6, 7, 9, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 23, 24, 25, 28	19
0,71 – 1,00	Easy	1, 8, 27	3

Before the research is carried out, we also prepare learning tools that will be used by students during the learning process, namely in the form of teaching modules and student worksheets. We carried out this research for five meetings. The schedule for the implementation of the research can be seen in table 2.

Table 2. Implementation Schedule

No.	Day/Date	Activities
1	Monday/11 August 2025	Pretest
2	Wednesday/13 August 2025	Learning 1
3	Wednesday/20 August 2025	Learning 2
4	Monday/25 August 2025	Learning 3
5	Wednesday/27 August 2025	Posttest

The first meeting was the pretest, conducted on August 11, 2025. The second, third, and fourth meetings were learning sessions conducted on August 13, August 20, and August 25, 2025, respectively. The fifth meeting was the posttest, conducted on August 27, 2025. The learning intervention was implemented in three sessions using STEAM-integrated Game-Based Learning supported by PhET Simulations.

Each learning session followed the Game-Based Learning stages proposed by Kiili (2005), namely preparation, gameplay, and debriefing. The learning activities also incorporated the

principles of Game-Based Learning proposed by Kapp (2012), including meaningful narrative, collaboration, immediate feedback, and learning reflection. At the beginning of the study, students completed a pretest to identify their initial understanding of simple fractions. After participating in the three learning sessions, students completed a posttest to measure their conceptual understanding following the intervention.

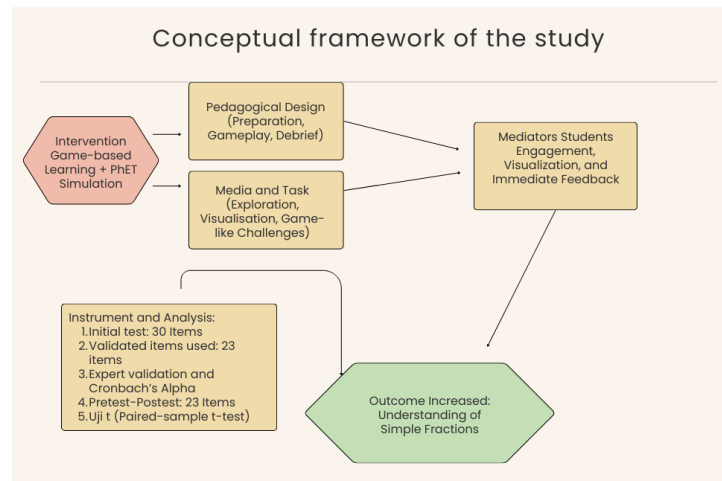


Figure 3. Conceptual framework of the study

Data Analysis

The data were analyzed using IBM SPSS Statistics 31. Descriptive statistics were used to describe students' pretest and posttest scores. The Shapiro-Wilk test was conducted to determine whether the pretest and posttest data were normally distributed as a prerequisite for the paired-sample t-test. A paired-sample t-test was then conducted at a 5% significance level to determine whether there was a statistically significant difference between students' pretest and posttest scores.

N-Gain analysis was also conducted to determine the level of improvement in students' conceptual understanding of simple fractions after the implementation of the learning intervention. In addition, item analysis was conducted to examine the quality of the test instrument, including item difficulty, discrimination, and internal reliability using Cronbach's Alpha.

RESULTS

The results show a significant improvement in students' understanding of simple fractions after the implementation of STEAM Integrated Game-Based Learning supported by PhET simulations. The Shapiro-Wilk test confirms that pretest and post-test scores are distributed normally, allowing the use of parametric testing. Paired sample t-tests revealed statistically significant differences between pretest and posttest scores, suggesting that the intervention effectively improved student learning outcomes. In addition, the analysis of normalized gains (N-gains) shows an average score of 0.3153, which falls into the moderate category, indicating a significant level of improvement.

Implementation of STEAM Integrated Game-Based Learning Supported by PhET

The implementation of learning was carried out in three lessons, each following the stages of preparation, gameplay, and debriefing based on a game-based learning design integrated with the PhET Simulation.

Lesson one: Understanding Simple Fractions

The first lesson focused on the introduction of the concept of simple fractions through the game "Fraction Chef's Magic Kitchen." At the beginning of the activity, the teacher explained the learning objectives and, at the same time, introduced how to use the PhET Simulation so that students feel comfortable before starting the exploration. As the game progresses, students manipulate various visual models to understand the relationship between parts and wholes and try to create equally large divisions, as well as complete initial challenges that require them to recognize basic fractions such as halves, thirds, and quarters. The introduction to the use of PhET simulations is an effort to make students feel familiar and ready before further exploration; this is part of the technology element in the application of STEAM.

Simulations provide immediate feedback, so students can immediately see and correct their misunderstandings. After the game, the teacher invites students to share their findings, discuss strategies, and correct misconceptions that arise about fractional representation. This is part of the science element, where students will conduct experiments and observations. As a form of appreciation, each group gets a worksheet with a star badge, and the group with the best performance is given a small prize to keep motivation and the learning atmosphere enthusiastic.



Figure 4. Students use the PhET simulation "Intro Fractions" to visualize simple fractions

Figure 4 shows students interacting with the PhET simulation "Fractional Intro" directly. During the first lesson, students explored how the whole can be divided into equal parts and represented visually as simple fractions. This activity helped students build an initial understanding by connecting the visual fraction model with its symbolic shape. Students also identified basic fractions such as half, third, and quarter, which form the basis for the next lesson. At this stage of the game, students can manipulate various visual models to understand simple fractions and try to tinker with the challenges given. This is part of mathematics as well as engineering in the STEAM stage.

Lesson two: Identifying and Determining Equivalent Fractions

In the second lesson, the focus of learning shifted to understanding the relationship between numerators and denominators in equal fractions. At the preparation stage, the teacher reviewed the simple fractions and introduces the concept of equality. During gameplay, students worked on fraction mission cards and continue to use the PhET simulation "Fractions: Intro" to build equivalent fraction models. They then used the game "Fraction Matcher" to reinforce their understanding through matching tasks with live feedback. Through the application of this model, students were not only trained to understand the concept of mathematically valued fractions, but also develop critical thinking, collaboration, and problem-solving skills through game-based

learning experiences. In the debriefing phase, students reflected on the patterns they observed and clarified why different fractions can represent the same value. Similar to the first lesson, a star badge was used as a game indicator on a student's learning worksheet, and the group with the best results received a reward to support engagement during the game.



Figure 5. Use of the PhET “Fraction Matcher” game in Lesson 2 to reinforce equivalent fraction concepts.

Figure 5 shows how students start trying out the PhET game “*Fraction Matcher*” after they complete the mission card. At this stage, they were not only playing, but completely re-examining their understanding of fractional equality. Each answer was directly fed feedback by the simulation, so students can see whether or not the two fractions they matched are of equal value. This process helps them test ideas, correct mistakes, and reinforce concepts in a more fun and interactive way, as if they were learning while playing.

Lesson three: Addition and Subtraction of Fractions

The third lesson focused on the ability of students to perform addition and subtraction operations with fractions, either with the same or different denominators. In the preparation stage, the teacher reviewed the equivalent fractions and explained that these concepts would be used to solve the problem of addition and subtraction. During gaming, students worked on assignments in learning worksheets and used PhET simulations to perform operations with the same and dissimilar denominators. This learning aims to not only understand the concept of procedural addition and subtraction of fractions, but also be able to visualize them through PhET simulations and relate them to real-life contexts in a fun way. The simulation guided them to generate equivalent fractions before adding or subtracting, allowing them to visualize each step and correct errors through real-time feedback. In the debriefing phase, students discussed the strategies they used and reflect on the importance of converting fractions into equivalent forms when completing fraction operations. As in the previous lesson, symbolic game badges and small prizes were awarded to the most successful group, which helped maintain student motivation and participation.

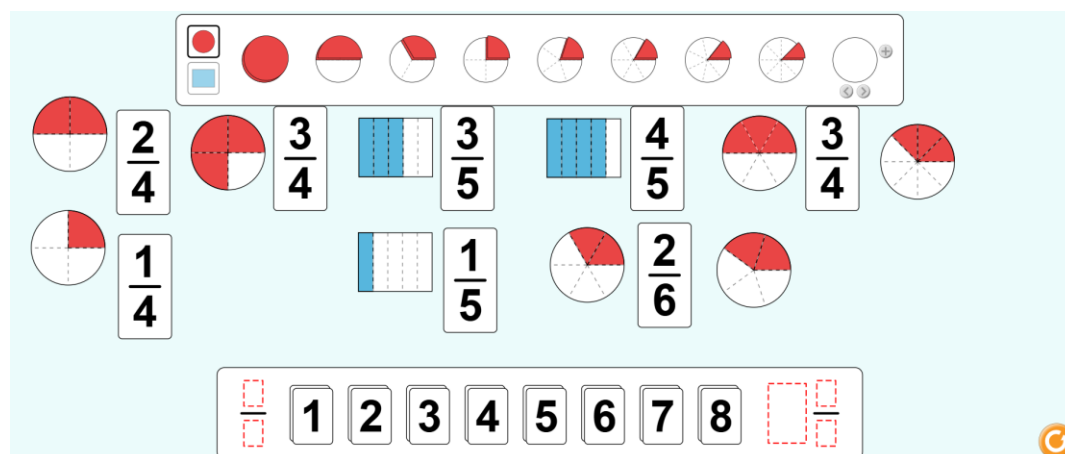


Figure 6. Students using the PhET Simulation to perform addition and subtraction of fractions in lesson 3.

Figure 6 shows students working with fractions and visualizing them in the PhET Simulation in Lesson 3. Through this visual environment, students can convert fractions into equivalents and perform addition and subtraction more systematically. This activity supports the development of procedural fluency while maintaining conceptual understanding.

Application of Game-Based Learning Principles

The implementation of the three learning sessions incorporated the main principles of Game-Based Learning proposed by Kapp (2012). First, clear goals and rules were provided at the beginning of each session so that students understood the learning objectives, game missions, and reward system. Second, challenges and progress were designed progressively, from identifying simple fractions to equivalent fractions and fraction operations. Third, meaningful gameplay required students to apply fraction concepts while completing missions using PhET Simulations. Fourth, immediate feedback was provided through the PhET simulations, allowing students to identify and correct their responses. Finally, motivation and rewards were supported through star badges and small rewards for successful groups.

Descriptive Analysis

The descriptive analysis was conducted to examine the students' pretest and posttest scores after the implementation of STEAM-integrated Game-Based Learning supported by PhET Simulations. The analysis included the number of participants, minimum and maximum scores, mean scores, and standard deviations.

Table 3. Results of descriptive analysis

	N	Minimum	Maximum	Mean	Std. Deviation
Pre-test	27	30	65	44.93	10.099
Post-test	27	48	83	62.30	8.969

Table 3 shows that the mean score increased from 44.93 in the pretest to 62.30 in the posttest. The minimum score increased from 30 to 48, while the maximum score increased from 65 to 83. The standard deviation decreased from 10.099 in the pretest to 8.969 in the posttest. The individual pretest and posttest scores are also presented in Figure 7.

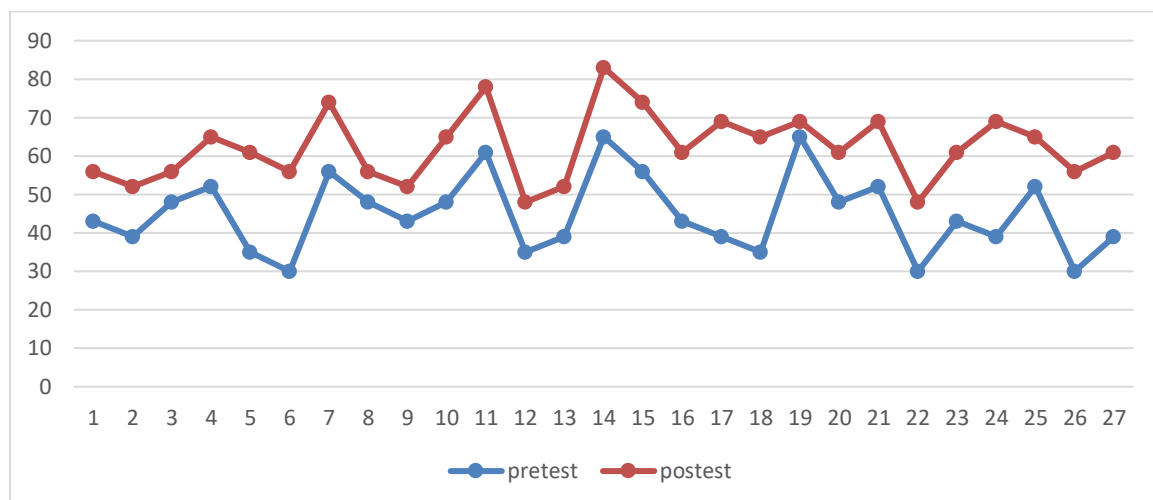


Figure 7. Presents the comparison of students' individual pretest and posttest scores. The scores show an increase in student' performance following the implementation of the learning intervention

Normality Test

Before conducting the paired-sample t-test, a Shapiro-Wilk normality test was conducted to determine whether the pretest and posttest data met the assumption of normality.

Table 4. Normality test

	Shapiro-Wilk		
	Statistic	df	Sig.
Pre-test	0.950	27	0.217
Post-test	0.965	27	0.467

Table 4 shows that the significance value for the pretest was 0.217 and that for the posttest was 0.467. Both values were greater than 0.05, indicating that the pretest and posttest data were normally distributed. Therefore, the paired-sample t-test could be conducted.

Hypothesis Test

A paired-sample t-test was conducted to determine whether there was a statistically significant difference between students' pretest and posttest scores.

Table 5. T-test results

	Mean	t	df	Sig. (2 tailed)
Pretest-Posttest	-17,30	-12,82	26	< 0,001

The paired-sample t-test resulted in a mean difference of -17.370, with $t = -12.842$, $df = 26$, and $\text{Sig. (2-tailed)} < 0.001$. When interpreted based on the direction of the scores, the mean score increased by 17.37 points from the pretest to the posttest. The significance value was below 0.05, indicating a statistically significant difference between students' pretest and posttest scores.

N-Gain Analysis

N-Gain analysis was conducted to determine the level of improvement in students' conceptual understanding of simple fractions after the learning intervention.

Table 6. N-Gain test results

Class	N-Gain Value (%)	Criteria
Experiment	31.53%	Moderate

The average N-Gain score was 0.3153 or 31.53%. This indicates a moderate level of improvement in students' conceptual understanding of simple fractions after the implementation of STEAM-integrated Game-Based Learning supported by PhET Simulations.

DISCUSSION

The findings of this study show that the implementation of the STEAM Integrated Game-Based Learning supported by PhET simulations has a significant positive impact on students' conceptual understanding of simple fractions. The results showed an increase in students' average scores from pretest to posttest, with an increase of 17.37 points. It identifies that PhET simulations can assist students in understanding simple fractions. PhET simulations make students think more critically and creatively (Doyan et al., 2023; Drastisianti et al., 2024; Salsabila et al., 2024). Through the application of PhET integrated with game-based learning, students are more motivated to learn (Pranata, 2024). In the context of this study, fractional material is taught by presenting lessons in the form of games where each student meeting is given a mission to solve.

Fractional learning packed with STEAM and games can create a more enjoyable learning atmosphere. Game-based learning environments can enhance learning by encouraging student motivation, engagement, and active participation (Fendrik et al., 2020; Kapp, 2012; Yeh et al., 2019). Experiential play environments support deeper conceptual learning because students are encouraged to explore, experiment, and reflect on their actions (Kiili, 2005). Improved student post-grading supports these theories, suggesting that game-based activities can help elementary school students understand the concept of fractions that are usually abstract and difficult to understand. The fractional material presented with a direct example simulation makes it easier for students to understand the concepts being taught.

The integration of PhET simulations also contributes significantly to the conceptual growth of students. As part of the Technology element in the STEAM framework, interactive simulations present dynamic visual representations so that abstract concepts become easier to understand. Interactive simulations provide visual and dynamic representations that simplify the understanding of abstract concepts (Batamuliza et al., 2024; Vegisari et al., 2020). In this study, the PhET Simulation helped students visualize the part-whole, equivalent fractions, and comparisons relationships more concretely, making abstract ideas in fractional learning more accessible. Digital interactive media improves the reasoning and understanding of elementary school students by offering multimodal representations (Chusna et al., 2024). In addition, the combination of STEAM Integrated Game-Based Learning supported by PhET simulations seems to address the common difficulties students face in simple fractional learning. Many students tend to memorize procedures without understanding the underlying concepts. However, the interactive nature of learning activities such as manipulating fractional models, competing in games, and receiving feedback directly allows students to build conceptual understanding through hands-on exploration.

Conceptual understanding develops when students are actively involved in reasoning and building knowledge (Ateş & Cataloglu, 2007; Hačatrjana & Namsone, 2024). The use of a game-based approach in mathematics can increase student motivation and participation (Byusa et al., 2022; Zheng et al., 2024). In this study, students became more enthusiastic, collaborative, and focused when learning through games and simulations. The use of STEAM Integrated Game-Based Learning supported by PhET simulations allows students to explore for themselves how fractions can be divided. Students can experiment and make their own hypotheses regarding how strategies

can be used in completing missions. Through this activity, students are also trained to be able to discuss with their group mates and find solutions to the problems presented. Such positive shifts in learning behaviors are likely to contribute to their improved performance in the posttest, resulting in an increase in student learning outcomes. The integration of STEAM in math learning encourages students to actively build understanding through hands-on experience (Ichsan et al., 2024; Muntazah et al., 2025).

However, N-Gain scores are showing that even if the intervention is effective, some students may still need additional support. Factors such as limited experience with digital tools, varying levels of math readiness, and differences in learning speed may have affected overall effectiveness. Prior to this study, most students had little or no experience using Chromebooks or interactive digital media, which means they need additional time to adapt to the learning environment. This is in line with Hamari et al., (2014) and Qian & Clark, (2016), who noted that successful game-based learning requires familiarity with digital interfaces and adequate scaffolding.

Overall, the discussion showed that STEAM Integrated Game-Based Learning supported by PhET simulations is a promising approach to improving elementary school students' conceptual understanding of simple fractions. These findings underscore the importance of integrating interactive and exploratory learning tools in mathematics teaching, especially for abstract and challenging concepts for young learners.

CONCLUSION

This study concludes that the integration of STEAM-integrated game-based learning supported by PhET simulations has a significant positive effect on fourth-grade students' conceptual understanding of simple fractions. The statistical analysis shows a substantial increase in students' scores from the pretest to the posttest, with a gain of 17.37 points, and the paired sample t-test confirms that this improvement is statistically significant. The N-Gain score of 0.3153, categorized as moderate, indicates that the learning intervention was reasonably effective in enhancing students' conceptual understanding. The findings demonstrate that STEAM-integrated game-based learning supported by PhET simulations creates an enjoyable and interactive learning environment that increases students' motivation and engagement in mathematics. Meanwhile, PhET Simulation provides dynamic visual representations that help students comprehend abstract fraction concepts more concretely. The combination of these two approaches offers a meaningful and student-centered learning experience, enabling students to explore mathematical ideas through hands-on and visual interactions. Overall, the results highlight that STEAM-integrated game-based learning supported by PhET simulations is a promising instructional approach for improving students' understanding of simple fractions and can be recommended for broader implementation in mathematics education.

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