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GAMIFIED LEARNING AND FRACTION HEROES: EFFECTS ON STUDENTS' MASTERY AND GENDER DIFFERENCES

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ABSTRACT

Aim/Purpose	This study examined the effects of gamified learning using Fraction Heroes, an educational game developed with the ADDIE model, on students' understanding of fractions. Additionally, the research explored gender differences and the interaction between the game and students' initial ability levels.
Background	Understanding fractions is essential for mastering advanced mathematics and real-life problem-solving, yet students often struggle due to misconceptions and ineffective teaching methods. Gamified learning, rooted in constructivist theories, can enhance engagement and motivation, but its effectiveness depends on balancing competition, fostering collaboration, and promoting intrinsic motivation, warranting continued investigation.

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Methodology	The study employed a one-group pre-test and post-test experimental design involving Year 7 students from three public junior high schools in Banda Aceh, Indonesia. Participants engaged with Fraction Heroes as part of their learning activities. Data collected through pre- and post-tests were analyzed using one-sample t-tests and gain scores to measure performance improvement. Subsequently, a paired-samples t-test was conducted to examine gender differences in learning outcomes. We also used a two-way ANOVA to determine whether there is an interaction between the developed educational games and students' mathematical understanding of fractions, with initial ability level as a covariate.
Contribution	This research contributes to the field of gamified learning by demonstrating that carefully designed game-based instruction improves students' understanding of fractions, while considering variations in prior knowledge and gender. These findings support promoting more equitable and meaningful mathematics learning.
Findings	Results revealed a statistically significant improvement in students' understanding of fractions after using the game. Additionally, there was no significant difference in students' performance across genders. We also found no interaction between the developed educational games and students' mathematical understanding of fractions.
Recommendations for Practitioners	Based on the study's findings, we recommend that teachers try this innovation in their classrooms. Teachers can use diagnostic assessments to identify students' starting points and provide targeted support, maximizing the benefits of gamified learning interventions. Additionally, local contexts should be considered when implementing gamified tools like Fraction Heroes.
Recommendations for Researchers	Although this study found no significant gender differences in learning outcomes, we recommend that future researchers delve deeper into how boys and girls engage with different game elements (e.g., competition, storytelling, rewards) to fine-tune game design for maximum appeal and effectiveness.
Impact on Society	The findings highlight the potential of theory-driven gamified learning environments to guide the development of effective, inclusive, and engaging mathematics instruction in secondary education.
Future Research	Future research should investigate the long-term retention of fraction concepts learned through Fraction Heroes and its adaptability to other mathematical domains and learner populations.

Keywords	educational game, online game, understanding fractions, students' mastery of fractions

INTRODUCTION

Understanding fractions is crucial for students as it forms the foundation for advanced mathematical concepts and everyday problem-solving. Mastery of fractions enhances students' abilities in proportional reasoning and is essential for success in higher mathematics, including algebra and calculus (Powell, 2018). Fractions are integral to grasping concepts such as magnitude and equivalence, which are foundational for advanced mathematics (Bouck et al., 2023). Moreover, a solid understanding of fractions helps students apply mathematical reasoning in real-life contexts, enhancing their problem-solving skills.

Despite the recognized importance of fractions, students across educational levels struggle with this topic, leading to persistent difficulties over time (Bruce et al., 2023). Additionally, educators face challenges in identifying effective teaching methods for fractions. Many teachers rely heavily on textbooks for instruction (Cady et al., 2015). Addressing these challenges through innovative instructional strategies is critical for fostering a deeper understanding of fractions. Recent studies emphasize that teaching fractions poses significant challenges for both teachers and students (Wilkins & Norton, 2018). These difficulties arise from students' conceptual misunderstandings, the effectiveness of instructional methods, and the influence of learning environments. Common issues include misunderstandings of fraction equivalence and the concept of equal parts (Hariyani et al., 2023). Misconceptions regarding the representation and manipulation of fractions also hinder students' overall mathematical development (Erdoğan et al., 2023).

Effective teaching strategies, such as using visual aids, number lines, and unit fractions, have been shown to enhance understanding (Bruce et al., 2023). Furthermore, integrating technology, such as virtual and augmented reality, can provide interactive learning experiences that support fraction instruction (Tadeu, 2024). However, the transition to online learning has introduced additional obstacles, such as materials that may not adequately cover fraction concepts (Hariyani et al., 2023). Teachers also face challenges, including overcrowded classrooms and insufficient training, which limit their ability to teach fractions effectively (Nqabeni et al., 2023). While these challenges are significant, studies suggest that targeted strategies and resources can improve students' comprehension and engagement in this critical area of mathematics.

Gamified learning presents a promising approach to teaching fractions by using game mechanics to enhance student engagement and conceptual understanding. Research indicates that both digital and non-digital gamification methods can significantly improve students' mathematical achievement in fractions and support deeper conceptual learning. Gamified approaches also increase student motivation and participation, making learning more enjoyable and interactive (Hunt et al., 2023). For example, digital games designed to illustrate part–whole relationships and number line representations have been shown to facilitate better understanding of fraction equivalence and magnitude (Thoma et al., 2023). Moreover, game-based learning environments positively influence students' attitudes toward mathematics and learning behaviors, which in turn contribute to improved academic performance (Setambah et al., 2023).

Despite these benefits, several challenges remain. Concerns have been raised regarding the overemphasis on numerical scoring and competition in gamified learning, which may detract from meaningful learning experiences if not carefully designed (González Vallejo, 2024). In addition, the availability of high-quality educational games that explicitly target fraction concepts remains limited, constraining effective classroom implementation.

Importantly, existing studies have largely focused on commercially available or generic educational games (e.g., Bitter et al., 2016; Marques et al., 2024), with limited attention to culturally contextualized, curriculum-aligned games developed for specific learning contexts, particularly in developing countries. There is also a lack of empirical evidence examining whether such games support equitable learning outcomes across gender and students' initial ability levels.

Addressing this gap, this current study contributes to gamified learning research by evaluating Fraction Heroes, a custom-developed educational game designed using the ADDIE model and aligned with the Indonesian junior high school curriculum. Using experimental data rather than self-reported perceptions, this study provides objective evidence of the game's effectiveness in improving students' understanding of fractions. Furthermore, this study demonstrates that the benefits of Fraction Heroes are consistent across male and female students and interact meaningfully with students' initial ability levels, thereby supporting equitable and inclusive mathematics learning.

This article's structure is organized into the following sections. First, the conceptual framework and research questions are introduced. Second, the research methodology is explained. Third, the results

are presented and discussed. Finally, the article concludes with a summary of findings, limitations, and suggestions for future research.

LITERATURE REVIEW

STUDENTS' STRUGGLE WITH FRACTIONS

Students frequently encounter substantial challenges in learning fractions, a foundational concept in mathematics. Research attributes these difficulties to a combination of teaching methods, cognitive demands, and individual learning differences. Fitousi and Noyman (2024) highlighted that fractions are challenging for both children and educated adults due to difficulties in integrating information from numerators and denominators. Similarly, Papadimitriou and Tzivinikou (2020) emphasized the complexity of teaching fractions, which requires both conceptual understanding and procedural skills. Many students struggle to grasp rational numbers, complicating their transition from arithmetic to algebra. Sullivan et al. (2023) further noted that a dominant part-whole conception often limits students' comprehension of fractions. Additionally, Kim and Park (2018) observed that students frequently rely on whole-number-dominance strategies when ordering fractions, leading to persistent misunderstandings.

Addressing these challenges is critical for improving instructional effectiveness. Traditional teaching approaches often confuse due to inconsistent interpretations of fractions, which can increase anxiety and reduce performance (Salazar et al., 2021). Students with learning disabilities, in particular, benefit from tailored strategies, including the use of manipulatives and multiple representations, to better understand fraction concepts (Bouck et al., 2023).

Research suggests that engaging students in productive struggle, where they work through challenging tasks, can improve mathematical achievement, demonstrating the value of well-designed cognitive challenges in fostering understanding (Paurowski et al., 2024). However, common errors, such as misunderstandings in reading and interpreting fractions, often stem from a lack of interest and inadequate mastery of prerequisite knowledge (Suardi et al., 2022). The absence of manipulative tools in teaching fractions is another significant barrier to student comprehension (Salazar et al., 2021). The multifaceted nature of fractions, including their intricate algorithms and the divide between conceptual and procedural knowledge, exacerbates these difficulties, as noted by Karamarkovich and Rutherford (2019). While these studies underscore the challenges students face with fractions, they also highlight the transformative potential of effective teaching practices to improve student outcomes significantly.

EFFECTS OF GAMIFIED LEARNING ON STUDENT ACHIEVEMENT

Gamified learning has been recognized as an effective way to contribute to student achievement, particularly in mathematics. Incorporating games into learning activities helps trigger students' interest, strengthen their motivation, and make learning more engaging and meaningful. Evidence from Southeast Asia further supports these benefits. In the Philippines, Lagmay et al. (2024) found that using game-based activities in mathematics lessons improved students' achievement and increased their confidence. Similar results were reported in Indonesia, where students learning through gamified platforms performed better on mathematics tests than those in traditional classrooms. Features such as immediate feedback and adaptive challenges were shown to help students retain knowledge and develop stronger problem-solving skills (Maryana et al., 2024). Likewise, Atin et al. (2022) demonstrated that a gamified mobile learning application for mathematics enhanced Indonesian students' engagement and overall learning outcomes.

In addition, gamified learning has also been shown to support broader learning experiences. A study conducted in Northern Mindanao by Oledan (2025) found that combining gamified learning with open-ended mathematical tasks and video-based instruction increased engagement, creativity, and independent learning. This suggests that gamification can function as an inclusive, student-centered

instructional approach. Supporting this view, Zhao et al. (2021) reported that students in a gamified flipped classroom consistently outperformed their peers, highlighting the added value of gamification in helping learners independently grasp abstract concepts such as fractions.

Furthermore, GBL has also been applied in STEM education. GBL has been shown to increase student engagement and motivation in STEM subjects significantly. A study by Zubair et al. (2024) demonstrated that simulation games improved students' understanding and satisfaction compared to traditional teaching methods, with 85% of students acknowledging the game's utility in reinforcing concepts. Similarly, a serious game designed for middle schoolers increased interest in STEM careers and reported substantial learning gains (Emihovich et al., 2025).

Theoretical Framework for Gamified Learning

Gamified learning incorporates game elements into educational settings to enhance student engagement and motivation, while also promoting deeper learning experiences. A strong theoretical foundation for gamified learning is rooted in various learning theories, particularly constructivism. This theory emphasizes active knowledge construction through student-centered and experiential learning (Stevenson, 1998).

According to Kalina and Powell (2009), Piaget's constructivism focuses on the individual's process of knowledge construction, whereas social constructivism emphasizes the role of interactions with teachers and peers in this process. Social constructivism values collaboration and cultural context, encouraging learners to share in problem-solving in game-based environments. This aligns well with gamification, as it promotes exploration, problem-solving, and critical thinking, which are essential as students navigate challenges in a game-like setting. It emphasizes learners' active role in constructing knowledge through hands-on experiences (Griffin & Richard, 2023).

Vygotsky's (1978) theory suggests that incorporating the social aspect of constructivism enriches gamified learning by creating collaborative environments where students share knowledge and engage in peer interactions. This social dimension facilitates the co-construction of knowledge, a critical feature of gamification in educational contexts. By designing gamified experiences that prioritize cooperation, educators can develop dynamic learning environments that enhance both individual problem-solving and group learning through collective participation.

Key components of gamified learning, such as rewards, challenges, and feedback, are essential for maintaining student interest and motivation (Challco et al., 2023). These interactive elements increase engagement and improve learning outcomes. Additionally, customizing gamified experiences to accommodate individual learning styles and personality traits boosts their effectiveness, ensuring that all learners remain engaged and motivated (Elshorbagy et al., 2022). However, despite its potential, gamified learning requires a careful balance among competition, collaboration, and intrinsic motivation. Overemphasizing external rewards can hinder cooperative learning and detract from meaningful educational experiences. Achieving this balance is crucial for fostering positive educational outcomes.

This study aims to examine the impact of a game-based learning approach on Year 7 students' performance in fractions. Additionally, it examines learning outcomes by gender. Understanding gender differences in learning outcomes is essential to ensure equitable access to effective instructional strategies and to address any disparities that may arise, fostering an inclusive learning environment for all students. For the study, we asked the following research questions:

RQ1: Do students make gains in understanding fractions after learning using Fraction Heroes?

RQ2: Do students' performances vary by gender?

RQ3: Is there an interaction between the developed educational games and students' mathematical understanding of fractions in terms of students' initial abilities?

METHOD

DESIGN

This study employed an experimental research design with a single-group pretest-posttest. Three classes from three schools were selected as the experimental groups. Students were initially given a pretest to measure their baseline understanding of fractions. The teacher delivered fractions in four lessons, and students were engaged with Fraction Heroes as part of their learning activities, with each lesson lasting 80 minutes. Following the intervention, a post-test was administered to evaluate the students' performance and any improvements attributable to the gamified learning experience. Both post-test and pre-test items underwent face and content validity by a mathematics education expert before being deemed valid and used in the study.

PARTICIPANTS

The study involved Year 7 students from three classes across three junior high schools in Banda Aceh, Indonesia. The schools were selected using a purposive sampling method based on their suitability for technology implementation, particularly the policy permitting students to bring mobile phones to school during the research period. The total sample consisted of 86 students, 43 females, and 43 males. The selection of participants was intended to provide a representative sample of students at this educational level to assess the impact of gamified learning on mathematical performance. Table 1 presents students' demographic information by school and gender.

Table 1. Students' demographic information by schools and gender

School	Male	Female	Total
School X	12	13	25
School Y	16	16	32
School Z	15	14	29
Total	43	43	86

MATERIALS

The primary instructional tool used in this study was Fraction Heroes, an educational game specifically developed to enhance students' understanding of fractions. The game was developed following the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model to ensure a systematic, effective development process. Both the game and the accompanying mathematical problems underwent rigorous validation by subject-matter experts prior to implementation to ensure their appropriateness and effectiveness in achieving the learning objectives.

Figure 1 presents a snapshot of the final version of Fraction Heroes. This Android-based game was installed on students' devices. The problems in the game were developed based on the current Indonesian curriculum (Merdeka Curriculum), emphasizing student-centered learning. The problems were also developed to cover different levels of difficulty (easy, moderate, and hard).

DATA COLLECTION

Student performance data were collected through problem-solving tasks embedded within the game. These tasks were designed to align with the learning objectives and provide insights into students' mastery of fraction concepts before and after the gamified learning intervention. Table 2 presents the items included in the Fraction Heroes.

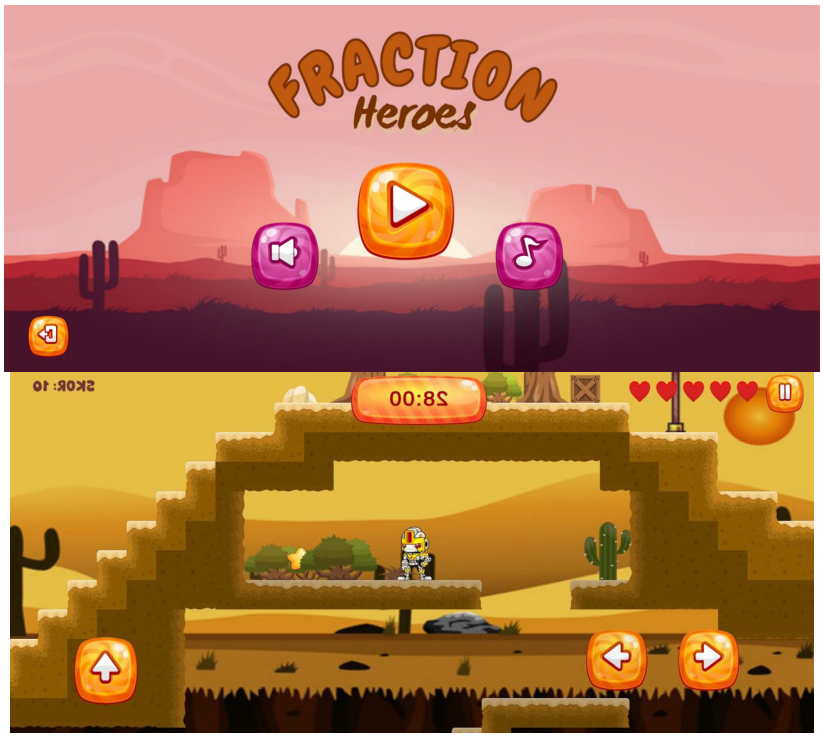

Figure 1. The display of Fraction Heroes

Table 2. Examples of problems included in Fraction Heroes

Level	Item
Easy	The correct option below is … a. 3/10 of 50 = 50% of 3 b. 3% of 50 = 6% of 100 c. 50:30 = 30:50 d. 3/10 x 50 = 5/10 x 30
Moderate	Rina, Ali, and Siti bought the same chocolate. Rina ate 1/4 of her chocolate, Ali ate 3/8 of his piece, and Siti ate 2/5. The correct order of the people, from smallest to largest piece of chocolate left, is: a. Rina, Ali, Siti b. Siti, Ali Rina c. Rina, Siti, Ali d. Ali, Siti, Rina
Hard	Mirna was taking a math test and managed to complete 1/2 of the problems. Afterwards, she did 1/3 she had missed. She then completed the remaining in 15 minutes. Assuming each question takes the same time to solve, how long did it take Mirna to complete the test? a. 30 minutes b. 45 minutes c. 90 minutes d. 110 minutes

DATA ANALYSIS

We use the Kolmogorov-Smirnov test with a significance level of 0.05 to assess normality (Table 3). Because the p-value is > 0.05, the standardized residuals come from a normally distributed population.

Table 3. Normality test of the residual standard values of students' mathematical comprehension ability

	Kolmogorov-Smirnov test		
	Statistic	**df**	**Statistical significance**
Standardize the students' mathematical comprehension ability	0.057	86	0.200

Next, we use Levene's test at the 0.05 significance level to assess homogeneity of variance (Table 4). The results indicate the variances are homogeneous.

Table 4. Homogeneity of variances test

	Levene statistic	**df1**	**df2**	**Statistical significance**
Standardize the students' mathematical comprehension ability	2.077	8	58	0.053

Based on the results of the normality and homogeneity tests, a one-sample t-test can be used to determine the statistical significance of the differences between pre-test and post-test scores across all schools. Additionally, normalized gain (n-gain) scores were calculated to assess the magnitude of improvement in students' performance. Subsequently, a paired-samples t-test was conducted to examine gender differences in learning outcomes. We also used a two-way ANOVA to determine whether there is an interaction between the developed educational games and students' mathematical understanding of fractions, with initial ability level as a covariate. The results of the calculation of the two-way ANOVA test were carried out with the help of SPSS at a significance level of $\alpha = 0.05$. These statistical methods provided a comprehensive evaluation of the effectiveness of the Fraction Heroes game in enhancing students' understanding of fractions.

RESULTS AND DISCUSSION

In this section, we present the study's results. We organized the results according to the research questions posed. In the following section, we answer those questions and provide possible interpretations of the results in the discussion.

DESCRIPTIVE STATISTICS

Descriptive statistics, correlations, t tests, and standard multiple regression were conducted using SPSS 25. Table 5 presents the means, standard deviations, minimum and maximum values, and correlation coefficients for all variables. Table 5 presents a correlation matrix and descriptive statistics for four variables: Post-test, Pre-test, School, and Gender. A strong positive correlation ($r=0.686$, $p<0.000$) exists between Post-test and Pre-test scores, while moderate correlations are observed between Post-test and School ($r=0.320$, $p<0.05$) and Pre-test and School ($r=0.240$, $p<0.05$). Gender

shows weak and non-significant correlations with other variables. Descriptive statistics indicate that Post-test scores have a mean of 79.30 (SD = 15.40), and Pre-test scores have a mean of 46.28 (SD = 18.79). The minimum and maximum values range from 40 to 100 for the Post-test and from 10 to 80 for the Pre-test.

Table 5. Descriptive statistics and correlation for the overall sample

Variable	1	2	3	4
1. Post-test	-			
2. Pre-test	0.686**	-		
3. School	0.320*	0.240*	-	
4. Gender	0.061	0.000	0.029	-
M	79.30	46.28	2.05	0.50
SD	15.400	18.790	0.796	0.503
Min	40	10	1	0
Max	100	80	3	1

Note: *p<0.050, ** p<0.000

RQ 1: Do Students Make Gains in Understanding of Fractions After Learning Using Fraction Heroes?

We examine the overall effects of Fraction heroes on students' learning outcomes across schools using a paired-samples t-test to compare pre-test and post-test scores. Regardless of the school origin, the students improved their performance from pre-test (M=46.28, SD=18.790) to post-test (M=79.30, SD=15.400; t(85)=-22.038, p<0.000). Table 6 presents the Paired-sample t-test results. The results indicate significant differences between the pre-test and post-test across schools, indicating that, overall, students' performance improved after learning with Fraction Heroes. The findings of this study confirm that Fraction Heroes significantly improved students' understanding of fractions and effectively addressed students' learning challenges. Fraction Heroes was designed with the characteristics of high school students who love gradual challenges in mind, including Indonesian students. The features, including the point system, indicator level, and problem-solving duration, were designed to give students a real game experience.

Table 6. Paired-sampled t-test results

	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference		T	df	p
				Lower	Upper			
Pre-test - Post-test	-33.023	13.896	1.498	-36.003	-30.044	-22.038	85	0.000

These results are consistent with previous studies highlighting the role of gamification in enhancing student engagement and comprehension in mathematics (Sun-Lin & Chiou, 2019). The interactive nature of Fraction Heroes likely contributed to the student's ability to grasp complex fraction concepts, as gamified tools facilitate active learning and sustained attention. This finding underscores the importance of prior knowledge in shaping learning outcomes, consistent with constructivist learning theories (Piaget, 2003) and previous research by Rianto et al. (2022). This finding suggests that teachers can leverage diagnostic assessments to identify individual learning needs and provide targeted support, maximizing the benefits of gamified learning tools for all students, regardless of their starting point.

As a complement to the t-test, the Normalized Gain Score (N-Gain) test was conducted. Based on the criteria for obtaining the N-Gain score in Table 7, the developed educational game is effective in improving students' mathematical understanding of fraction material, with the N-Gain Score falling within the medium category (Hake, 1998, p. 65).

Table 7. N-Gain test results

School	Number of students	Mean of pre-test score	Mean of post-test score	Mean of N-Gain score	Category
School X	25	23.20	210.40	0.48	Medium
School Y	32	22.73	161.82	0.40	Medium
School Z	29	16.55	219.66	0.44	Medium

RQ 2: Does the Students' Performance Vary Depending on Gender?

An independent-samples t-test was conducted to compare post-test performance across genders after learning with Fraction Heroes. The test revealed no significant difference in post-test scores between female (M=78.37, SD=13.62) and male students (M=80.2, SD=17.11); t(84)=−0.56, p=0.578. Levene's test indicated that the assumption of equal variances was met (F=3.48, p=.066). The mean difference was -1.86 (SE = 3.34), with a 95% confidence interval of -8.49 to 4.77. These results suggest that gender did not significantly impact students' performance after using Fraction Heroes. Table 8 presents the results of an independent t-test.

Table 8. Results of an independent t-test for gender differences

	Levene's test for equality of variances		t-test for equality of means							
	F	Sig.	T	df	Significance		Mean difference	Std. error difference	95% confidence interval of the difference	
					One-sided	Two-sided			Lower	Upper
Equal variances assumed	3.482	0.066	-0.558	84	0.289	0.578	-1.860	3.335	-8.492	4.771
Equal variances not assumed			-0.558	79.965	0.289	0.578	-1.860	3.335	-8.497	4.776

Previous research on gender differences in game-based learning has yielded mixed findings. Some found that females outperformed males in mathematics performance (Khan et al., 2017), while others reported the opposite (Mellado et al., 2024). In this study, the analysis showed no significant difference in post-test performance between male and female students. This finding aligns with that of Zhang et al. (2024), who found that boys and girls achieve equally well in fraction concepts when learning through game-based instruction.

The findings of this study suggest that the use of Fraction Heroes is effective for all students, regardless of gender. One factor contributing to this finding was the game design, with the user interface (UI) and user experience (UX) both engaging and gender-neutral. This finding also supports the notion that gamified learning approaches can provide equitable benefits across genders, as prior research suggests (Setambah et al., 2023). In contrast, some previous studies (McLaren, 2022; Nguyen et al., 2022; Salami & Spangenberg, 2024) found that gamified mathematics learning tends to be more advantageous for female students, with females outperforming their male counterparts.

Several factors may explain these findings. McLaren (2022) reported that certain game features reduced the sense of competition by withholding score displays until the end of the game, thereby increasing female students' confidence and reducing stress. Nguyen et al. (2022) suggested that female students tend to be more careful and systematic when solving mathematical problems. In addition, gamified learning has been shown to reduce boredom and mathematics-related anxiety among female students (Salami & Spangenberg, 2024). These findings, along with the absence of gender disparities in this study, emphasize the urgency of ensuring the principles of inclusive education. The choice to design a neutral game may result in Fraction Heroes effectively caters to diverse learners without bias. Such equity in outcomes is critical in addressing the broader educational goal of reducing achievement gaps.

RQ 3: Is There an Interaction Between the Developed Educational Games on Students' Mathematical Understanding of Fractions in Terms of Students' Initial Abilities?

Based on previous testing results, the N-Gain data on mathematical understanding ability from the three schools are normally distributed, and the variances are homogeneous. Thus, to determine whether there is an interaction between the educational game developed at the student level and students' ability to understand fraction material, a two-way ANOVA was conducted. The results of the calculation of the two-way ANOVA test conducted with the help of SPSS at the significance level $\alpha = 0.05$ are presented in Table 9. Because the significance value (Sig.) = 0.714 > 0.05, it can be concluded that there is no interaction between school and level (excellent, average, and low) on the improvement of mathematical understanding ability. A further explanation of the interaction is presented in Figure 2.

Table 9. Analysis of variance of n-gain data of students' mathematical understanding ability

Tests of between-subjects effects					
Dependent variable: Mathematical ability improvement					
Source	**Type III sum of squares**	**df**	**Mean square**	**F**	**Sig.**
Corrected Model	1.028[a]	8	0.128	1.803	0.095
Intercept	9.512	1	9.512	133.513	0.000
Level of Pre	0.728	2	0.364	5.110	0.009
Level of School	0.184	2	0.092	1.294	0.282
Level of Pre * Level of School	0.151	4	0.038	.531	0.714
Error	4.132	58	0.071		
Total	17.139	67			
Corrected Total	5.160	66			

Note: a. R Squared = .199 (Adjusted R Squared = .089)

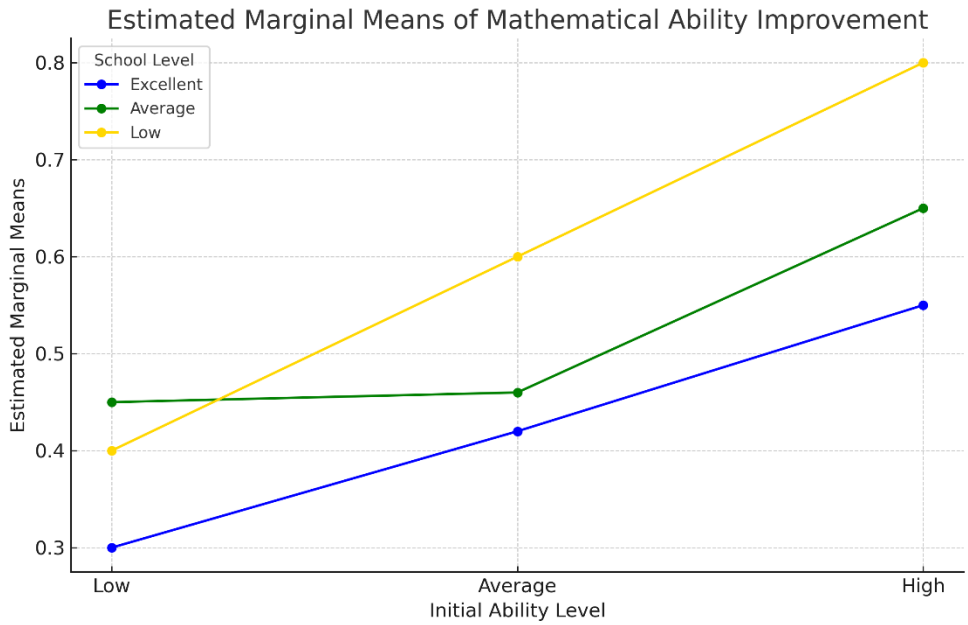

Figure 2. An interaction chart between school and level on the improvement of mathematical understanding ability

Based on Figure 2, there is no interaction between schools at excellent and average levels, or between excellent and low levels. However, interaction occurs between average and low school levels. It can be interpreted that the educational game developed on fraction material can improve students' mathematical understanding of fraction material relative to their initial ability across all levels, with excellent school levels showing the greatest improvement, and average and excellent school levels showing improvement, though not as much, when viewed from low and average school levels. A study by Clark et al. (2016) found that, while digital games can increase engagement, their effects on improving math knowledge are inconsistent.

Moderate correlations between school origin and pre-test and post-test scores suggest that contextual factors such as school resources, teacher expertise, and instructional practices may influence students' learning outcomes. These findings align with research emphasizing the role of school-level variables in shaping academic performance (Eickelmann et al., 2017; Polly et al., 2018). While Fraction Heroes demonstrated effectiveness across schools, understanding how local contexts mediate its impact can inform strategies to enhance its implementation and scalability.

CONCLUSIONS, LIMITATIONS, AND FUTURE RESEARCH

This study demonstrates that Fraction Heroes is a highly effective educational game for teaching fractions, significantly improving students' understanding of fraction concepts. The paired-sample t-test results confirmed substantial learning gains, highlighting the potential of gamified learning to address persistent challenges in mathematics education. Furthermore, the absence of significant gender differences in post-test performance underscores the game's ability to deliver equitable learning outcomes, supporting the principles of inclusive education and bridging achievement gaps across diverse learner groups.

The strong positive correlation between pre-test and post-test scores emphasizes the importance of prior knowledge in shaping learning outcomes, consistent with constructivist theories of learning. Teachers can use diagnostic assessments to identify students' starting points and provide targeted support, maximizing the benefits of gamified learning interventions. Additionally, the moderate

influence of school origin on performance suggests that contextual factors, such as resources and instructional practices, shape outcomes. These findings underscore the need to consider local contexts when scaling and implementing gamified tools like Fraction Heroes.

The validation process for Fraction Heroes confirmed its high technical and pedagogical quality, with strong usability, content alignment, and navigational design. Revisions based on expert feedback further refined the game's features, ensuring its readiness for classroom use. These validations, combined with the study's findings, position Fraction Heroes as an innovative and impactful tool for enhancing mathematics education.

This study has some limitations. While the game incorporates Acehnese ethnomathematics, it only represents a fraction of Indonesia's rich cultural diversity. Therefore, the results in this region may not necessarily generalize to other regions of the country. On the other hand, the study focused on immediate learning outcomes after gameplay. Long-term retention and the impact on students' overall mathematical mindset were not measured, leaving a gap in understanding the game's sustainability in learning.

Future research should expand the cultural contexts to include other ethnic groups to enhance the game's broader appeal and cultural inclusiveness. A longitudinal study may also be a promising direction for investigating the long-term retention of fraction concepts learned through Fraction Heroes and its adaptability across other mathematical domains and learner populations. Exploring the game's impact on student motivation and performance over extended periods can provide further insights into its effectiveness and scalability in diverse educational contexts. A comparative study exploring the impact of games across regions may also be necessary to obtain a more comprehensive understanding of how gamified learning affects students.

REFERENCES

Atin, S., Syakuran, R. A., & Afrianto, I. (2022). Implementation of gamification in mathematics m-learning application to creating student engagement. *International Journal of Advanced Computer Science and Applications*, *13*, 542–556. https://doi.org/10.14569/IJACSA.2022.0130765

Bitter, G. G., Puglisi, J., Gorges, A., & Uppal, H. K. (2016). The effects of an online collaborative elementary math program using team-based games to improve student math achievement, attitude, and motivation. *International Journal for Innovation Education and Research*, *4*(7), 113–138. https://doi.org/10.31686/ijier.vol4.iss7.568

Bouck, E., Bouck, M., & Anderson, R. D. (2023). Teaching fractions to elementary students with learning disabilities using evidence-based practices. *Intervention in School and Clinic*, *60*(3), 135–140. https://doi.org/10.1177/10534512231178480

Bruce, C. D., Flynn, T., Yearley, S., & Hawes, Z. (2023). Leveraging number lines and unit fractions to build student understanding: Insights from a mixed methods study. *Canadian Journal of Science, Mathematics and Technology Education*, *23*(2), 322–339. https://doi.org/10.1007/s42330-023-00278-x

Cady, J. A., Hodges, T. E., & Collins, R. L. (2015). A comparison of textbooks' presentation of fractions. *School Science and Mathematics*, *115*(3), 105–116. https://doi.org/10.1111/ssm.12108

Challco, G. C., Bittencourt, I. I., Reis, M., Santos, J., & Isotani, S. (2023, June). Gamiflow: Towards a flow theory-based gamification framework for learning scenarios. In N. Wang, G. Rebolledo-Mendez, V. Dimitrova, N. Matsuda & O. C. Santos (Eds.), *Artificial Intelligence in Education* (pp. 415–421). Springer. https://doi.org/10.1007/978-3-031-36336-8_65

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research, 86*(1), 79-122. https://doi.org/10.3102/0034654315582065

Eickelmann, B., Gerick, J., & Koop, C. (2017). ICT use in mathematics lessons and the mathematics achievement of secondary school students by international comparison: Which role do school-level factors play? *Education and Information Technologies*, *22*, 1527–1551. https://doi.org/10.1007/s10639-016-9498-5

Elshorbagy, S. A., Sherief, N., & Abdelmoez, W. (2022). A framework for utilizing unexplored game elements in designing learning systems. *Advances in Computing & Engineering*, *2*(2), 96-131. https://doi.org/10.21622/ACE.2022.02.2.096

Emihovich, B., Roque, N., Criley, W., Criley, R., Criley, S., Alagoz, J., & Vukanovic-Criley, J. (2025, October). Increasing STEM career interest in middle schoolers through a health-themed serious game. In *Proceedings of the 18th European Conference on Game-Based Learning, 19*(1). Academic Conferences and publishing limited. https://doi.org/10.34190/ecgbl.19.1.4098

Erdoğan, D., Özkan, E., & Özkan, N. (2023). Investigation of studies on fraction teaching in primary school. *Pedagogical Perspective*, *2*(1), 36-56. https://doi.org/10.29329/pedper.2023.559.3

Fitousi, D., & Noyman, R. (2024). Why fractions are difficult? Modeling optimal and sub-optimal integration strategies of numerators and denominators by educated adults. *Cognition*, *242*, 105656. https://doi.org/10.1016/j.cognition.2023.105656

González Vallejo, R. (2024). Notes on gamification and education. *SAP Gamification and Augmented Reality*, *2*, 44. https://doi.org/10.56294/gr202444

Griffin, L. L., & Richard, J. F. (2023). A games-based approach as a constructivist model of game-based teaching. In S. Pill, E.-A. Gambles, & L. Griffin (Eds.), *Teaching games and sport for understanding* (1st ed., pp. 87–97). Routledge. https://doi.org/10.4324/9781003298298-10

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64–74. https://doi.org/10.1119/1.18809

Hariyani, M., Herawati, H., Andriani, M., & Suherman, S. (2023). Students' learning obstacles in understanding of fraction concept during online learning. *Journal of Didactic Mathematics*, *4*(2), 58-64. https://doi.org/10.34007/jdm.v4i2.1849

Hunt, J. H., Taub, M., Marino, M., Duarte, A., Bentley, B., Holman, K., & Kuhlman, A. (2023). Effects of game-enhanced supplemental fraction curriculum on student engagement, fraction knowledge, and STEM interest. *Education Sciences*, *13*(7), 646. https://doi.org/10.3390/educsci13070646

Kalina, C., & Powell, K. C. (2009). Cognitive and social constructivism: Developing tools for an effective classroom. *Education*, *130*(2), 241–250. https://docdrop.org/static/drop-pdf/Powell-and-Kalina-U6g4p.pdf

Karamarkovich, S. M., & Rutherford, T. (2019). Fraction errors in a digital mathematics environment: Latent class and transition analysis. *Journal of Numerical Cognition*, *5*(2), 158–188. https://doi.org/10.5964/jnc.v5i2.150

Khan, A., Ahmad, F. H., & Malik, M. M. (2017). Use of digital game-based learning and gamification in secondary school science: The effect on student engagement, learning, and gender difference. *Education and Information Technologies*, *22*, 2767–2804. https://doi.org/10.1007/s10639-017-9622-1

Kim, Y. R., & Park, M. S. (2018). The persistent difficulty of early fraction ideas in early secondary school mathematics. *Journal of Education and Practice*, *9*(29), 32–42. https://www.iiste.org/Journals/index.php/JEP/article/view/44674/46306

Lagmay, S. B., Duldulao, S. M. D., Gallena, B. D., Pascua, M. T., & Dela Cruz, N. J. (2024). Effects of game-based mathematics learning on students' academic achievement. *International Journal for Multidisciplinary Research*, *6*(5), 1-22. https://doi.org/10.36948/ijfmr.2024.v06i05.28280

Marques, J. A. B. T., Ferreira, J. L. A. P., & Silva, F. G. M. (2024). Math-masters: An educational game to practice the mathematical operations. In L. V. Costa, N. Zagalo, A. I. Veloso, E. Clua, S. Arnab, M. Vairinhos, & D. Gomes (Eds.), *Videogame sciences and arts* (pp. 166–173). Springer. https://doi.org/10.1007/978-3-031-51452-4_12

Maryana, M., Halim, C., & Rahmi, H. (2024). The impact of gamification on student engagement and learning outcomes in mathematics education. *International Journal of Business, Law, and Education*, *5*(2), 1697–1608. https://doi.org/10.56442/ijble.v5i2.682

McLaren, B. M. (2022). A digital learning game for mathematics that leads to better learning outcomes for female students: Further evidence. *Proceedings of the 16th European Conference on Games Based Learning*, *16*(1), 339–348. https://doi.org/10.34190/ecgbl.16.1.794

Mellado, R., Cubillos, C., Vicari, R. M., & Gasca-Hurtado, G. (2024). Leveraging gamification in ICT education: Examining gender differences and learning outcomes in programming courses. *Applied Sciences*, *14*(17), 7933. https://doi.org/10.3390/app14177933

Nguyen, H. A., Hou, X., Richey, J. E., & McLaren, B. M. (2022). The impact of gender in learning with games: A consistent effect in a math learning game. *International Journal of Game-Based Learning*, *12*(1), 1–29. https://doi.org/10.4018/ijgbl.309128

Nqabeni, N., Buka, A. M., & Nomtshongwana, T. (2023). Examining the dynamics of teaching algorithms of fractions: A case study of grade 3 rural schools in South Africa. *E-Journal of Humanities, Arts and Social Sciences*, *4*(5), Article 9. https://doi.org/10.38159/ehass.20234539

Oledan, A. M. B. (2025). Students' perceptions and experiences with gamified learning, open-ended mathematical tasks, and self-directed learning via video lessons in mathematics. *International Journal of Learning, Teaching and Educational Research*, *24*(11), 440–463.https://doi.org/10.26803/ijlter.24.11.21

Papadimitriou, P. G., & Tzivinikou, S. (2020). Strategies for fractions on RtI instructional framework: The effect on learning disabled middle grades students' performance. *Psychology*, *11*(5), 692–703. https://doi.org/10.4236/psych.2020.115047

Paurowski, M., Glassmeyer, D., Kim, J., & Id-Deen, L. (2024). Struggling as part of success: International Baccalaureate students' productive struggle is strongly correlated to mathematical achievement. *International Journal of Mathematical Education in Science and Technology*, *56*(5), 851–868. https://doi.org/10.1080/0020739x.2023.2296583

Piaget, J. (2003). Part I: Cognitive development in children--Piaget development and learning. *Journal of Research in Science Teaching, 40*, S8-S18. https://eric.ed.gov/?id=EJ773455

Polly, D., Wang, C., Martin, C., Lambert, R., Pugalee, D., & Middleton, C. (2018). The influence of mathematics professional development, school-level, and teacher-level variables on primary students' mathematics achievement. *Early Childhood Education Journal*, *46*, 31–45. https://doi.org/10.1007/s10643-017-0837-y

Powell, A. B. (2018). Reaching back to advance forward: Towards a 21st-century approach to learning and teaching fractions. *Perspectiva*, *36*(2), 399-420. https://doi.org/10.5007/2175-795X.2018v36n2p399

Rianto, B., Lutfi, A., Naser, A. D. M., & Dasari, D. (2022). The effect of prior knowledge and learning motivation on mathematics learning outcomes of junior high school students. *Jurnal Pendidikan MIPA*, *23*(4), 1876-1886. https://doi.org/10.23960/jpmipa/v23i4.pp1876-1886

Salami, O. O., & Spangenberg, E. D. (2024). Exploring the gender-based impact of mathematical games on the academic performance of senior secondary school students. *Interdisciplinary Journal of Sociality Studies*, *4*, 1–15. https://doi.org/10.38140/ijss-2024.vol4.10

Salazar, J., Bedón, P., Salazar, Y., & Salazar, M. (2021). Recursos en el aula de clase para la enseñanza de fracciones en educación general básica media de las instituciones de educación públicas de la ciudad de Latacunga, Ecuador [Classroom resources for teaching fractions in lower secondary basic education in public schools in the city of Latacunga, Ecuador].*Revista Boletín Redipe, 10*(5), 121-138. https://doi.org/10.36260/rbr.v10i5.1289

Setambah, M. A. B., Rajoo, M., Othman, M. S., Shuib, T. R., & Ibrahim, M. A. (2023). Non-digital gamification: Effects of teaching on mathematics achievement and student behavior. *Nurture*, *17*(4), 504–515. https://doi.org/10.55951/nurture.v17i4.388

Stevenson, I. (1998). Radical constructivism. Ernst von Glasersfeld. *Educational Studies in Mathematics*, *35*, 93–104. https://doi.org/10.1023/A:1003018912036

Suardi, S., EL Hakim, L., & Aziz, T. A. (2022). Kesalahan-Kesalahan Siswa pada Materi Pecahan [Students' errors in learning fractions]. *Griya Journal of Mathematics Education and Application*, *2*(2), 418–428. https://doi.org/10.29303/griya.v2i2.201

Sullivan, P. L., Barnett, J. E., & Killion, K. (2023). Beware of "gaps" in students' fraction conceptions. *Mathematics Teacher: Learning and Teaching PK-12*, *116*(12), 912–922. https://doi.org/10.5951/MTLT.2023.0109

Sun-Lin, H.-Z., & Chiou, G.-F. (2019). Effects of gamified comparison on sixth graders' algebra word problem solving and learning attitude. *Journal of Educational Technology & Society*, *22*(1), 120-130. https://drive.google.com/file/d/1sEbYGokaatw-8AeLWbp5eZIspyu9ZGT9/view

Tadeu, P. J. A. (2024). A synopsis of the importance of teaching fractions to children until K-10. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(8), Article em2485. https://doi.org/10.29333/ejmste/14878

Thoma, G., Bahnmueller, J., Lindstedt, A., Kiili, K., Wortha, S. M., Moeller, K., & Ninaus, M. (2023). Different aspects of fraction understanding are associated selectively with performance on a fraction learning game. *Progress in Brain Research*, *276*, 63-91. https://doi.org/10.1016/bs.pbr.2023.02.003

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes* (Vol. 86). Harvard University Press. https://www.hup.harvard.edu/books/9780674576292

Wilkins, J. L., & Norton, A. (2018). Learning progression toward a measurement concept of fractions. *International Journal of STEM Education*, *5*, Article 27. https://doi.org/10.1186/s40594-018-0119-2

Zhang, L., Lei, Y., Pelton, T., Pelton, L. F., & Shang, J. (2024). An exploration of gendered differences in cognitive, motivational, and emotional aspects of game-based math learning. *Journal of Computer Assisted Learning, 40*(6), 2633-2649. https://doi.org/10.1111/jcal.12956

Zhao, J., Hwang, G. J., Chang, S. C., Yang, Q. F., & Nokkaew, A. (2021). Effects of gamified interactive e-books on students' flipped learning performance, motivation, and meta-cognition tendency in a mathematics course. *Educational Technology Research and Development*, *69*(6), 3255-3280. https://doi.org/10.1007/s11423-021-10053-0

Zubair, M. U., Khan, M. A., Hassan, M. U., Ahmed, K., & Aziz, T. (2024). Enhancing student active engagement in class through game-based learning: A case of civil engineering education. *Sustainability, 16(*14), 6010. https://doi.org/10.3390/su16146010

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