iFractions: Using Games to Teach Children Fractions

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Abstract

Fractions are fundamental concepts in mathematics education and can be applied to various everyday tasks. However, teaching and learning fractions remain challenging due to their abstract nature. To mitigate this challenge, this paper introduces an open-source collection of educational minigames to support the teaching of fractions through interactive and visual approaches. At the same time, to evaluate its effectiveness, a quasi-experimental study was conducted using pre- and post-tests. The results demonstrated a significant improvement in students' hit ratio, with an average normalized gain of 0.767. With this work, we contribute to the teaching of mathematics by presenting an open-source tool that can facilitate the teaching and learning of fractions.

Keywords: Game-based learning, Mathematics education, Fractions, Game design, Quasi-experiment.

1. Introduction

Mathematics education plays an important role in the intellectual development of students, contributing to the enhancement of logical reasoning, problem-solving skills, and decision-making in everyday life (Ostrow et al., 2023; Sidney and Alibali, 2022). Within this context, the teaching of fractions occupies an important position, as it is directly associated with various practical situations, such as measuring, dividing, comparing quantities, and understanding proportions (Fazio and Siegler, 2024). A solid understanding of fractions is essential for success in more advanced mathematical topics and for building a conceptual foundation for real-world contexts (Fazio and Siegler, 2024; Obersteiner et al., 2023). Therefore, meaningful instruction in fractions contributes to developing autonomous, confident individuals better equipped to face mathematical challenges in daily life (Hansen et al., 2021; National Council of Teachers of Mathematics, 2023).

However, the abstract nature of fractions poses one of the greatest challenges in mathematics learning, particularly in the early years of elementary education (National Council of Teachers of Mathematics, 2023; Obersteiner et al., 2023; Sidney and Alibali, 2022). This difficulty stems from early learning gaps, hindering foundational concept consolidation and increasing students' math anxiety (Dowker et al., 2022; Ramirez et al., 2023; Wang et al., 2011). Teaching fractions requires a cognitive shift from the understanding of natural numbers to concepts such as part-whole relationships, proportionality, and equivalence (Braithwaite and Sprague, 2021; Mix et al., 2023; Siegler and Lortie-Forgues, 2023). This challenge directly impacts students' self-confidence and undermines their engagement in STEM fields (Beilock and Maloney, 2023; OECD, 2025; Sidney and Alibali, 2023).

In response to these challenges, we propose *iFractions*, a collection of educational minigames developed for elementary school students. This tool aims to address fraction-related content in an applied and playful manner by leveraging game mechanics to engage learners, promoting intuitive visualizations of formal concepts, and reducing the emotional barriers often associated with learning mathematics. The main objectives of *iFractions* are: *i)* to support the understanding of fractions through visual representations and playful interactions; *ii)* to provide teachers with a flexible and customizable platform, adaptable to different instructional contexts and student

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proficiency levels; and *iii)* to assist students during their initial contact with rational number concepts.

To evaluate the efficacy of the game, we conducted a quasi-experiment with fifth-grade classes at a public school in the state of São Paulo, Brazil. The sample consisted of two classes, totaling 55 students. The quasi-experiment consisted of students using *iFractions* and lasted approximately two hours, during which participants took a pre-test, played different minigames from *iFractions*, and took a non-evaluative post-test. Finally, pre- and post-test data were analyzed using normalized gain (g), calculated with Hake's formula (Hake, 1998) to quantify the relative improvement in student performance, and the Wilcoxon signed-rank test (Wilcoxon, 1945) to assess the statistical significance of differences between pre- and post-test scores.

The results obtained indicate that the use of *iFractions* generated statistically significant improvements in students' performance on fraction problems, with a high normalized mean gain of 0.767, suggesting relevant advances in conceptual understanding. However, these findings should be carefully interpreted, since the sample was limited, the intervention was one-off, and there was no control group, factors that limit the generalization and causal attribution of the observed effects. Thus, this study contributes to the field of mathematics education by providing initial evidence on the effectiveness of a digital resource in teaching fractions, while highlighting the need for broader, controlled, and long-term future investigations to consolidate understanding of its pedagogical impacts.

2. Background and Related Work

Mathematics plays a crucial role in society, supporting problem-solving across diverse fields and underpinning contemporary technologies such as machine learning, communication networks, and mobile applications (Nguyen et al., 2020). Despite its importance, persistent deficiencies in students' mastery of basic mathematics (Jordan et al., 2013; OECD, 2025; Siegler and Ramani, 2016) can hinder academic performance and career opportunities. Among these challenges, fractions stand out as one of the most problematic topics. A systematic review by da Silva Neves Lima et al. (2019) revealed that fractions remain a major obstacle even in higher education, echoing historical accounts such as De Morgan (1910)'s description of fractions as involving "extraordinary difficulties". In another secondary study, da Silva Neves Lima et al. (2024) identified 45 fraction-focused games published up to 2021, highlighting growing academic interest.

Over the past 15 years, international studies have demonstrated the potential of digital games for fraction learning. Jordan et al. (2013) showed significant gains for students with learning difficulties. Kiili et al. (2015) found that the game *Refraction* outperformed traditional instruction in conceptual understanding and problem-solving. Siegler and Ramani (2016) reported long-term learning effects and knowledge transfer to decimals and percentages. Hwang and Chen (2017) showed that cooperative games enhanced engagement and reduced math anxiety. More recently, Ostrow et al. (2023) validated a large-scale mobile game based on spaced repetition. At the same time, Smith et al. (2023) developed an AI-powered adaptive game that yielded strong gains in fraction equivalence and addition. To the best of our knowledge, our study is among the first to develop a collection of open-source minigames dedicated to teaching fractions, accompanied by a study that analyzes relative improvement in student performance.

3. Game Design

3.1. Instructional Design Principles

The instructional design of *iFractions* is grounded in established educational theories. Its visual representations and interactive elements are intended to facilitate the anchoring of new fraction concepts onto existing cognitive frameworks, aiming to promote meaningful learning beyond rote memorization (Ausubel, 1968). Complementing this, Vygotsky's sociocultural theory (Vygotsky, 1978) underscores the role of social interaction and scaffolding within the Zone of Proximal Development (ZPD). The playful and adaptive nature of the game is designed to act as a scaffolding tool, supporting learners as they navigate progressively complex fraction tasks.

Literature on digital games in education reinforces these theoretical insights by highlighting how game-based learning environments enhance motivation, engagement, and conceptual understanding (Gee, 2007; Ostrow et al., 2023). Games usually provide immediate feedback, promote active learning, and enable repeated practice in low-stakes settings, all of which contribute to improved learning outcomes. Specifically, for mathematics and fractions, digital games often offer visual and interactive affordances that can demystify abstract concepts and reduce math anxiety (Calder and Campbell, 2019; Ke, 2014).

The implications for curriculum development and teacher education are substantial. Integrating digital games like *iFractions* into mathematics curricula can offer diverse entry points for students with varying prior knowledge, fostering differentiated instruction aligned with Ausubel's and Vygotsky's theories (Ausubel, 1968; Vygotsky, 1978). For teachers, professional development should include training on effectively incorporating game-based tools into their pedagogical repertoire, emphasizing how to align game activities with learning objectives, assess student progress in digital environments, and facilitate meaningful reflection. Such integration supports a shift toward more student-centered and interactive mathematics instruction, potentially enhancing both engagement and achievement in foundational topics such as fractions.

iFractions was developed to support differentiated instruction by enabling extensive customization of its minigames to meet diverse student needs. For each game, educators can configure parameters such as the type of mathematical operation, game mode, difficulty level, and the presence of auxiliary visual elements (*e.g.*, fraction bars or shaded areas) that assist in problem-solving. These options are not merely cosmetic, but pedagogically meaningful. For instance, a teacher introducing part-whole relationships to younger students might select simpler game modes with visual aids enabled, while more advanced learners can engage with operations involving equivalence or addition of unlike fractions in more abstract settings. Altogether, the system offers 12 core combinations of game mechanics and operations. When variations in difficulty and visual support are considered, this expands to 104 distinct configurations. This flexibility allows *iFractions* to be used across different stages of instruction, from initial concept introduction to formative assessment, adapting to individual learning trajectories and instructional goals within the classroom.

3.2. Game Design Principles

In addition to its educational usefulness, the design of *iFractions* incorporates game design principles to encourage engagement and make learning enjoyable. This avoids the "chocolate-coated broccoli" effect, in which the game merely overlays repetitive exercises. In *iFractions*, enjoyment stems from the intrinsic motivation generated by its mechanics and visual design. The first principle is providing visual and auditory feedback through animations, sound effects, and visual highlights that reinforce correct and incorrect responses. This feedback promotes a sense of accomplishment and sustains engagement in learning tasks (Gee, 2007; Plass et al., 2015).

The game also employs the metaphor of the "Path of Knowledge" through its level map, which offers a clear visual representation of progression and motivates students with incremental goals and a tangible sense of achievement. Thematic coherence and playful metaphors enhance immersion by situating each minigame within a simple narrative (*e.g.*, flying to school, filling holes with a tractor, building a path). These contexts transform mathematical exercises into story-based challenges, aiming to reduce anxiety and promote a playful mindset. The use of color supports color-coded learning, with blue and green consistently representing addition and red representing subtraction. These nonverbal cues transform abstract rules into intuitive visual patterns, making gameplay more fluid and less cognitively demanding.

3.3. Implementation Details

iFractions is designed as an online, single-player educational game that combines technical efficiency with pedagogical accessibility. Its 2D interface can be accessed via mouse or touchscreen, supporting use across a range of devices, from desktop computers to tablets, and is available either through an open web page or seamlessly integrated into Moodle as an interactive Learning Module (iLM) via the iAssign package. This integration allows teachers to embed the game directly into their digital learning environments, aligning gameplay with course objectives and tracking student progress. Both *iFractions* and iAssign are distributed as free and open-source software under the GNU General Public License (GNU GPLv3), promoting equitable access and adaptability across educational contexts.

The game is built using HTML5, CSS, JavaScript, and PHP, and operates as a Single Page Application (SPA), meaning all game interactions occur on a single, continuously updated screen. This approach minimizes loading times and ensures a smooth, uninterrupted experience, which is essential for maintaining student engagement and focus during learning tasks. Visual and audio resources are loaded asynchronously using the Fetch API and native HTML elements, which improves performance, optimizes caching, and increases responsiveness, even in environments with limited connectivity.

The platform uses a client-server architecture that prioritizes client-side execution, meaning that most of the processing occurs directly in the user's browser. This design choice reduces server dependency and contributes to a more stable, fluid user experience. In the open web version, only player progress is transmitted to a MySQL database via PHP. In the Moodle-integrated version, data is stored within the LMS environment using iAssign functions, allowing for real-time updates to student records and progress tracking. Together, these technical features ensure that *iFractions* delivers not only robust pedagogical content but also a responsive and reliable digital learning experience.

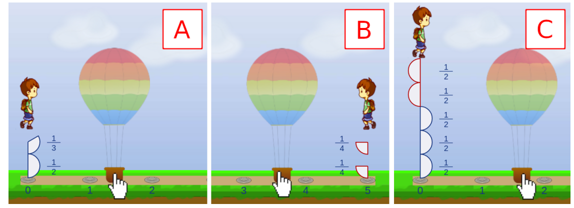
3.4. Gameplay Experience

The tool currently offers three customizable minigames, Circles I (Figure 1(i)), Quadrilaterals I (Figure 1(ii)), and Quadrilaterals II (Figure 1(iii)), which can be configured to generate a four-stage map with ascending levels of difficulty. The player progresses through this map by correctly solving the proposed activities, following the metaphor of a "path of knowledge" (Figure 1(iv)).

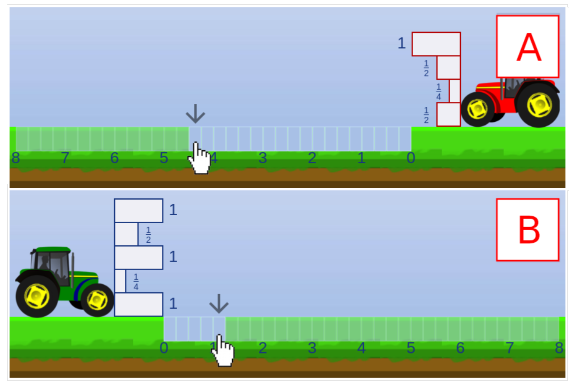
In the minigame **Circles I (Flying Theme)**, the player must guide their character through balloon school. Here, fractions are represented by arcs of a circle, with the distance traveled corresponding to the length of the arc. The game introduces addition (movement to the right) and subtraction (movement to the left). The player selects the correct fraction (by choosing either the ground or the arcs) (Figure 1(i)), causing the character to move along the number line. The arcs and colored tractors indicate the operation, and selecting the "Show fractions" option displays the symbolic form alongside the visual representation.

In the minigame **Quadrilaterals I (Rural Theme)**, fractions are represented as parts of a rectangle. The player's goal is to fill a hole in the ground by pushing blocks of grass with a tractor. The player must select the correct pile (or the hole) (Figure 1(ii)). When the correct choice is made, the hole in the ground is automatically filled in, visually confirming the accuracy of the player's decision. Otherwise, there may be piles of grass left over or missing space on the ground. This minigame allows players to practice adding and subtracting fractions. The "Show fractions" option reinforces the connection between the visual representation and the numerical representation.

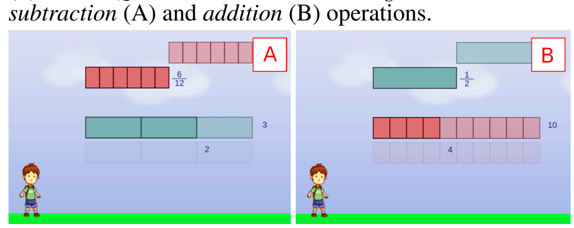
In the minigame **Quadrilaterals II (Equivalence Theme)**, players must help their character advance by identifying equivalent fractions in two rectangles that have been divided in different ways (Figure 1(iii)). This activity aims to promote an understanding of equivalence by encouraging players to compare areas that represent the same value, even though they are divided differently. Selecting two correct answers allows the character to advance on the map (Figure 1(iv)). The option "Show auxiliary rectangles" provides additional visual support.



(i) Game *Circles I* in *select balloon* mode with *addition* (A), *subtraction* (B) and *both* (C) operations.



(ii) Game *Quadrilaterals I* in *select ground* mode with *subtraction* (A) and *addition* (B) operations.



(iii) Game *Quadrilaterals II*, modes *largest subdivision on top* (A) and *largest subdivision on the bottom* (B), with fraction equality operations.

(iv) Level map.

Figure 1: *iFractions* examples.

This breakdown of the mechanics of the game illustrates how *iFractions* translates abstract fraction concepts into interactive actions. This direct mapping between player actions and mathematical concepts represents a central and carefully considered design element. *iFractions* is available from https://www.usp.br/line/ifractions/.

4. Methods

4.1. Study Design

To evaluate the educational potential of the developed collection of minigames, we carried out a case study structured around a quasi-experimental design, employing both pre-tests and post-tests to measure students' hit ratio normalized gain (g) before and after their interaction with the games.

4.2. Participants

The project involved two fifth-grade classes (Class 1 and Class 2) from a public elementary school in the state of São Paulo, Brazil. The fifth-grade classes were chosen as the target group because they represent a key stage in consolidating and deepening content taught in earlier grades, thereby preparing students for the academic demands of later years in basic education. Class 1 comprised 12 pairs and 3 individual students. The students working individually had difficulties with social interaction, despite being seated near one another in the computer lab. Class 2 comprised 13 pairs and 2 individual students. In this case, the individual arrangements were justified as one student had an intellectual disability and was accompanied by an assistant, while the other had limited proficiency in Brazilian Portuguese at the time of the experiment.

The initial sample consisted of 61 fifth-grade students, divided into two groups (*i.e.*, 30 in Group 1 and 31 in Group 2). However, due to the absence of six students (*i.e.*, three from each group), the study was effectively conducted with 55 participants. The predominant age was approximately 10 years, consistent with the educational stage under investigation. The activities were supported by a team composed of a coordinating teacher, three graduate students from the research laboratory, and two school teachers who served as moderators.

4.3. Materials

The study was conducted using the minigames described in Section 3. The activity was conducted in the school's computer lab, which was equipped with 15 student computers and one instructor computer, with the following technical specifications: AsRock N68-Gs4 FX motherboard, AMD FX-6300 processor (3.50 GHz), 4 GB RAM, onboard NVIDIA GeForce 7025 / NVIDIA nForce 630a graphics card (supporting OpenGL 2.1), and an LG Flatron L1550S monitor.

To enable students to explore *iFractions*, access was provided through individual login credentials to the research laboratory's Moodle platform. Upon logging in, students were directed to a course specifically created for this experiment. This course consisted of explanatory pages (*i.e.*, a Moodle resource) presenting the minigame model, followed by the activities to be completed by the students. The activities consisted of personalized *iFractions* pathways, configured with specific game modes, mathematical operations, and difficulty levels. The creation and customization of these activities were carried out using the *iTarefas* tool.

The test dynamic involved implementing a sequence of activities with the students, using each game module to explore the fraction concept associated with it thoroughly. This sequence of activities was developed based on the pre-test results, ensuring that the data obtained served as the "lower threshold" or "floor" of the activity level. In other words, this approach was adopted to guarantee that the activities were not cognitively below the students' level, in line with the theoretical framework of Ausubel (1968) and others. Furthermore, the purpose of this sequence was to cognitively mobilize the students, enabling them to make the necessary "leap" toward genuine concept formation (Vygotsky, 1987).

This approach made it possible to fully explore the software's potential across each of the nine modules, analyze whether the difficulty level in each module was appropriate (*i.e.*, whether it was meaningful and whether a higher or lower level between stages would be advisable), and investigate whether the use of the software in the teaching-learning process facilitated meaningful learning of the fraction concept.

4.4. Procedure

The methodological procedure adopted was structured into three stages: (1) Preparation, which involved defining and developing the study materials, identifying the site for the experiment, and selecting the participants; (2) Application, consisting of the administration of the pre-test, the teaching-learning test using *iFractions*, and the post-test; and (3) Analysis, which included the evaluation of satisfaction and perception questionnaires, as well as the analysis of the test results. Figure 2 summarizes the study's procedure.

The procedure involved administering a pre-test, followed by a session in which students explored the software under the guidance of researchers and the classroom teacher. This mediation aimed to foster the development of mathematical thinking related to the concept of fractions while simultaneously familiarizing students with the digital tool.

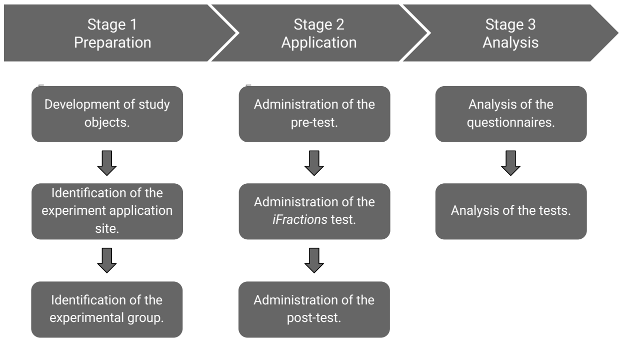


Figure 2: Study's procedure.

4.5. Measures

To carry out this case study, it was first necessary to assess the students' prior knowledge of basic fraction concepts. For this purpose, pre- and post-tests were administered. The objective of the post-test was to assess the students' meaningful learning regarding the concept of fractions, through questions with a higher cognitive level than the pre-test and with a different contextualization from those involved in the previous stages. This deliberate increase in cognitive demand and contextual variation between the tests was a key methodological choice. While it introduces a challenge for direct numerical comparison, it is a more valid approach for assessing meaningful learning and knowledge transfer, as defined by Ausubel's theory (Ausubel, 1968). The pre-test aimed to establish a baseline of procedural knowledge and basic conceptual understanding. In contrast, the post-test was designed to evaluate whether students could apply and integrate these concepts to solve novel and more complex problems, thereby providing stronger evidence of conceptual mastery beyond simple content retention. Thus, if the students were able to solve the test, it would provide evidence of meaningful learning. If not, the test would indicate which specific aspects of the fraction content were not sufficiently grasped.

The pre-test identified students' prior knowledge of fractions, including their meanings, reading, equivalence, comparison, and representations. It consisted of four questions, each with up to three subitems: the first assessed students' understanding of the concept of fractions and their representations; the second and third addressed equivalence and comparison; and the fourth focused on representations and meanings of fractions.

The post-test also allowed us to identify whether the learning was mechanical (Ausubel, 1968), in cases where it was not meaningful. Additionally, it provided insight into the feedback regarding the reasons for this mechanical learning (whether related to the software, the student's pre-existing cognitive level, the adopted methodology, among other factors). By comparing it with the pre-test results, it was possible to highlight the cognitive progress of each student and obtain evidence regarding the formation of concepts through the software. This enabled us to conclude the potential and contributions of the software to the process of teaching and learning fractions in the fifth grade, based on the context investigated.

The proportion of hit ratio was calculated for each student by dividing the number of correct responses by the total number of questions in each test. Based on these proportions, the normalized gain (g) was computed using Hake's formula (Hake, 1998), which quantifies the relative improvement in student performance.

4.6. Data Analysis

As the sample size was greater than 30 participants, the Shapiro–Wilk test was applied to assess the normality of the data distribution (Royston, 1995). The analysis indicated a violation of the normality assumption. Accordingly, the non-parametric Wilcoxon signed-rank test (Wilcoxon, 1945) was used to evaluate the statistical significance of differences between pre- and post-test scores.

Initially, LibreOffice Calc was used for data analysis. This tool was employed to record students' responses to the pre- and post-tests. Subsequently, Python was used for data analysis, employing the *pandas* library for data manipulation, and the *scipy* and *statsmodels* libraries to perform descriptive and inferential statistical analyses presented in this study.

5. Results

The average of students' hit ratio normalized gain (*i.e.*, Hake's g) achieved by the students was 0.767, which is considered a high gain according to established benchmarks in educational research, *i.e.*, gains above 0.7 typically indicate strong conceptual learning and effective instructional practices (Hake, 1998).

To assess the statistical significance of the difference between pre- and post-test students' hit ratio normalized gain, the Wilcoxon signed-rank test was applied. The results indicated a statistically significant difference ($W = 0.000$; $p < 0.001$). However, the effect size was negligible ($r = 0.00$). Figure 3 presents the comparison between pre- and post-test. The lines connecting individual pairs tend to be horizontal, reinforcing the interpretation of a reduced effect size.

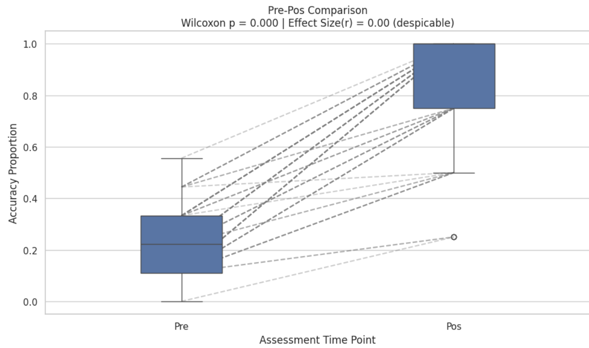


Figure 3: Comparison of pre-post results after applying the Wilcoxon test.

In summary, although the results indicated a statistically significant improvement in students' hit ratio normalized gain, the effect size suggests that the improvement may not have practical significance.

6. Discussion

The teaching and learning of fractions remains challenging, particularly due to their abstract nature. In this study, we present an open-source collection of educational minigames designed to support the teaching of fractions. We also evaluate its effectiveness through a quasi-experimental design using pre- and post-tests. The results of this study indicate that the average normalized gain ($g = 0.767$) was high, suggesting a substantial improvement in conceptual understanding to established benchmarks in educational research (Hake, 1998). The improvement was statistically significant, as measured by the Wilcoxon signed-rank test ($W = 0.000$; $p < 0.001$). However, the effect size was negligible ($r = 0.00$).

This apparent contradiction, in which there is a high learning gain alongside a negligible statistical effect size, can probably be explained by the characteristics of the sample. The low variability in post-test scores (*i.e.*, a potential ceiling effect) and the uniform improvement across most participants limit the ability of the effect size measure to detect a large practical impact, even though the absolute learning gains were significant.

At the same time, this apparent discrepancy may be explained by limitations such as a ceiling effect, in which several participants already performed near the maximum on the pre-test, leaving little room for measurable gains in the post-test, or the homogeneity of the sample, which reduces variability and thus limits the sensitivity of the analysis to detect substantial effects. As Coe (2002) emphasizes, in educational research, statistical significance does not always translate into meaningful educational impact. Furthermore, Fritz et al. (2012) and Morris (2008) stress that effect size estimates must be interpreted in light of the intervention context, the characteristics of the assessment instruments, and the sample composition. This is especially relevant in studies involving differentiated instruction, where intra-individual variability may be constrained (Schweig, 2016).

Our findings are consistent with previous research demonstrating that well-designed digital games can be effective tools for teaching fractions (Siegler and Lortie-Forgues, 2023; Zhang et al., 2019). The high normalized gain observed in this study aligns with the potential of interactive and visual tools to demystify abstract concepts. Specifically, the design of *iFractions* which provides immediate feedback and enables repeated practice in a low-stakes setting, aligns with known factors that contribute to improved learning outcomes in game-based environments (Plass et al., 2015). The significant gains support the argument that digital games offer unique affordances for mathematics learning, particularly in reducing anxiety and fostering engagement through visual and interactive representations (Calder and Campbell, 2019).

Similar studies focusing on fraction learning interventions have reported normalized gains ranging from moderate to high (*e.g.*, Siegler et al., 2017; Witzel et al., 2018), reinforcing the potential of targeted educational tools to improve understanding. Compared to these studies, the results obtained with *iFractions* confirm its effectiveness in facilitating significant improvements in students' conceptual grasp of fractions. For teachers, this level of gain implies that incorporating *iFractions* into classroom activities may substantially enhance students' learning outcomes, helping to bridge persistent gaps in fraction knowledge. It suggests that *iFractions* can serve as a valuable complement to traditional instruction by providing interactive and visual experiences that foster deeper engagement and understanding of complex mathematical concepts.

6.1. Practical Implications

For educational practice, the results suggest that *iFractions* can serve as a valuable complementary tool in the mathematics classroom. The high normalized gain indicates its potential to help bridge persistent gaps in fraction knowledge. Teachers can leverage the customizable nature of the platform to provide differentiated instruction, tailoring activities to meet students' diverse needs and proficiency levels, thereby supporting a more student-centered learning environment. Successful integration requires professional development that enables educators to align game-based activities with learning objectives and interpret the progress data provided by the platform.

Thus, *iFractions* can be used by teachers as part of a broader set of educational technologies, either independently or integrated with platforms such as Moodle, and can be combined with traditional teaching tools to support the teaching and learning of fractions. We also suggest that *iFractions* can be used as a supplementary activity, such as homework, when students have the opportunity to use it at home.

6.2. Limitations and Threats to Validity

This study presents several limitations and threats to validity that must be considered. First, the sample was limited to 55 students from two fifth-grade classes from a single Brazilian public school, which restricts the generalizability of the findings to broader educational contexts. Second, the short-term nature of the intervention (*i.e.*, a single session of approximately two hours) prevents any assessment of long-term knowledge retention. Third, the absence of a control group limits the ability to draw causal conclusions about the effectiveness of *iFractions* when compared to traditional instructional methods.

Additionally, the pairing of students during tasks may have introduced peer-related learning interference, potentially affecting individual outcomes. It is also important to acknowledge the possible influence of the researcher's presence in the classroom, which may have altered students' natural behavior during the intervention. Another relevant factor is the novelty effect associated with the use of a digital game, which could have temporarily increased student engagement without reflecting a lasting pedagogical impact.

Finally, although the post-test results showed statistically significant improvements, the calculated effect size indicates negligible practical implications. This may be attributed to factors such as a ceiling effect and sample homogeneity, which reduce data variability and limit the sensitivity of the statistical analysis.

6.3. Research Agenda

In this study, we conducted a case study comparing participants' pre- and post-test performance. While the study advances the literature, the findings are limited to a specific analytical context. Future research should incorporate complementary metrics, such as response time, standardized scores, confidence interval analysis, and qualitative data, to provide a more comprehensive and precise interpretation of the results.

Another limitation concerns the sample, which was restricted to a small group of students from a single public school in Brazil. Future studies should consider replicating the research with larger and more diverse samples, including students from different types of schools, other regions of Brazil, and even from different countries. Such efforts would help clarify how minigames influence student performance across varied populations.

Finally, this study focused on a single outcome variable. However, additional learning outcomes may act as mediators of students' experiences with the game. Future studies should therefore examine measures such as engagement, motivation, and flow experience to better capture the multifaceted nature of game-based learning.

6.4. Conclusion

The study of fractions continues to pose major challenges in mathematics education, demanding innovative strategies to promote meaningful learning. This study showed that *iFractions*, an open-source collection of educational minigames to support the teaching of fractions through interactive and visual approaches. The results of a quasi-experimental study demonstrate a significant improvement in students' hit ratio normalized gain with a negligible effect size. These results highlight the potential of the tool to complement traditional instruction and engage students in fractions learning. Looking ahead, expanding *iFractions* with new levels and multiplayer features, while safeguarding accessibility and privacy, can broaden its applicability across diverse contexts. As future studies, we aim to investigate long-term knowledge retention, effectiveness with different age groups, and impacts through experimental studies.

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Data Availability

The raw/processed data required to reproduce the above findings cannot be shared at this time as the data also forms part of an ongoing study.

Notes

The authors utilized generative artificial intelligence (*i.e.*, Microsoft Copilot) to improve the grammatical quality of the text.

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